The Quality of Night Sky in Hong Kong

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Abstract

This is a project about night sky brightness measurement of Hong Kong using a small telescope, CCD camera and commercial digital camera. By using this setup, the sky brightness is measured by relative photometry (comparing the light intensity from the background and the nearby standard stars). It was found that the brightness of the night sky in HKU campus was around 17 mag arcsec^{-2} near zenith in fairly good observation condition which no cumulus hindered the observation, but the results obtained by CCD and digital camera were differed by around half a magnitude. I doubt that the causes are the manipulation of received photons of the digital camera and the quantum efficiency of the imaging devices. Further tuning to the experiment is needed so that this method can be applied throughout Hong Kong.

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1 Introduction

Both population and economy of Hong Kong has been growing rapidly and prosperously in recent years. Numerous commercial complex, housing estates and infrastructures are being constructed throughout Hong Kong. Star-gazers could rarely find suitable sites for the observation in the outskirts of the city, of which only handful of sites which can allow them to admire the beautiful Milky Way Galaxy. The night sky seems to be out of reach in the city of Hong Kong; it is either blocked by the buildings or shone by the artificial lighting such as laser beams, sodium lamps, mercury lamps, metal halide lamps, Tungsten-halogen lamps, fluoscent lamps and LEDs suggested by Mizon. The brightened sky not only hinders researchers to do research on the dim objects on the heaven, but also the chance for the public, especially the young ones, to admire the beauty of natural night sky is limited.

As our city and neighbouring cites continue to grow in size, the night sky will be brighter than that of before. To preserve our delicate night sky, long-term surveys should be conducted to monitor our sky. In 2001, a local amatuer, Mr. Pang Huey (2001), conducted a night sky survey throughout Hong Kong. The images were taken by the same camera and same exposure time in different locations without any external. By comparing the peaks of histrograms in different images, the place which the sky was the brightest or dimmest could be determined.

In this project, the aim is to improve the above method and get a more precise answer, brightness (mag arcsec^{-2}). A small size telescope and an equatorial mount were used to measure the brightness around the zenith. Pictures were taken by a commercial digital camera and a CCD camera. Conventional research software package, Image Reduction and Analysis Facility(IRAF), was used to reduce the data. By using these data, the brightness of night sky can be computed.

Patat suggested that human activities, the environment, atmosphere, celestrial objects, galatic plane and the solar activities may affect the night sky brightness. However, we didn't have enough measurements to verify his findings, but the findings of this project may be used as a reference for related authorities or organizations to carry out a large scale survey in Hong Kong in future.

2 Theory

The source of brightness of night sky is either coming from natural or artificial light source. The findings of Massey and Foltz (2000) illustrated the details of the emission spectrum and zenith sky brightness in Kitt Peak and Mt. Hopkins around three years ago. From Figure 1, the OH bond in water vapour, oxygen $[OI]$ and nitrogen $[NI]$ in the atmosphere was the main natural source. They generate radiation due to the jumping of electron among S, P, D state.

The emission line of mercury $[HgI]$ and sodium $[NaI]$, Na D was observed too. It is impossible that there is a large amount of sodium and mercury present in the atmosphere and outer space. Therefore, the above findings suggested that these light sources came from high pressure sodium (HPS) lamps, low pressure sodium (LPS) lamps and mercury lamps.

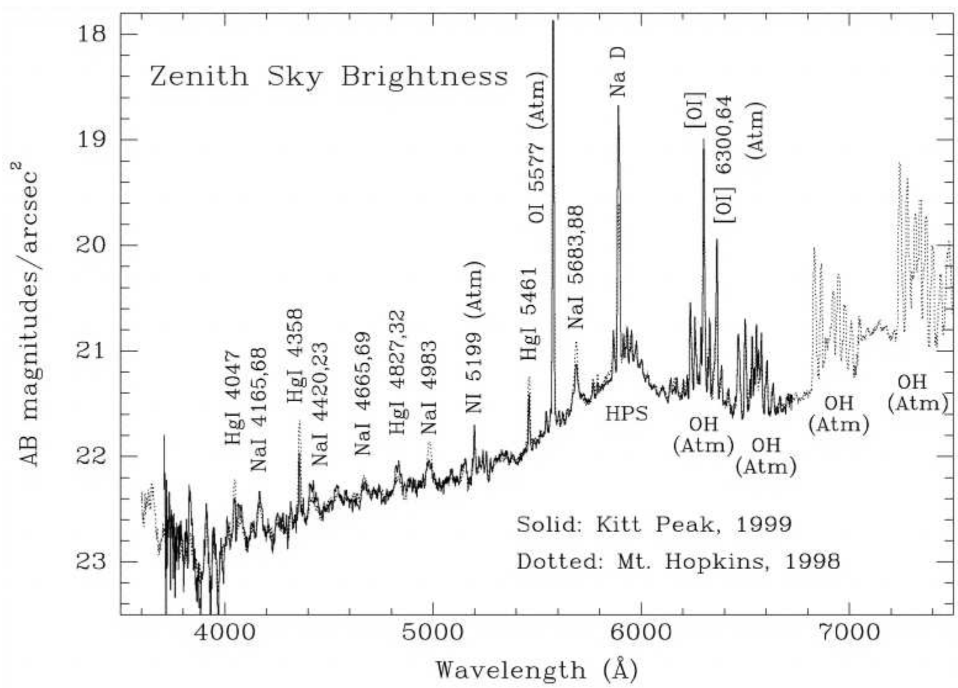

Figure 1: Zenith sky brightness of Kitt Peak and Mt. Hopkins

Taylor (2004) found the sky surface brightness by stacked galaxy image instead of standard stars. In this project, brightness (mag arcsec^{-2}) of night sky was measured as an amalgamation of natural and artificial sources. This value is done by relative photometry, i.e. the background per pixel is compared to the total counts coming from the standard stars.

Isobe (1998) took the data by film and analysed by densitometer. In this experiment, the images taken by CCD were stored in Flexible Image Transport System(FITS) format. For digital camera, they were stored in Tag(ged) Image File Format (TIFF). By using graphics software, the RGB channel was converted to grayscale.

There are two main ways of carrying out photometry - aperture photometry and point spread function (PSF). Aperture photometry was used in the whole reduction process. The value in each pixel is summed up inside the circular aperture which is placed at the center of the star and the radius is 1 to 3 times of the full width half maximum (FWHM) of the star. The sum minus by the background is the net counts from the star. By using the equation 1,

$$m = -2.5 \log f + c \tag{1}$$

where m is the instrumental magnitude of a given flux, f is the counts of the star after subtracting the background B and c is the constant. Due to atmospheric extinction, Rcihard suggested that airmass correction is applied to correct the instrumental magnitude

$$m = m_0 + k_v X \tag{2}$$

where m_0 is the visual magnitude m_v of the standard star above the Earth's atmosphere, m is the raw instrumental magnitude measured through an airmass, X, at the time of observation, and k_v is the visual extinction coefficient. At sea level, k_v is typically about 0.24 magnitude per airmass. Thus, equation 1 becomes

$$c = m_v + k_v X + 2.5 \log f \tag{3}$$

Since no filters are applied in this experiment, the first-order extinction is simply used instead of the second order one which involves differences of the observed magnitudes in different filters.

Beside airmass correction, aperture correction is needed to correct the instrumental magnitude of the faint stars. Two apertures ($1.4 \times FWHM$ and $4 \times FWHM$) are selected to measure the flux of a bright star. Then, equation 4 and equation 1 are applied. The difference of two magnitude, Δ, is obtained and plugged into equation 5. The aim of applying this correction is to compensate the loss of singals because using small aperture can minimize the noise from the background.

$$\Delta = m(4 \times FWHM) - m(1.4 \times FWHM) \tag{4}$$

$$m = m(1.4 \times FWHM) + \Delta \tag{5}$$

After applying equation 4 and equation 5, equation 3 becomes

$$c = m_v + k_v X + 2.5 \log f - \Delta \tag{6}$$

By using the command "imexamine" in IRAF, the mean and standard deviation of the background are obtained.

The field of view of the images are needed to be determined to find out the plate scale per pixel. From the astronomical almanac, the RA and DEC of standard stars are known and plugged into equation 7 to find out the angular separation of two stars.

$$\cos\theta = \cos\delta_1 \cos\alpha_1 \cos\delta_2 \cos\alpha_2 + \cos\delta_1 \sin\alpha_1 \cos\delta_2 \sin\alpha_2 + \sin\delta_1 \sin\delta_2 \tag{7}$$

where θ is the angular separation between two objects, δ and α are celestial coordinates. [1] The angular distance in arcsec is divided by the pixel distance on the image to get the field of view of each pixel. The other method to obtain the angular distance is to make use of star atlas software, TheSky. By clicking two stars successively, the angular distance will be found in the information dialog.

Finally, the intensity is divided by the square of arcsec is plugged into equation 1.

$$m' = -2.5 \log \frac{B}{PP'} + c \tag{8}$$

where B is the background per pixel, P is the plate scale per pixel and P' is the plate scale in another dimension. From equation 8, the sky brightness, m', is obtained.

[1] The unit of RA is hour:min:sec, conversion back to degrees is needed before plugging into equation 7.

3 Apparatus

The whole setup is shown in the Figure 2. The details of each components will be discussed in the following subsections.

