1 Introduction

In this observatory practical we will view asteroids and possibly also comets. We will measure their angular motion across the sky and also estimate their brightness. For comets we should be able to see the *coma*, the atmosphere of gas and dust that surrounds the nucleus.

The primary characteristic of comets and asteroids that we will exploit to distinguish them from stars is that they appear to move relative to the stars. We can see this if we compare two images separated by some period of time, say, 10 or 20 minutes. This sort of comparison is not so straightforward, however, as the tracking of the telescope is not perfect and in 20 minutes even the distant stars will appear to have shifted somewhat in the image. So we cannot simply overlay the two images and look for what has shifted. We must first align the images using stars and then look to see if there is another body, an asteroid or comet, that appears to move.

Some basic background on asteroids and comets can be found in Chapter 10 of the course Lecture Notes. The exercise also uses concepts from Chapter 3 on angular measurement (plate scale and point spread function) and from Chapter 5 on photometry.

2 Procedure

2.1 Selecting candidate targets

For this exercise we will first use a planetarium program such as Starry Night to tell us which asteroids are easily visible. If we observe in the early evening when the Sun has just set, then the asteroids towards the east will be more fully illuminated than those in the west. Choose an asteroid not too low in the sky but at least somewhat towards the east. Starry Night will give an estimate of the asteroid's magnitude; try to find a relatively bright one.

There are many websites that give information on what comets are visible at any given time. A useful one is maintained by the Comet Section of the British Astronomical Association (BAA). It can be found at

`www.ast.cam.ac.uk/~jds/`

If you follow the link on upcoming comets you will see what is visible and when. For November 2006, the comet 4P/Faye is a good candidate.

Although Starry Night will give the declination and right ascension of asteroids (and of some comets), this may not be sufficiently accurate. To obtain an accurate prediction of where to find a given asteroid or comet as a function of time, go to the Minor Planet and Comet Ephemeris Service from the IAU Minor Planet Center [2] at

`cfa-www.harvard.edu/iau/MPEph/MPEph.html`

This can produce an *ephemeris* (plural: ephemerides), i.e., a table of the coordinates as a function of time, of a wide range of asteroids and comets.

Select "return ephemerides" for the ephemeris interval choose "hours". Enter the name of the asteroid or comet in the box and click the button. The data returned will be of the form:

Date	UT h m s	R.A. (J2000)	Decl.	Delta	r	El.	Ph.	V	Sky Motion "/min	P.A.
2006 11 30	160000	03 01 07.7	+21 21 38	0.885	1.844	160.3	10.4	7.2	0.48	222.6
2006 11 30	170000	03 01 06.3	+21 21 17	0.885	1.844	160.3	10.4	7.2	0.48	222.6
2006 11 30	180000	03 01 04.9	+21 20 56	0.885	1.844	160.2	10.4	7.2	0.48	222.5
2006 11 30	190000	03 01 03.5	+21 20 34	0.885	1.844	160.2	10.5	7.2	0.48	222.5
2006 11 30	200000	03 01 02.1	+21 20 13	0.886	1.844	160.1	10.5	7.2	0.48	222.4
2006 11 30	210000	03 01 00.7	+21 19 52	0.886	1.844	160.1	10.5	7.2	0.48	222.4
2006 11 30	220000	03 00 59.4	+21 19 31	0.886	1.844	160.0	10.5	7.2	0.48	222.3
2006 11 30	230000	03 00 58.0	+21 19 10	0.886	1.844	160.0	10.6	7.2	0.48	222.3

The important columns are the right ascension and declination. Here they have been reported hourly, and so you can make a rough interpolation for the actual time of your observation. The "V" column gives the apparent visual magnitude. The sky motion, here $0.48''$/min, is also an interesting number to know. This should be a sizeable fraction of an arc-second per minute in order to detect the motion of the asteroid in a reasonable amount of time.

Before going up to the observatory you should obtain and print out the ephemerides for at least several candidate targets.

2.2 Telescope setup

When looking for asteroids or comets, it is useful to have a somewhat wider field of view than what is usually obtained with our $f/10$ telescope. We can effectively reduce its focal length from its nominal value of $F = 3048$ mm by using a *focal reducer*. The observatory demonstrator will show you how to insert the $f/6.3$ focal reducer between the telescope's rear cell and the SBIG ST-7E CCD camera. This is a positive focal length lens which reduces the focal length by a factor of 0.63. (It is called an $f/6.3$ focal reducer as many telescopes, like ours, have a nominal focal ratio of $f/10$. A negative lens would increase the focal length; this is called a *Barlow lens*.)

Using the focal reducer increases the length of the camera assembly somewhat. If we also use filters or the flip mirror, then the camera will extend too far from the telescope. So we will not use these and you therefore will not be able to see directly what you are pointing at and furthermore the photometry measurements will not be directly comparable to those obtained using BVR filters. The primary goal of the observations, however, will be to determine the angular movement of the asteroid or comet, and filters are not needed for this.