Figure 2: The whole setup. Left: Pronto with CCD. Right: Pronto with digital camera

3.1 Telescope

A small refracting telescope, Pronto Televue, was used in this experiment. The aperture, focal length and focal ratio are 70mm, 480mm and 6.8 respectively. The telescope is highly portable. The experimenter can carry it to remote sites to fetch data. And also most amateurs can join this scheme to monitor the sky brightness throughout Hong Kong.

3.2 Imaging Devices

The commercial digital camera, Nikon Coolpix 4500 was tested. The reason of selecting this camera is its favorable functions:

- adapter for connecting camera to telescope
- bulb switch for long time exposure
- manual focus
- saving images as TIFF to reduce data loss

The actual details of the CCD are not available because dealer in Hong Kong is not willing to disclose the detail specification of this product. Therefore, the structure of CCD can only be estimated from the amateur web site. [2]

Another imaging device is MX916 CCD camera. The specification of this camera is listed here.

- CCD type: Sony ICX083AL SuperHAD CCD with ultra low dark current and vertical anti-blooming.
- CCD pixel data: Pixel size: 11.6 x 11.2um, image format 752 x 580 pixels (High Res. mode), or 23.2 x 22.4um, image format: 376 x 290 pixels (High sensitivity mode, pixels binned 2 x 2). Software controlled.
- CCD size: Imaging area: 8.7mm (horizontal) x 6.5mm (vertical).
- Spectral response: Peak response at 520nm (Green), 50% at 400nm (Violet) and 670nm (Near infra-red). (Note the very good blue light performance, excellent for tri-colour and photometric work.)
- Quantum efficiency: Approx. 65% peak at 520nm.
- Readout noise: Less than15 electrons RMS.
- Full-well capacity: Greater than 300,000 e- (binned mode).
- Anti-blooming: Overload margin greater than 800x
- Dark current: Dark frame saturation time greater than 100 hours. Less than 0.1 electrons/ second at +10C ambient.
- Data format: Full 16 bits.
- Computer interface: 8 bit unidirectional parallel port with bi-directional status lines (Standard Centronics interface). 25 pin 'D' style plug for LPT1, 2 or 3, via a 5 metre x 6mm diameter cable.
- Image download time: Typically 6 seconds with a 200MHz PC and 'Fast Interface' module.
- Power requirements: 115VAC / 240VAC @ 12VA, or 12VDC @ 900 milliamps max.
- Cooling system: Regulated constant-current cooling supply built-in. Single-stage thermoelectric cooler to give a CCD temperature of approximately -30C below ambient.
- Size: 63 x 95mm black anodised aluminium barrel with M42 thread at CCD window end and 15 way 'D' style input plug at rear.

[2] http://www.digital.idv.tw/Classroom/MROH-CLASS/oh11/index-oh11.htm

- Weight: 250g.

It connects to notebook to store the images. The details of this CCD may be found in here. [3]

3.3 Mount

At the beginning this project, portability of the whole equipment was the main concern, thus, a common aluminium tripod with a video head to was bought to support the telescope. However, it was found that longer exposure was needed to assure the quality of the data. Hence, the tripod is the subsituted by the Vixen GP equatorial mount with tracking motor.

3.4 Adapter

For CCD, it can directly connect to the 2" eyepiece holder of the telescope. On the other hand, William Optics DCL-28 eyepiece digital camera adapter is applied to connect the digital camera and 1.25" eyepiece holder of the telescope. The adapter is a 24mm plossol eyepiece which eye relief is 16mm and the field of view is 52^o.

[3] http://www.starlight-xpress.co.uk/mx916.htm

4 Methodology

This part introduces how the data were taken and processed.

4.1 Planning for an observation

Target Field
There are some criteria for selecting a good field:

- the objects should be main sequence stars as the spectrums were known well.
- they should not be variable stars or close binary systems.
- there should be no extended objects in the field such as planets, globular clusters, planetary nebula, supernova remnant or galaxies because inter-stellar gas or dust or the objects themselves may corrupt the data.
- the selected field should be close to a bright object which can be clearly seen by naked eye. The reason is that the sky is heavily polluted so you may not be able to find the faint stars in unfamiliar field. And the stars could be located on the LCD screen of digital camera.
- several stars which m_v ranges from 6 to 9 locate around the center of the frame since more data of different stars could be obtained. Also, the target in the center of the field can get rid of some aberrations such as coma, astigmatism, distortion and field curvature.
- the objects should not be close to the zodiac because reflected or scattered light from the dust of the orbital plane of the planets in solar system may contaminate the data.
- stars of different magnitude could be found in the field and at least one of the stars should be relatively bright.
- the bright stars make good use of the dynamic range of the electron well, but not saturated. It can maximize the contrast bewteen the total flux of the star and background.

The plate scale of digital camera is generally smaller than that of CCD, so the field of view of digital camera is smaller than that of CCD. The field of view of CCD is around 2 arcdegrees while that of digital camera is bigger than 3 arcdegrees. Thus, you may need to move the center of the imaging area to include more stars.

The images were taken by two techniques. Prime focus was applied when using CCD, For digital camera, afocal photography was applied.

Vignetting is the big problem in afocal photography. This problem can be solved by pressing the zoom in button but keeping the aperture to maximum size, therefore the plate scale may be needed to determine everytime.

4.2 Data Taking Procedures

The digital camera contains a lot of functions that is needed to be set such that data are collected in a reasonable way.

- Integrating time
  A number of pictures of different integrating time are taken to find out the minimum exposure time that the background signal is detected by using digital camera. It was found that the minimum exposure time was around 2 seconds. However, the exposure time should not be too long, otherwise, the pictures were taken without tracking so the stars will become "sausages". The other factor affecting the "length" of the star on the images is the magnification or field of view. To get a wider field, the camera is "zoom out" so that the stars move slowly. It was found that the acceptable integrating time is around 4 seconds, but the images of stars are oval in shape. On the other hand, as the dynamic range of the digital camera is so low that the maximum value is only 255. The brightest star for reduction is at most $m_v = 4.5$.

  After using equatorial mount, the integrating time is lengthened. However, due to the inaccurate alignment to the polar axis, the maximum exposure time is around sixty seconds. Hence, the dim stars which viusal magnitude is around 10 can be detected.

- File Format
  The images are saved as TIFF in order to reduce data loss because TIFF is the best format to preserve the images.

- Aperture
  The aperture is set to the smallest value or biggest size to receive maximum amount of incident photons from the sky.

- White Balance
  The pictures are either taken in auto-white balancing mode or in black and white mode. Black and White mode is preferrable because three channels will have the same value that the color of the stars may be neglected.

On the other hand, CCD has the same defect of digital camera that there is an upper limit of counts, but the dynamic range of CCD is bigger than that of digital camera. The maximum counts per pixel of CCD is around 25000. Moreover, the quantum efficiency of CCD is higher that the integrating time should be shorter when both digital camera and CCD were used to take the same stars.

Establishing Thermal equilibrium of the system
To let them reach thermal equilibrium, all devices are left on the site for 10 minutes in prior to observation after the equipment is set up properly. So the whole optical system are stablized to certain temperature and the air current inside the tube is steady.

Taking data and dark frame
After finding a nearby bright star, "zoom in" to check that if the star is properly focused. If the image is sharp, move to the desired field and activate the self-timer before taking a shot. It can damp the vibration when pressing the shutter. Due to the large file size in TIFF format, it takes around 30 seconds to record a picture to the memory card. Also, small adjustment to the field to bring the target back to the center. Hence, only one picture can be taken in one minute in average. For CCD, the process is more or less the same. Trial pictures could be taken to check if the focusing is proper and there is any saturated stars. But the whole process is faster due to the saving process. Two images could be taken within one minutes if the integrating time is less than fifteen seconds.

If the weather is hazy or the sky is brightened by the Moon or cirrus exists, the integrating time are adjusted to obtain better contrast of background and the stars when using CCD. You may not able to do so when you are using digital camera because the time is pre-set that the shutter is controlled manually.

For dark frame, it was taken in three intervals - before taking data frames, middle of the process and after taking the data frames. Each interval took two dark frames. The black lid provided by the manufacturer was used to cover the opening of the telescope. For digital camera, the maximum number of frames can be taken is 10 for a 128mb compact flash card, because the size of each frame is around 11mb. There is no quota for CCD because the images are stored in the hard-disk of notebook.

4.3 Data Pre-processing

TIFF to FITS
The images were processed by GNU Image Manipulation Program (GIMP). Three RGB channels are combined to one channel - grayscale. Then, they are saved in Flexible Image Transport System (FITS) file format as it can be processed by IRAF.

Dark frame
In data reduction, dark frames and flat field are required. It was discovered that the mean signal and standard deviation in the dark frames were less than 1 and around 0.5 respectively if the exposure time was less than 4 seconds. Over 99% of the pixels did not contain any signals. So the dark frames were not used in the reduction. The hot pixel, however, could not be ignored as they could be found in the dark frame. These hot pixels would not be used when imaging and data processing. However, if the integration time exceeds 4 seconds, the dark noise may not be neglected. The data frames should be subtracted by dark frame so the dark noise could be reduced. The histrogram of the data which the integrating time is eight seconds is shown in Figure 3.

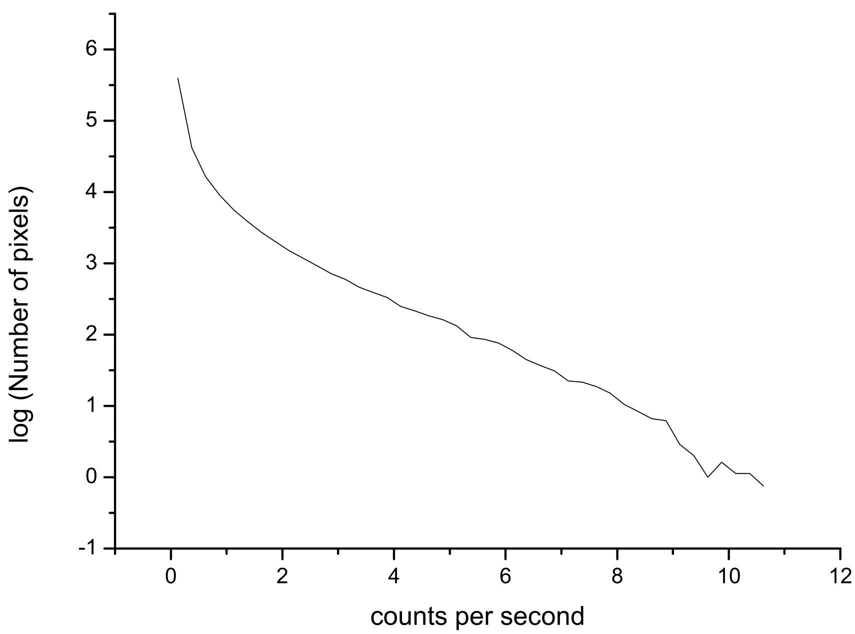

Figure 3: Histogram of a dark frame taken on 2004/07/14 by using digital camera. The integrating time is 8 seconds.

On the other hand, the dark noise of CCD could not be neglected. In the dark frame, the average counts per pixel was around 3000 when the exposure time was 8 seconds. Most pixels had the same data value. The histogram of the data value which the epxosure time is eight seconds is shown in Figure 4. A parabolic curve is observed in this graph. If this graph converts back to linear scale, a guassian curve will be observed. It shows that the dark noise fits poisson distribution.

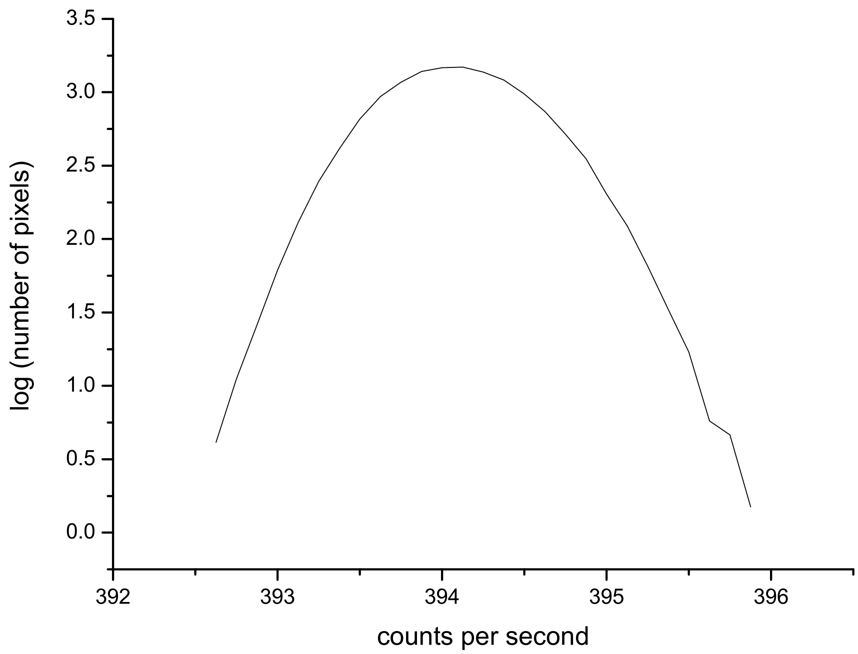

Figure 4: Histogram of a dark frame taken on 2004/07/14 by CCD. The integrating time is 8 seconds.

A number of dark frames taken each night were combined by the task "imcombine" in IRAF. Each data frame was subtracted by the averaged dark frame.

Flat frame
The flat frames were not taken as it was difficult to obtain either a good twilight sky or well-illuminated screen. Thus, no modification was done on the data frames.

4.4 Data Processing

The APPHOT package of IRAF was used to produce information for further analysis. 'Phot' is a one of the functions which computes the flux and other photometric results, with reference to the parameters in datapars, centerpars, fitskypars and photpars.

This is the details on how the data were extracted. The inner radius

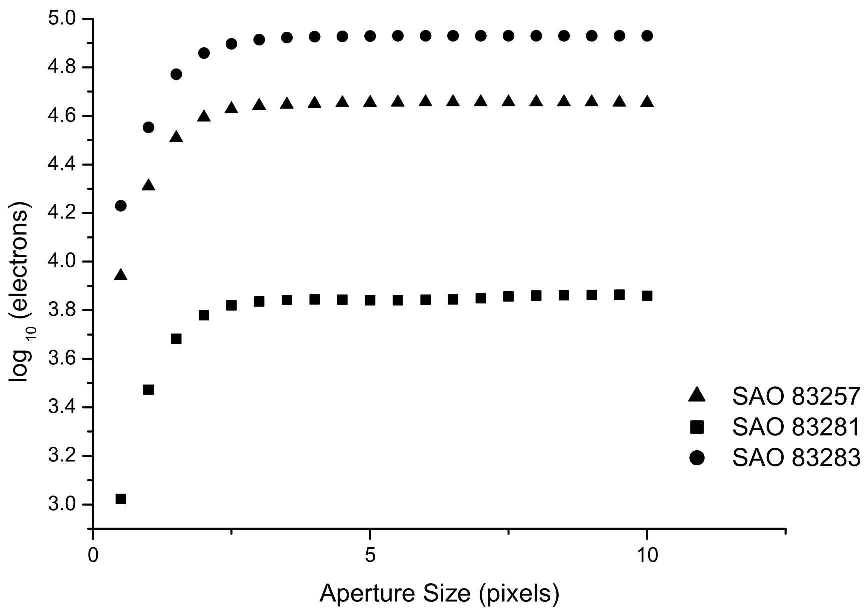

Figure 5: Flux of SAO 83283, SAO 83257 and SAO 83281 taken on 2004/07/24 by CCD. The FWHM of stars is around 2 pixels. The radius of inner annulus and diameter of the annulus is 2 and 10 pixels respectively. The exposure time is six seconds.

of the annulus was set to be equal to the aperture radius to get the best estimation of the background. And the width of the annulus was 10. The above initial value was inputted to these 'pars' and run phot for our reduced data. The FWHM, standard deviation of background, exposure time, observation date, observation time, airmass were inputted to the datapars. Poisson was selected for the noise. The gain and CCDread were left blank for digital camera while the gain was 5 and CCDread was 15 for CCD. In centerpars, the centerbox width was set as 2.5 to 4 times of FWHM. For fitskypars, the inner radius and width of the annulus was inserted. The aperture radius was fixed in the photpars. Finally, running 'phot' for results. Table 6 shows the results of a data frame taken by digital camera while table 5 lists the results of a data frame taken by CCD.

It was found that the flux of bright star was generally increasing when the aperture size increased. Critical points were often observed. Thus, the aperture was determined where the first maximum point was observed. For CCD data, the flux of the stars stablize when the aperture size reaches around 1.5 $\times$ FWHM. For digital camera data, the bright stars also sta-

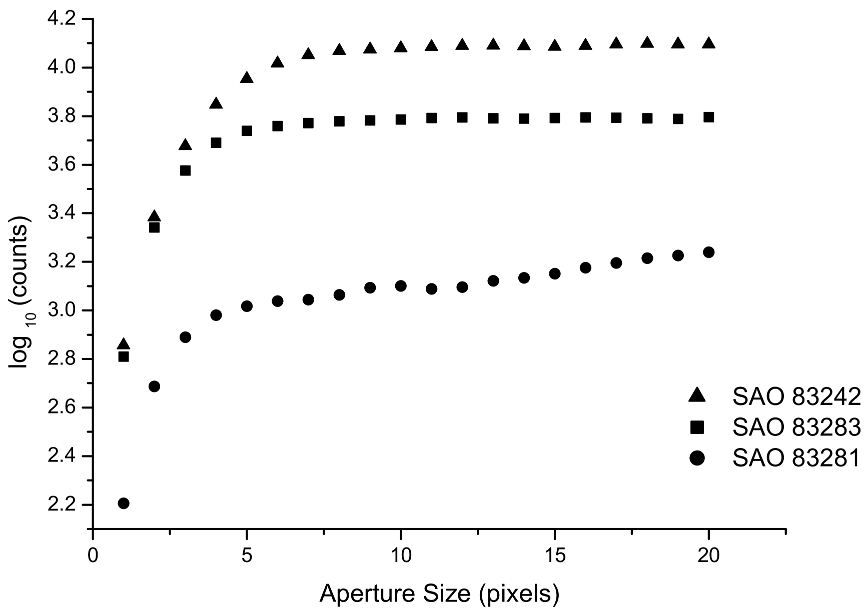

Figure 6: Flux of SAO 83283, SAO 83281 and SAO 83242 taken on 2004/07/24 by digtal camera. The FWHM of stars is around 7 pixels. The radius of inner annulus and diameter of the annulus is 10 and 10 pixels respectively. The exposure time is eight seconds.

blize when the aperture size reaches around 1.5 $\times$ FWHM, but the dim stars do not. Hence, aperture correction was applied on faint stars. Romanishin suggested that a bright star was measured in a small aperture $(1.4 \times FWHM)$ and a big aperture $(4 \times FWHM)$. Then, the correction constant was obtained which instrumental magnitude of big aperture subtracted that of the small aperture. The faint stars were measured in a small aperture. Their corrected magnitude was equal to its instrumental magnitude plus the correction constant.