Carefully attach the camera and cable it up. All screws must be "(very) firmly finger tight". If in doubt, ask the observatory demonstrator. Set the temperature set-point to a reasonable value ($-18°$ or so) and turn on the thermoelectric cooler.

2.3 Finding the asteroid or comet

The "raw" pointing accuracy of the telescope is not sufficient to simply slew directly to the position of the asteroid or comet. First find a bright star reasonably close to the comet and synchronise the coordinates. Optimise the focus, first with the manual coarse focus and then with the electric focuser. You may want to then move to a star even closer to the desired target and repeat the procedure. Remember you can get the Hipparcos catalogue numbers from Starry Night (right click and go to "info window").

You will want to recalibrate the plate scale of the telescope with the focal reducer. To do this, record an image with at least two known, well separated stars whose angular separation can be found from, e.g., Starry Night. Note that the entire field of view is around $10'$ across.

Using published values for the asteroid's apparent magnitude, make a rough estimate of how bright you expect it to appear on the image by comparing to known stars. Remember that 2.5 magnitudes is a factor of 10 in flux. (You can use ImageJ to do a quick background subtraction; choose equal areas for the signal and background regions.)

Finally, to move to the predicted coordinates of the asteroid, press and hold the "mode" key for around two seconds and release. This will display the telescope's current right ascension and declination. Start the CCD readout in focus mode (use low resolution and read out the entire image) with an exposure time of, say, 2 seconds.

Once you are pointing at the correct coordinates, you may or may not immediately recognise the target asteroid or comet. Record an image with a sufficiently long exposure to determine the positions of at least two background stars. Save them in FITS format with file names that contain the target's name, exposure time and image number, e.g., `alexandra_20s_1.fit`, `alexandra_20s_2.fit`, and so forth. Make sure that the time that the image was taken is recorded in the header of the FITS file (this should be done automatically). Continue to record images every 5 or 10 minutes. Once you have found the target you should continue to take data until the end of the observing session, or at least long enough to clearly see and measure the angular motion of the comet or asteroid.

3 Analysis

You can begin the analysis as soon as you have recorded at least two images. The first step is to see if the asteroid is moving relative to the background stars. To do this we first need to align the stars in the images using the CLEA Astrometry Toolkit [1].

Start the program CLEA Astrometry Toolkit. From the File menu, go to "load images", and open the files as "Image 1", "Image 2", etc. It may be necessary to go first to the "Set Image File Type" under the file menu and select FITS, in addition to selecting this format when you open the file.

Next, go to the "Images" menu and select "Blink". The program will present the first image and ask you to click on a star. Hopefully you will have some idea as to which object is the asteroid or comet, so you can avoid this. Click on a star and then click continue.

The program will then request that you choose a second star. The program will use these two stars to align the images, so it is best to choose the second star to be reasonably far away from the first one, both horizontally and vertically.

The program will then present the second image and ask you to again click on *the same* stars as those that you selected from the first image. Starting from the assumption that the images are approximately aligned, the program will estimate where the star should be. In general it will miss by some amount, so you simply have to click directly on the correct star. For the final star, i.e., the second one in the second image, its guess will usually be spot on.

Once you have selected the stars, click on "Blink". If the program complains that it cannot deal with full resolution, simply click "yes" and continue. The program will blink back and forth between the two images, and you should be able to see the motion of the asteroid relative to the background stars.

You can improve the image quality by going to "view/adjust" under the Images menu. Then right click on one of the images and select "adjust image". (The exact sequence of commands here may vary depending on the version of the software.) You can then vary the brightness, contrast, etc.

In order to illustrate this part of your analysis in your report, it is probably best to stop the blinking for each image in turn, then save the image window by selecting it and pressing alt-print screen; then paste it into a program such as Paint and save it, or paste it directly into a Word document.

3.1 Angular motion

You should measure the target's total angular speed in arc-seconds per minute, as well as the time rate of change of its right ascension α and declination δ. Remember that a (small) angular change $\Delta\theta$ is related to the corresponding changes $\Delta\alpha$ and $\Delta\delta$ by

$$\Delta\theta = \sqrt{(\Delta\delta)^2 + \cos^2\delta(\Delta\alpha)^2} \quad (1)$$

You will first need to calibrate the plate scale of the telescope using a pair of stars of known separation. If this cannot be achieved, use the formula $P = 1\,\text{rad}/F$. With the $f/6.3$ focal reducer we have $F = 0.63 \times 3048$ mm. The pixel spacing of the SBIG ST-7E camera is approximately 9.0 μm.

Make reasonable estimates for the uncertainties in all of your measurements. Explain how you have arrived at the error estimates, comment on their causes and discuss and how they could be reduced. Compare the values that you obtain to those provided by the Minor Planets Ephemeris Service (see e.g. [2] for an explanation of the the quantities printed out in the ephemerides).