Figure 7: The view at the dome in different directions - North direction (upper left), East direction (upper right), South direction (lower left) and West direction (lower right)

5 Data and Error Analysis

5.1 Location of the observation site

The observation site was the dome at the roof of Chong Yuet Ming Physics Building inside the main campus of The University of Hong Kong (longitude: $114^o08'30''E$ and latitude: $22^o17'N$). The site is around 100 meters above sea level. This site is severely suffered from the artificial lightings of the commercial buildings in Central district (East of the dome), the container terminals in Kwai Chung, the residence in Kowloon and nearby buildings. The situation can be recognized in Figure 7.

5.2 Stars for calibration

The basic information of standard stars such as right ascension, declination, visual magnitude and spectral type are shown in table 1. All the information of stars are from the SAO catalog Epoch 2000.0 , namely I/131A. The database is maintained by Center de Données astronomiques

Table 1: Visual Magnitude, RA, DEC and Spectral type of stars

SAO	Visual Magnitude (m_v)	RA ($h:m:s$)	DEC ($d:m:s$)	Spectral Type	Area
83233	8.6	14 13 47.43	+20 01 49.0	G0	B
83238	8.7	14 14 16.43	+20 26 17.9	G5	B
83241	8.0	14 14 41.12	+21 24 49.8	K2	A
83242	6.4	14 14 40.97	+21 52 24.5	A2	A
83247	8.8	14 14 59.8	+20 33 37.5	K5	B
83249	6.6	14 15 3.67	+19 54 1.8	F5	B
83257	7.9	14 16 11.20	+21 14 34.9	F8	A
83259	6.4	14 16 32.78	+20 07 17.3	F5	B
83260	8.9	14 16 32.97	+21 05 00.9	K5	A
83281	9.1	14 18 13.14	+21 11 14.2	A7	A
83283	6.7	14 18 21.36	+21 18 14.9	K0	A
83285	8.0	14 18 31.22	+21 28 23.2	K0	A

de Strasbourg (CDS). [4]

In this project, two groups of stars were selected to fetch the data. They are called area A and area B, shown in Figure 8. In section data and error analysis, it will be mentioned which group of stars was used.

5.3 Background

Part of the image which contains the least amount of objects which m_v is above 22 is sliced to determine the background. The reason why the stars which $m_v < 22$ are considered is that it was known that the limiting magnitude of the night sky was around 22 mag arcsec^{-2} from Figure 1. The sky background and its standard deviation is obtained by using the function 'imstatistic'. To verify if the value reflects the background, the maximum value or the standard deviation is checked if it is too large. The histograms, Figure 3 and Figure 4, are plotted if they are similar to a Gaussian curve. One background image is extracted form one data frame to obtain the background value and standard deviation. Thus, the sky background of that night was simply calculated by taking the mean of these data. Assume that there are n data frame and $\bar{B} = \frac{x_1+x_2+...+x_n}{n}$.

$$(d\bar{B})^2 = \frac{(dx_1)^2 + (dx_2)^2 + \ldots + (dx_n)^2}{n^2} \tag{9}$$

By the formula of propagation of error, equation 9, was used for computing the error. So equation 10 becomes

[4] http://vizier.cfa.harvard.edu/viz-bin/VizieR?-source=I/131A

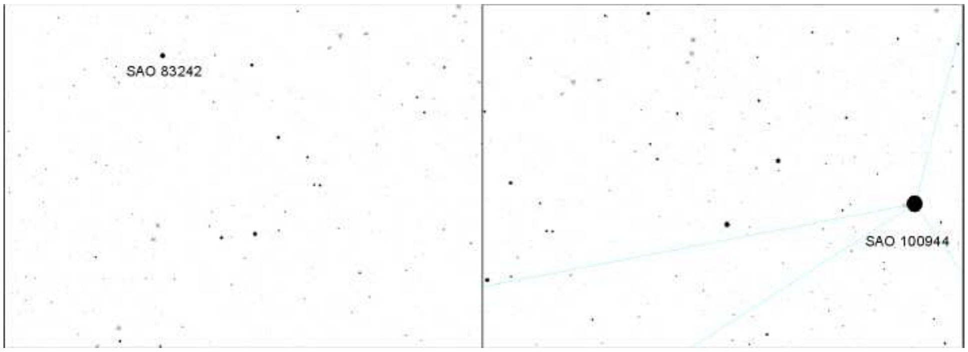

Figure 8: The stars which I used in this project. The left image is Area A. The brightest star in Area A, SAO 83242, is near the left upper corner of the image. The right one is Area B. The brightest star in Area B, Arcturus SAO 100944, is on the right side of the image. The field of view is around 2 degrees.

$$(dB)^2 = (\frac{\partial B}{\partial x_1})^2(dx_1)^2 + (\frac{\partial B}{\partial x_2})^2(dx_2)^2 + ... \tag{10}$$

As ten data frames were taken on each night, n is set as 10. The complete data set is listed in table 2 and table 3. Each data is the statistical result from 2500 pixels.

Table 2: Data of sky background (digital camera). The statistics results are taken form 2500 pixels on each processed data frame. HKT means Hong Kong Time.

Date	Time (HKT)	Exposure Time (s)	Background(counts)
2004/07/13	2114 - 2131	8	16.23 ± 0.569
2004/07/14	2152 - 2207	8	17.76 ± 0.686
2004/07/24	2034 - 2045	8	27.66 ± 0.908
2004/08/02	2133 - 2143	8	40.34 ± 0.819
2004/08/03	2138 - 2149	8	15.01 ± 0.810

5.4 Data for determining the plate scale per pixel

Determining the position of stars on images
Table 4 shows the data which were obtained on 17/2/2004 by using digital camera, where line is x-coordinate and col is y-coordinate. The reasons for selecting that day are that the stars are focused properly, thus, the FWHM of the stars are small and the stars should not be located near the edge. Imexamine, function key 'a' can compute the center of the objects. The

Table 3: Data of sky background (CCD)

Date	Time (HKT)	Exposure Time (s)	Background(counts)
2004/07/13	2155 - 2201	8	859.7 ± 6.4
2004/07/14	2232 - 2239	8	879.8 ± 6.4
2004/07/24	2107 - 2114	6	1088 ± 7.0
2004/08/02	2105 - 2121	10	2975 ± 11.5
2004/08/03	2236 - 2242	8	2278 ± 10.2

Table 4: Plate scale per pixel

Date	Time (HKT)	94027's COL	94027's LINE	94054's COL	94054's LINE	separation on image (pixel)
d6602-g.fit	1945	402.00	674.00	1197.70	969.42	849.71
d6604-g.fit	1947	384.86	718.76	1181.80	1028.69	855.11
d6606-g.fit	1949	399.27	588.50	1187.35	920.87	855.30
d6608-g.fit	1951	439.00	410.50	1220.49	763.67	857.59
d6610-g.fit	1953	455.50	681.99	1221.94	1045.95	848.47
d6612-g.fit	1955	408.00	686.50	1163.47	1078.99	851.34
d6614-g.fit	1957	333.50	667.50	1141.03	1071.40	853.80
d6616-g.fit	1959	406.89	790.07	1149.03	1210.49	841.56
d6618-g.fit	2000	532.20	498.52	1263.38	932.33	850.10
d6620-g.fit	2002	511.00	255.00	1246.74	707.24	864.04

object centers are determined by centroid, i.e., computing the intensity weighted means of the marginal profiles in x and y. The marginal sums are:

$$\rho(x_i) = \sum_{j=-a}^{a} I_{ij} \tag{11}$$

$$\rho(y_j) = \sum_{i=-a}^{a} I_{ij} \tag{12}$$

where a is the FWHM of the image. The next step is to compute the mean intensities, $\bar{X}$ and $\bar{Y}$, of each marginal:

$$\bar{X} = \frac{1}{2a+1}\rho(x_i) = \sum_{j=-a}^{a} I_{ij} \tag{13}$$

$$\bar{Y} = \frac{1}{2a+1}\rho(y_j) = \sum_{i=-a}^{a} I_{ij} \tag{14}$$

The final step is to compute the image centroid using only those points that lie above the mean intensities. These are presumably the points that have the most signal from the star. That is, a new estimate of the center of the stellar image is given by:

$$x_1 = \frac{\sum_{i=-a}^{a}(\rho(x_i - \bar{X})x_i}{\sum_{i=-a}^{a}(\rho(x_i - \bar{X})} \quad (15)$$

$$y_1 = \frac{\sum_{j=-a}^{a}(\rho(y_j - \bar{Y})y_j}{\sum_{j=-a}^{a}(\rho(y_j - \bar{Y})} \quad (16)$$

where the summation is for those i and j such that $\rho(x_i) \geq \bar{X}$ and $\rho(y_j) \geq \bar{Y}$ respectively. At this point, it is important to check that the new estimation of the center (x_1, y_1) lies within one pixel of the initial guess (x_0, y_0). If this is not the case then it is necessary to repeat the process with (x_1, y_1) becoming the new initial guess (x_0, y_0). In the other words, this centering method is an iterative process.

Calculating the plate scale per pixel
The name of two stars located in Taurus are Aldebaran (SAO94027) and σ 2 (SAO94054). The RA and DEC of Aldebaran and σ 2 are $04h35m55.25s, +16^o30'33.3''$ and $04h39m16.5s + 15^o55'0.49''$ respectively. The angular distance between two stars is 3596.71 arcsec. From the table 4, the mean distance between two stars is 852.702 pixels. Assume that each pixel is square in size, the plate scale per pixel is, therefore, equal to 4.218 ± 0.028 arcsec. The percentage of error is 0.664%. The field of view of each pixel is 17.79 ± 1.00 arcsec^2.

Due to the vignetting, enlarge the aperture size and press "zoom in" button until the value of aperture is bigger than f/3.0. On 3rd August, the value of aperture is set to f/3.3. Therefore, the plate scale per pixel is to be determined separately. The data is listed in table 5.

For the plate scale per pixel on 3rd August 2004, the angular distance between SAO 83257 and SAO 83283 is 1832 arcsec while the pixel distance is 530.3 ± 7.8. Therefore, the plate scale per pixel is 3.455 ± 0.051 and the field of view per pixel is 11.94 ± 0.35 arcsec^2.

For CCD, the optical system is less complex. The images are formed by prime focus. There, we can calculate the plate scale per pixel directly. By using equation 17,

$$V = arctan(\frac{P}{F}) \quad (17)$$

the plate scale per pixel is calculated, where V is field of view, P is the pixel size and F is the focal length of the telscope. However, the pixel is

Table 5: Plate scale per pixel of 03/08/2004

File Name	Time (HKT)	83257's COL	83257's LINE	83283's COL	83283's LINE	separation on image (pixel)
d7249.fit	2138	1242.76	1373.42	1109.94	584.78	541.17
d7250.fit	2139	1231.28	1330.44	1098.62	572.49	535.39
d7251.fit	2140	1223.73	1321.55	1091.42	563.52	536.89
d7252.fit	2141	1214.81	1313.31	1082.67	555.55	536.24
d7253.fit	2142	1206.83	1306.35	1074.84	548.71	535.46
d7256.fit	2145	1197.99	1305.10	1067.32	546.57	531.65
d7257.fit	2146	1188.50	1300.39	1058.10	542.10	521.71
d7258.fit	2147	1179.25	1298.97	1048.87	541.08	521.71
d7259.fit	2148	1168.20	1287.35	1037.49	529.35	521.92
d7260.fit	2149	1037.49	1281.01	1029.74	522.82	521.07

not square in size. The plate scale per pixel in horizontal direction and vertical direction are 9.94 arcsec and 9.63 arcsec respectively. The field of view of each pixel is 95.72 arcsec^2.

5.5 Comparsion of Data with Photometry of Standard Stars

Before we start to analyze the data, we make some change to equation 6.

$$\log f = -0.4(m_v + k_v X - \Delta) + 0.4c \quad (18)$$

For each data frame, the graph of $\log F$ against $(m_v - \Delta)$ with a fixed slope (-0.4) is plotted. The y-intercept is determined and the constant, c , is just $5 \times y - intercept$.

Here are the details how the data taken on 24 July 2004 were processed. First of all, the value of Δ is determined. Table 6 lists the value of Δ.

The mean of Δ is -0.049 and the standard deviation is 0.042.

The same method is applied to all other data sets. The value of Δ for CCD and digital camera data are obtained on each night in table 7.

The next step is to gather the flux of other stars. Table 8 to Table 11 show the integrated counts of the stars and the corresponding instrumental photometry. For DC, the data obtained in the reduction process is directly used to plot the graphs. However, for CCD, the counts is multiplied by five times as the gain is 5.