3.2 Brightness

You should estimate the brightness of the asteroid or comet by using the same basic procedures as those used in Observatory Practical #3 and described in the lecture notes. For a chosen reference star in the image you should compute the magnitude difference $m_{\text{ast/com}} - m_{\text{ref}}$. If you can identify the star and find a published value for its magnitude, then you can determine the apparent magnitude of the target. Compare this to the value predicted by the Ephemeris Service (the column "V" in the ephemeris is the predicted visual magnitude). Remember to estimate and briefly discuss measurement errors.

3.3 PSF and angular size of a comet

You should first use one of the stars in your image to estimate the width of the point spread function (PSF). You can do this using the program ImageJ by creating a narrow rectangular region of interest about a star as shown in Fig. 1(a) [3]. Then select "plot profile" from the

Analyse menu. This will project the measured pixel values into a histogram along the horizontal direction as shown in Fig. 1(b).

(a) (b)

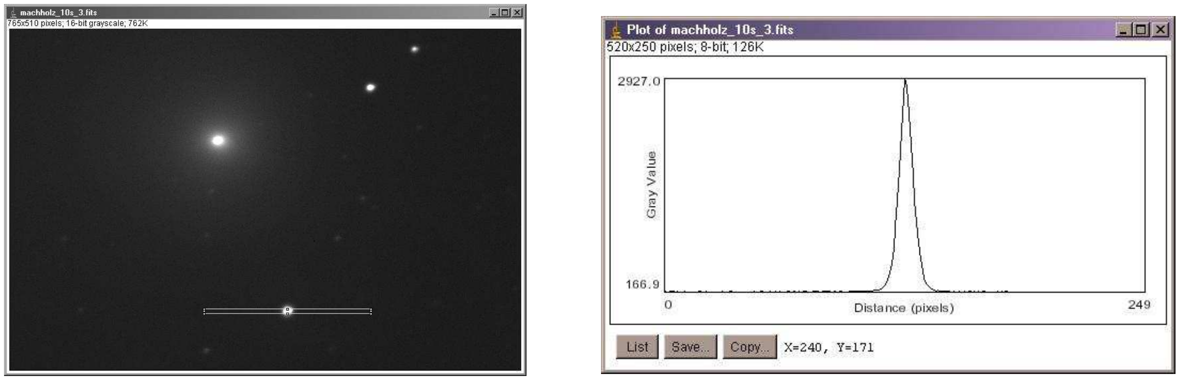

Figure 1: (a) Rectangular region of interestion (ROI) placed around a star and (b) the intensity profile from the ROI projected onto the horizontal axis.

The envelope of this histogram, after subtraction of the background level, is essentially the shape of the point spread function. By moving the cursor to the left and right edges of the curve at the half-way point between the peak and the background level, estimate the full width at half maximum of the profile in units of arc-seconds.

Then repeat the procedure with the comet using the same rectangular region of interest, as shown in Fig. 2. Again measure the full width at half maximum after subtraction of the background level.

(a) (b)

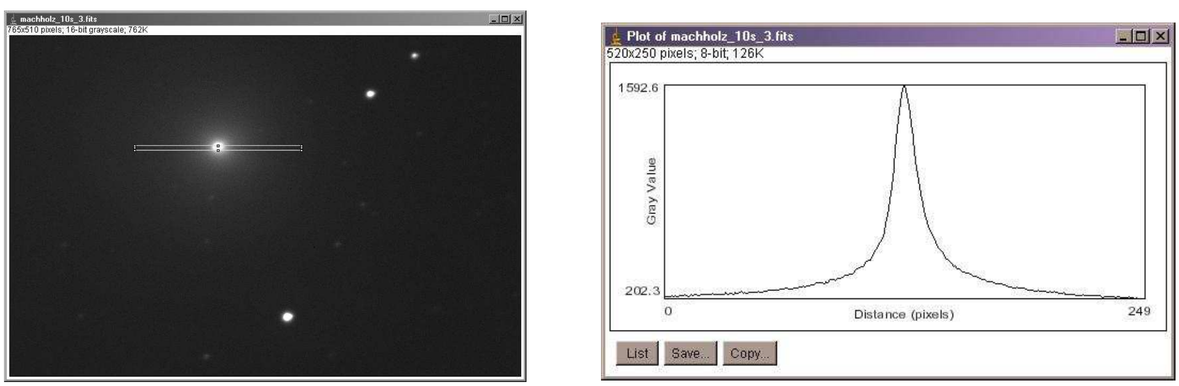

Figure 2: (a) Rectangular region of interestion (ROI) placed around Comet Machholz and (b) the intensity profile from the ROI projected onto the horizontal axis.

Even if you are unable to observe a comet, you should estimate the width of the PSF and compare this to what you expect. As an extension to this project, or even as a 3rd-year major project, you could measure the surface brightness of the comet as a function of position from its nucleus.

References

[1] Project CLEA, public.gettysburg.edu/~marschal/clea/CLEAhome.html.

[2] Guide to the MPES, cfa-www.harvard.edu/iau/info/MPES.pdf, Minor Planets Ephemeris Service, Harvard-Smithsonian Center for Astrophysics, 2005.

[3] Image of Comet Machholz taken by Melissa George, RHUL Physics, 13 January, 2005.

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