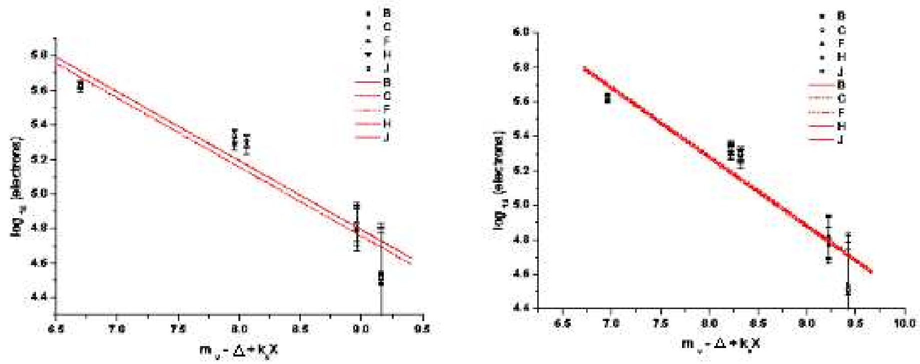

Figure 9: Linear fitting of the data obtained on 2004/07/24 by CCD

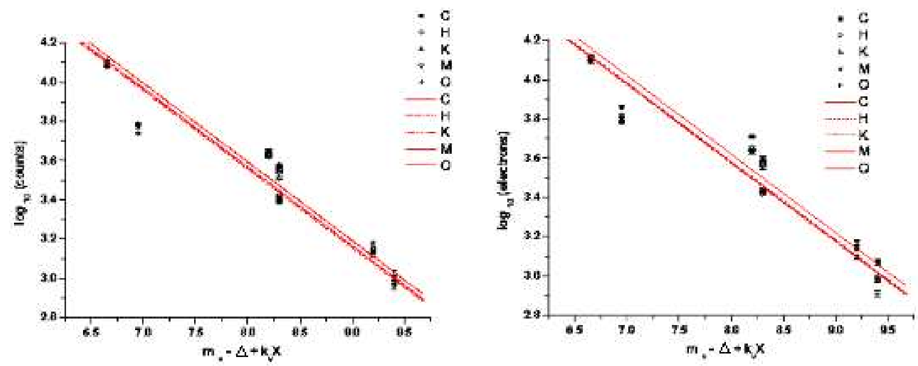

Figure 10: Linear fitting of the data obtained on 2004/07/24 by digital camera

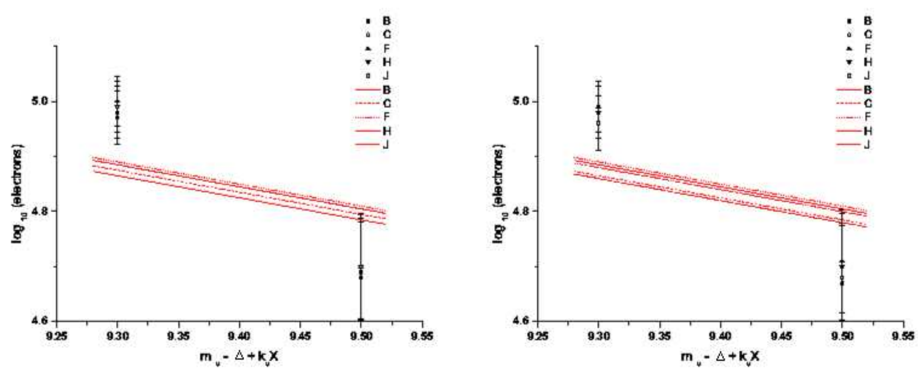

Figure 11: Linear fitting of the data obtained on 2004/07/13 by CCD

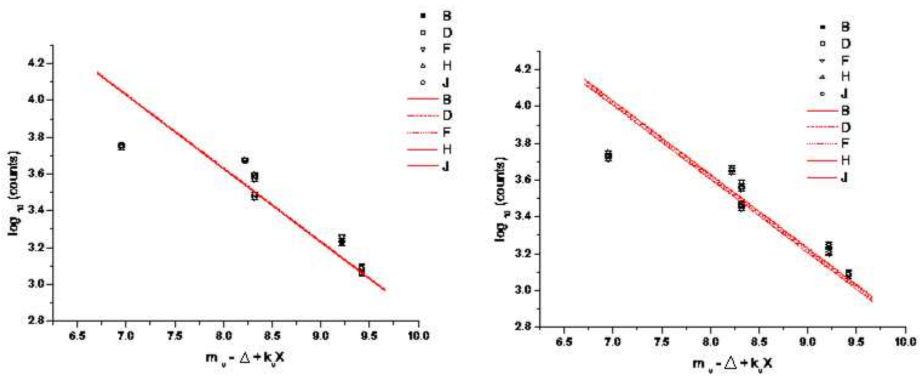

Figure 12: Linear fitting of the data obtained on 2004/07/13 by digital camera

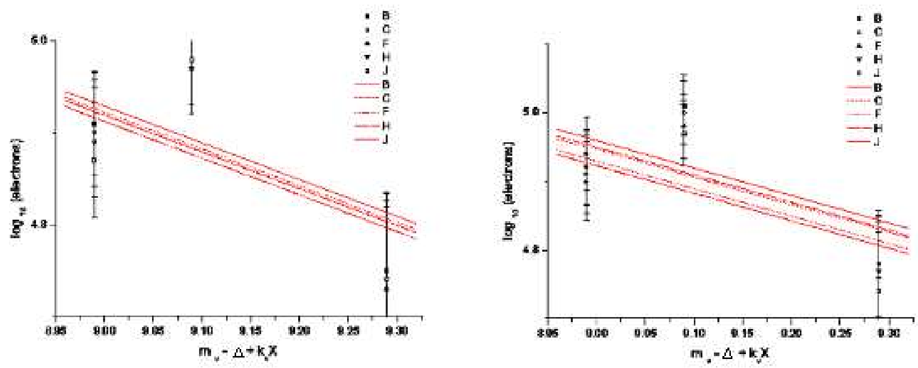

Figure 13: Linear fitting of the data obtained on 2004/07/14 by CCD

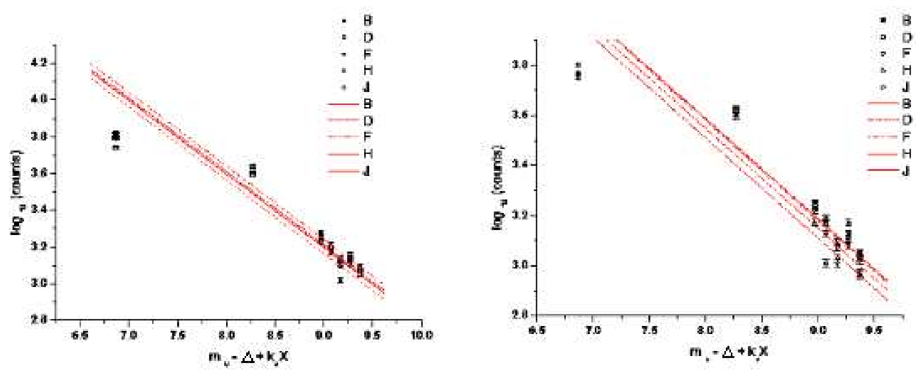

Figure 14: Linear fitting of the data obtained on 2004/07/14 by digital camera

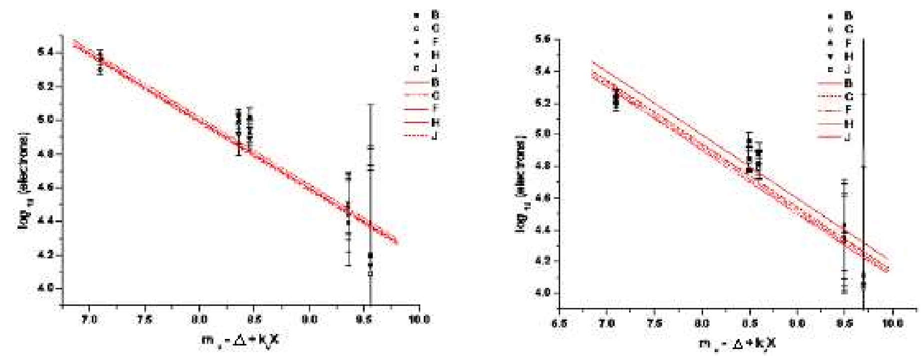

Figure 15: Linear fitting of the data obtained on 2004/08/02 by CCD

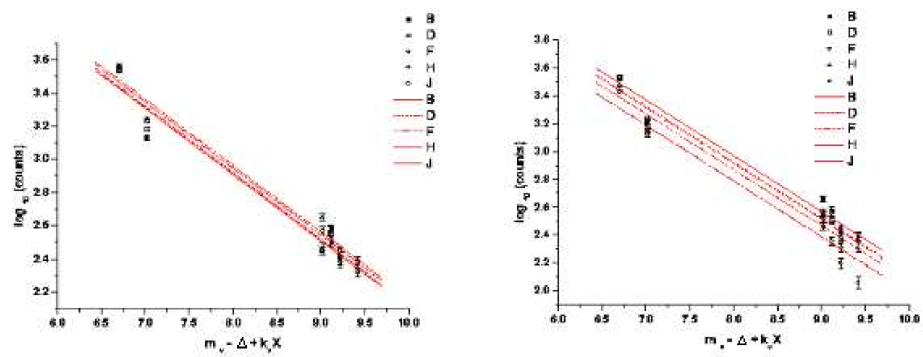

Figure 16: Linear fitting of the data obtained on 2004/08/02 by digital camera

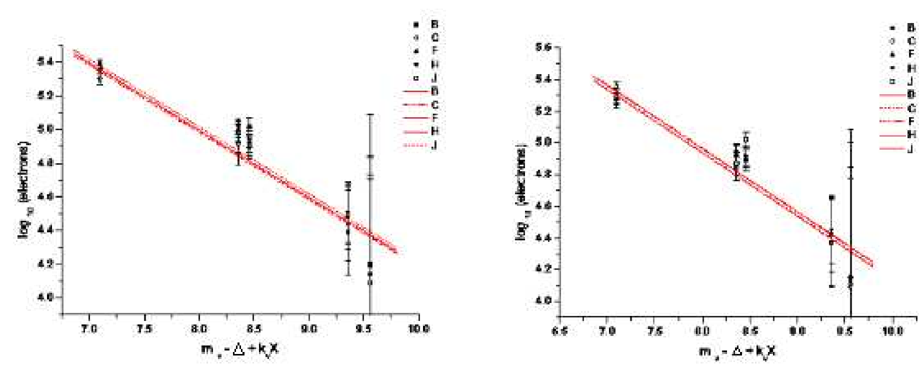

Figure 17: Linear fitting of the data obtained on 2004/08/03 by CCD

Table 6: Table of the flux (two aperture size) of a bright star, SAO 83242, which the FWHM is around 5 pixels

File name	Counts (1.4 * FWHM)	Counts (4 * FWHM)	Δ
d7211.fit	11849	11534	discarded
d7212.fit	11861	12324	-0.042
d7213.fit	11994	12214	-0.020
d7214.fit	12135	12321	-0.017
d7215.fit	12657	12786	-0.011
d7218.fit	13028	13411	-0.031
d7219.fit	11847	12972	-0.099
d7220.fit	12247	13118	-0.075
d7221.fit	12415	13979	-0.129
d7222.fit	12410	12639	-0.020

Table 7: List of Δ

Date	Observation Time (CCD)	Δ (CCD)	Observation Time (DC)	Δ (DC)
2004/07/13	2155 - 2201	-0.137 ± 0.007	2114 - 2131	-0.068 ± 0.011
2004/07/14	2232 - 2239	no bright stars	2152 - 2207	-0.105 ± 0.052
2004/07/24	2107 - 2114	-0.061 ± 0.014	2034 - 2045	-0.049 ± 0.042
2004/08/02	2105 - 2121	-0.199 ± 0.047	2133 - 2143	-0.116 ± 0.046
2004/08/03	2107 - 2114	-0.253 ± 0.064	2034 - 2045	-0.242 ± 0.077

The linear fit of the data are plotted in Figure 9 and Figure 10. Ten data frames are taken each night, therefore there are ten sets of data. Five sets of data are placed in each graph. By using the linear fitting function of a plotting software, Origin, the constant equals to 21.20 ± 0.16 and 16.94 ± 0.11 for CCD and digital camera respectively on 2004/07/24. Whereas, the linear fit of the data on other nights are plotted in Figure 11 to Figure 18. And the values are plotted in Table 12 and table 13.

For the error bar, the square root of the received counts or electrons is regarded as the error of counts or electrons, but the read noise has to be taken in account. The read noise per pixel is less than 15 electrons RMS. 15 electrons were taken as error in the calculation. The dark noise is less than 0.1 electron per pixel per second. As the integrating time is less than 10 seconds, the dark current is negligible. For the calculation, logarithm is taken to plot the graph. To show this error in the graph, some calculation is needed. Let $y = \log x$.

Table 8: Data Obtained on 24/7/2004 by digital camera. The airmass is around 1.04. SAO 83283 and SAO 83242 are relatively bright. Therefore, aperture correction does not apply to these stars. The aperture size is equal to the value which obtains the maximum counts. (Part 1)

File name	Observation Time (HKT)	Star	m_v	$m_v + k_v X - \Delta$	log (counts)
d7211.fit	2034	83285	8.0	8.30	3.56
		83283	6.7	6.95	3.77
		83281	9.1	9.40	3.00
		83260	8.9	9.20	3.14
		83257	7.9	8.20	3.64
		83241	8.0	8.30	3.39
		83242	6.4	6.65	4.08
d7212.fit	2035	83285	8.0	8.30	3.55
		83283	6.7	6.95	3.77
		83281	9.1	9.40	2.99
		83260	8.9	9.20	3.12
		83257	7.9	8.20	3.63
		83241	8.0	8.30	3.42
		83242	6.4	6.65	4.08
d7213.fit	2036	83285	8.0	8.30	3.51
		83283	6.7	6.95	3.74
		83281	9.1	9.40	2.98
		83260	8.9	9.20	3.15
		83257	7.9	8.20	3.62
		83241	8.0	8.30	3.39
		83242	6.4	6.65	4.09
d7214.fit	2037	83285	8.0	8.30	3.54
		83283	6.7	6.95	3.78
		83281	9.1	9.40	2.96
		83260	8.9	9.20	3.12
		83257	7.9	8.20	3.63
		83241	8.0	8.30	3.40
		83242	6.4	6.65	4.08
d7215.fit	2038	83285	8.0	8.30	3.58
		83283	6.7	6.95	3.79
		83281	9.1	9.40	3.03
		83260	8.9	9.20	3.18
		83257	7.9	8.20	3.65
		83241	8.0	8.30	3.41
		83242	6.4	6.65	4.11

Table 9: Data Obtained on 24/7/2004 by digital camera. (Part 2)

File name	Observation Time (HKT)	Star	m_v	$m_v + k_v X - \Delta$	log (counts)
d7218.fit	2041	83285	8.0	8.30	3.60
		83283	6.7	6.95	3.86
		83281	9.1	9.40	3.07
		83260	8.9	9.20	3.14
		83257	7.9	8.20	3.64
		83241	8.0	8.30	3.44
		83242	6.4	6.65	4.12
d7219.fit	2042	83285	8.0	8.30	3.58
		83283	6.7	6.95	3.80
		83281	9.1	9.40	2.98
		83260	8.9	9.20	3.17
		83257	7.9	8.20	3.64
		83241	8.0	8.30	3.43
		83242	6.4	6.65	4.09
d7220.fit	2042	83285	8.0	8.30	3.56
		83283	6.7	6.95	3.79
		83281	9.1	9.40	2.99
		83260	8.9	9.20	3.10
		83257	7.9	8.20	3.64
		83241	8.0	8.30	3.42
		83242	6.4	6.65	4.09
d7221.fit	2043	83285	8.0	8.30	3.57
		83283	6.7	6.95	3.82
		83281	9.1	9.40	2.91
		83260	8.9	9.20	3.17
		83257	7.9	8.20	3.65
		83241	8.0	8.30	3.42
		83242	6.4	6.65	4.10
d7222.fit	2045	83285	8.0	8.30	3.55
		83283	6.7	6.95	3.78
		83281	9.1	9.40	2.99
		83260	8.9	9.20	3.15
		83257	7.9	8.20	3.63
		83241	8.0	8.30	3.44
		83242	6.4	6.65	4.10

Table 10: Data Obtained on 24/7/2004 by CCD. The airmass is around 1.09. SAO 83283 is relatively bright. Therefore, aperture correction does not apply to this star. The aperture size is equal to the value which obtains the maximum counts. The value of counts is multiplied by 5 to change back to number of electrons. (Part 1)

File name	Observation Time (HKT)	Star	m_v	$m_v + k_v X - \Delta$	log (electrons)
01.fit	2107	83285	8.0	8.32	5.30
		83283	6.7	6.96	5.63
		83281	9.1	9.42	4.54
		83260	8.9	9.22	4.83
		83257	7.9	8.22	5.33
02.fit	2110	83285	8.0	8.32	5.31
		83283	6.7	6.96	5.64
		83281	9.1	9.42	4.51
		83260	8.9	9.22	4.84
		83257	7.9	8.22	5.33
03.fit	2110	83285	8.0	8.32	5.27
		83283	6.7	6.96	5.61
		83281	9.1	9.42	4.48
		83260	8.9	9.22	4.79
		83257	7.9	8.22	5.29
04.fit	2107	83285	8.0	8.32	5.27
		83283	6.7	6.96	5.61
		83281	9.1	9.42	4.48
		83260	8.9	9.22	4.80
		83257	7.9	8.22	5.29
05.fit	2111	83285	8.0	8.32	5.31
		83283	6.7	6.96	5.63
		83281	9.1	9.42	4.52
		83260	8.9	9.22	4.83
		83257	7.9	8.22	5.34

Table 11: Data Obtained on 24/7/2004 by CCD. (Part 2)

File name	Observation Time (HKT)	Star	m_v	$m_v + k_v X - \Delta$	log (counts)
06.fit	2113	83285	8.0	8.32	5.32
		83283	6.7	6.96	5.63
		83281	9.1	9.42	4.59
		83260	8.9	9.22	4.82
		83257	7.9	8.22	5.35
07.fit	2113	83285	8.0	8.32	5.32
		83283	6.7	6.96	5.61
		83281	9.1	9.42	4.58
		83260	8.9	9.22	4.84
		83257	7.9	8.22	5.35
08.fit	2114	83285	8.0	8.32	5.28
		83283	6.7	6.96	5.61
		83281	9.1	9.42	4.49
		83260	8.9	9.22	4.81
		83257	7.9	8.22	5.31
09.fit	2114	83285	8.0	8.32	5.25
		83283	6.7	6.96	5.62
		83281	9.1	9.42	4.51
		83260	8.9	9.22	4.81
		83257	7.9	8.22	5.30
10.fit	2114	83285	8.0	8.32	5.32
		83283	6.7	6.96	5.62
		83281	9.1	9.42	4.55
		83260	8.9	9.22	4.87
		83257	7.9	8.22	5.33

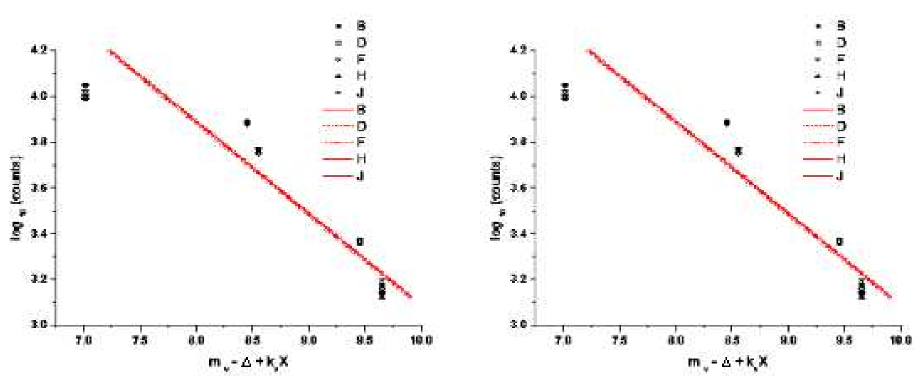

Figure 18: Linear fitting of the data obtained on 2004/08/03 by digital camera

Table 12: Data of constant(CCD)

Date	Area	No. of Stars for calibration	Constant c
2004/07/13	A	2	21.74 ± 0.26
2004/07/14	B	3	21.33 ± 0.12
2004/07/24	A	5	21.20 ± 0.16
2004/08/02	A	5	20.35 ± 0.15
2004/08/03	A	5	20.44 ± 0.16

Table 13: Data of constant(Digital Camera)

Date	Area	No. of Stars for calibration	Constant c
2004/07/13	A	6	17.06 ± 0.16
2004/07/14	B	7	16.94 ± 0.12
2004/07/24	A	7	16.94 ± 0.11
2004/08/02	B	6	15.28 ± 0.09
2004/08/03	A	5	17.73 ± 0.19

$$dy = log(x \pm dx) - logx \Rightarrow dy = log(1 \pm \frac{dx}{x}) \tag{19}$$

As $|log(1 + \frac{dx}{x})|$ is smaller than $|log(1 - \frac{dx}{x})|$, the latter one is taken as the error of counts.

The data of other nights are reduced in similar procedures. The lists of constants may be found in table 12 and table 13.

Table 14: Sky Brightness (Digital Camera)

Date	Time	mean airmass	brightness	Moon Phase (%)	Moon Altitude (azimuth)
2004/07/13	2114 - 2131	1.04	17.16 ± 0.18	14	-42^o
2004/07/14	2152 - 2207	1.11	16.94 ± 0.14	8	-34^o
2004/07/24	2034 - 2045	1.04	16.46 ± 0.12	43	$+47^o$ (233^o)
2004/08/02	2133 - 2143	1.26	14.39 ± 0.09	95	0^o
2004/08/03	2138 - 2149	1.30	17.48 ± 0.20	90	-7^o

Table 15: Sky Brightness (CCD)

Date	Time	mean airmass	brightness	Moon Phase (%)	Moon Altitude (azimuth)
2004/07/13	2155 - 2201	1.10	17.61 ± 0.26	14	-44^o
2004/07/14	2232 - 2239	1.21	17.17 ± 0.12	8	-41^o
2004/07/24	2107 - 2114	1.09	16.81 ± 0.16	43	$+42^o$ (233^o)
2004/08/02	2105 - 2121	1.20	14.87 ± 0.15	96	-6^o
2004/08/03	2236 - 2242	1.65	15.44 ± 0.16	89	$+5^o$

6 Result

By equation 8 and the data in previous section, the brightness of night sky is computed. To calulate the brightness by CCD data, the background counts should be multiplied by five because electrons is the unit used in the calculation. For the error of the brightness, furthers steps are needed. First, logarithm base 10 is converted to natural logarithm.

$$\log x = \frac{\ln x}{\ln 10} \tag{20}$$

Then equation 8 becomes

$$m' = -\frac{2.5}{\ln 10} \ln x + c \tag{21}$$

where $x = \frac{B}{F}$. The error of m' is therefore given by

$$(dm')^2 = -(\frac{-2.5}{\ln 10})^2 (\frac{dx}{x})^2 + (dc)^2 \tag{22}$$

where

$$(dx)^2 = (\frac{dB}{F})^2 + (\frac{B^2}{F^4})(dF)^2 \tag{23}$$

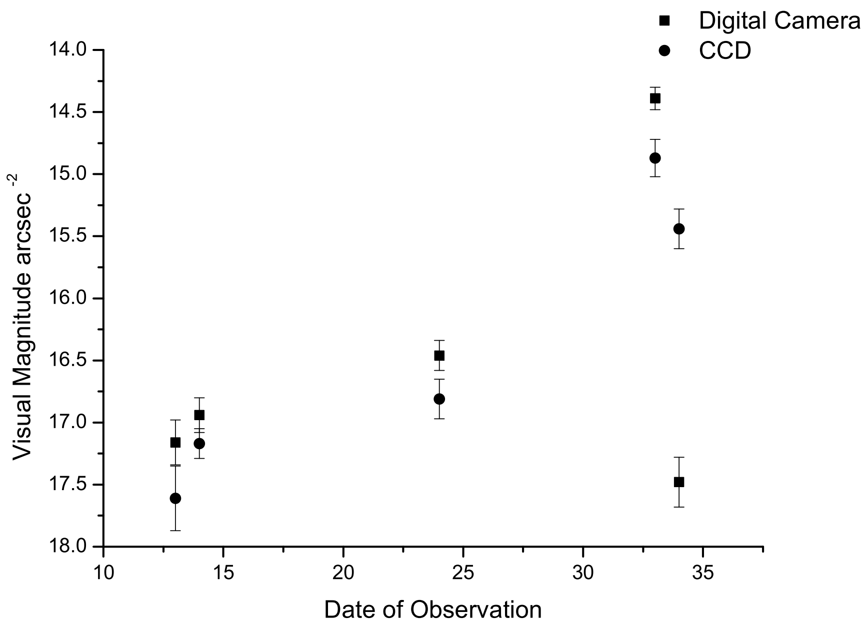

Figure 19: The graph of brightness against date of observation

By the above equations, the brightness and its deviation of five nights is computed in table 14 and table 15, stated with the aimass of the stars, moon phase and moon altitude. And the graph of brightness against date of observation and the graph of brightness against date of observation are shown in Figure 19 and Figure 20.

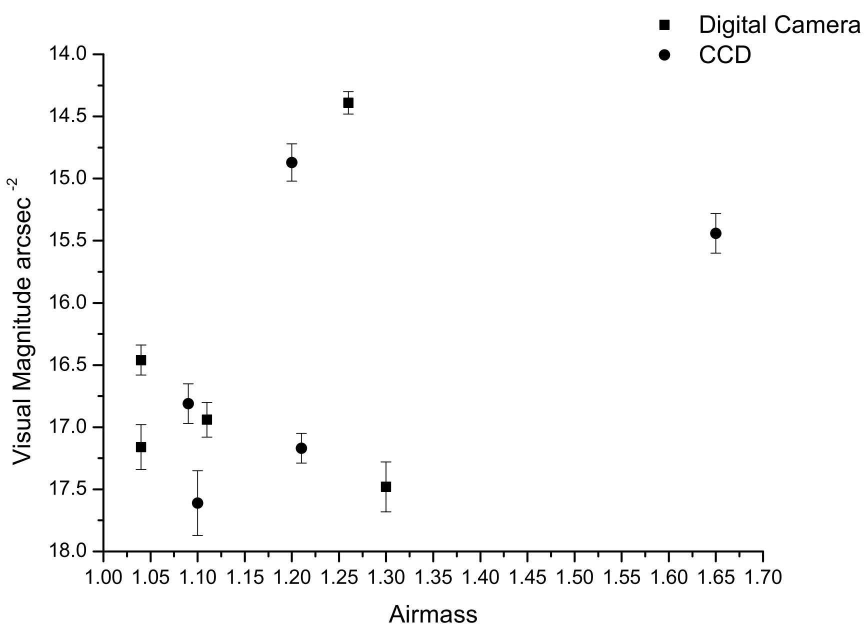

Figure 20: The graph of brightness against airmass

Place	Nights of data	Year	U	B	V	R	I	Reference
			Sky brightness mag arcsec^{-2}					
McDonald	5	1960		22.8	21.7			Kalinowskiet *al* (1975)
Junipero Serra	1	1966		23.0	21.9			Walker (1970)
San Pedro Martir	2	1970		22.9	21.9			Walker (1971)
Junipero Serra	1	1971		22.9	21.9			Walker (1973)
McDonald	6	1973		22.7	21.7			Kalinowskiet *al* (1975)
San Benito	1	1976		22.9	21.9			Walker (1988)
La Silla	1	1978		22.8	21.7	20.8	19.5	Mattila *et al* (1996)
Sacramento Peak	12	1978			21.9			Schneeberger *et al* (1979)
Kottamia	1	1980		22.9	21.9		20.1	Nawar *et al* (1995)
San Benito	7	1981		22.6	21.6			Walker (1988)
Kitt Peak	7	1987		22.9	21.9			Pilachowski *et al* (1988,9)
Cerro Tololo	2	1987		22.9	22.0			Geisler (1987)
San Benito	6	1985-7		22.9	21.9			Walker (1988)
La Palma	4	1987			21.8			
Cerro Tololo	1	1988		22.5	21.6			Geisler (1988)
Siding Spring		1989		22.7				Savage (1989)
Mauna Kea	16	1989-91		22.7	21.9			Krisciunas (1997)
Calar Alto	3	1990	22.2	22.6	21.5	20.6	18.7	Leinert *et al* (1995)
La Palma	9	1990-2		22.5	21.5			
Cerro Tololo	1	1991	22.4					Pettini (private comm.)
Mauna Kea	8	1995-6		22.8	21.9			Krisciunas (1997)
La Palma	43	1994-6	22.0	22.7	21.9	21.0	20.0	

Figure 21: Benn (1998) listed the near zenith dark-of-moon broad band sky brightness measured at various observatories

7 Discussion

The prelimary results suggest that the brightness of the night sky in HKU campus is limited to 17 mag arcsec^{-2} near zenith in fairly good observation condition. [5] Referring to Figure 21, our sky is around one hundred times brighter than all observatories in V. This implies that our sky is heavily polluted.

However, there is plenty of room to improve our technique. It was found that the results from CCD were generally dimmer than that of digital camera, even though the measurements were taken within one hour. I propose that the manipulation of signals of digital camera is not known. Secondly, the sensitivity of two imaging devices are different. So they detect different frequencies of photons and give different results.

These are the problems found in this experiment:

- The counts of the stars, especially the weak sources, are not steady as the aperture grows bigger.

[5] Fairly good observation condition means that no cumulus are observed, but high clouds which cannot be seen easily may affect the observation. And transparency is above 10km

- The received counts from the same star on the same night are not steady from time to time. The fluctuation is much larger then the square root of total counts.
- It is quite difficult to observe if there is any cloud at high altitude (above 6km). To find out if there is any clouds obstruction, the contrast of the image is increased that patches of cloud may be seen.
- The manipulation of signals by the digital camera is a commercial secret. The formula for converting the signals to RGB value has to figure out so that the data were interpreted correctly.
- There are two ways to obtain a flat field sample. The first one is to construct a well-illuminated white screen, but due to lack of appropriate apparatus, I fail to get one by this method. The second method is to obtaining the flat field from twilight sky. However, due to the unfavorable climate and hazy weather, it is unlikely to obtain an image of sky with more or less the same tone.
- The error of delta, Δ, in aperture correction is quite large. Further studies are needed to verify if aperture correction is necessary.
- Hong Kong's climate is sub-tropical, tending towards temperate for nearly half the year[6]. The observation is often intervened by the clouds and dust. Handful of observations can be carried. Thus, there are less chances to carry out observations.
- The sensitivity to the photon of different frequencies is different for two imaging device. Therefore, brightness obtained from digital camera and CCD does not match well.
- The visual magnitude of the dimmest stars in SAO catalog is around 10. Therefore, another catalog is needed if the standard stars is much dimmer than those star in SAO. The other problem is that we assume that the visual magnitude obtained from SAO catalog is corrected to zero airmass, i.e. this is the actual viusal magnitude of the star without atmospheric extinction. If the stars are measured at zenith, the brightness calculated in this project should be brighter by 0.24 magnitude.
- The error found in this report is just the statistical error. The systematic error is needed to determine in future.
- The correlation of brightness against airmass and brightness against date of observation is not strong. More data are needed to verify the relation.

[6] http://www.hko.gov.hk/wxinfo/climat/climahk.htm

Here are some recommendations for this survey:

- Sky monitoring should be carried out in various observation sites to investigate the effect of the surrounding on the sky brightness.
- The results can be compared to the moon position, moon phase, [7] visibility (transparency), cloud amount and concentration of suspended particles if there is large amount of data.
- The interval between the measurement by CCD and digital camera should be as short as possible because the altitude of stars will change, thus, the sky brightness changes.
- V band filter may be applied to this experiment to solve the problem of color.
- The integrating time and stars used to take data should be chosen carefully because the background signal varies every night. To obtain good data, review your images immediately, then correct the exposure time or switch to other stars if necessary.
- The error of brightness depends largely on the error of the constant c. The deviation of brightness can be reduced if a better method to determine the constant c was devised.
- The observation with CCD and equatorial mount might be carried out in outdoor area with the assistance of amateurs. The lead acid battery can drive both CCD and the motor so that we can take the data outside HKU campus. With the help of the astronomy societies, we can share the equipments and work with them more closely in future.
- Hubble Guide Star Catalog (GSC) maintained by Russell, et al (1990) contains more stars than SAO catalog. Also, the stars in GSC are dimmer than those in SAO. However, GSC gives photometric magnitude, but not visual magnitude.

[7] http://www.gemini.edu/sciops/ObsProcess/obsConstraints/ocSkyBackground.html

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