1 Introduction

This handout describes some of the activities that you will do during observatory sessions with the LX200 telescope. This is a 10-inch Schmidt-Cassegrain telescope with a theoretical angular resolution of around 0.4 arc seconds, although because of the atmospheric conditions the "seeing" in Egham is usually lot worse than this. It has a light gathering power several thousand times greater than the naked eye. The telescope is equatorially mounted, motor driven and computer controlled and can, in theory, make a very wide range of astronomical measurements.

In these practicals you are going to learn the skills you need to be able to operate the telescope. Each practical will consist of one or possibly two viewing sessions followed by some basic data analysis. Each write-up should be roughly three to four pages of text plus the appropriate data tables, images, graphs, etc. The write-up should have the standard format that you have learned in the lab, with a brief description of the procedure, results, conclusions, etc.

Because these projects can be done at different times of year, and because the weather may not co-operate, not all the astronomical observations suggested in this script will be possible. You should discuss with your supervisor what reasonable alternatives to study.

You will observe and photograph a range of astronomical objects and perform some simple analysis using those photos. This will involve learning how to use the telescope itself, the cameras and data acquisition systems associated with it, and familiarising yourself with operations in the dome. The analysis of the data will be done offline after the observing sessions.

The bulk of the work will clearly have to be done at night (although some very simple observations can be made during the day). You should find out what the arrangements are for supervision of this work and you must arrange to be free on the allocated evenings. Since the British weather may not co-operate, you should also be prepared to grab observations when you can- check with your supervisor!

2 Key Learning Objectives

Some of the key learning outcomes of these exercises are:

- Be familiar with the working environment of the telescope dome and the operating procedures for making observations.
- Become familiar with the basic operation of the telescope, including alignment, focussing, pointing and tracking of the telescope, the safe operation of the telescope and how to mount equipment such as CCD cameras onto the telescope. See the separate 'RHUL Observatory User's Guide' on the web for more information.
- Be able to make observations of an object given its celestial co-ordinates in Right Ascension and Declination.

- Capture photographs of objects using the WebCam CCD camera and the SBIG ST-7E CCD camera.
- Analyse the data from photographs taken with the telescope, in terms of the angular size of the objects viewed, their physical dimensions (given their distance).

3 Your first observing session

3.1 Safety

You must be familiar with the dome safety procedures and the telescope operating instructions, these will be explained by the demonstrator. To summarize, the main hazards in the dome are: The trapdoor – make sure it is closed when you are up there, and follow the procedures for going up and down the spiral stairs. The danger of eye damage if you point the telescope at the sun without correct filters in place. The danger of falling off the roof as there is only a very low ledge and no safety rail. NEVER approach the edge of the roof.

3.2 Getting Started – Finding a star the hard way

The first thing we are going to do is to figure out where to point the telescope. We are going to aim for the bright star Vega, which is located at Right Ascension 18 hours 36 minutes 56.3 seconds, Declination +38.470. We can observe Vega even during twilight, but we need to know where to point our telescope to do so... and be very sure that the sun isn't in our field of view.

We will make the first observation optically, so put a low powered eyepiece into the back cell of the telescope (the demonstrator will show you how to do this the first time). You may need to focus the telescope- ask the demonstrator to show you how.

Since the telescope is equatorially mounted, we can do this rather easily using the setting circles on the telescope. For declination, use the setting circle on the left hand side of the telescope. Simply loosen the knob, pivot the telescope until the setting circle reads 38.470 and retighten the knob again.

The other setting circle works in hour angles rather than RA, so we need to know the local sidereal time as well. You can look this up on the web at `http://tycho.usno.navy.mil/sidereal.html` or use the telescope's control panel, or use Starry night on the PC in the dome.

The hour angle h is related to the LST and right ascension α by

$$h = \mathrm{LST} - \alpha \tag{1}$$

You should be able to observe Vega in the finder scope, although you will be lucky if you are accurate enough to see it in the eyepiece without a little tweaking.

Next Step: Synchronising and automatic pointing of the telescope

At this stage the telescope will need to be synchronised. This updates and refines the telescope's knowledge of where it is pointing. It performed by getting the telescope to GOTO an object, which may not be exactly in the centre of the field of view. Centre the object, then tell the telescope you have done it. After doing this on several objects the telescope's automatic pointing should be able to take you where you want to go. Ask the demonstrator to show you how. You should not touch the setting circle knobs; use the drive and the hand controller instead.

Then you can start using the GOTO functions of the telescope. You can find Vega again by pressing the GOTO key and entering the RA and Dec for Vega. The telescope will slew to those co-ordinates automatically. Again you may need to tweak the position slightly. Try using the guide scope as well.

The telescope has a library of bright stars. Vega is star number 214 (the catalogue numbers are in the manual by the telescope). Try hopping to some other stars, like Aldebaran (33), Betelgeuse (56) or Altair (226), depending on what is up at the time. Do this by pressing the STAR key, entering the star number, and pressing enter. Then press GOTO and the scope will slew there.

You can also use Starry Night on the dome PC. This very useful program will show you what is up in the sky right now, tell you RA and dec co-ordinates should you need them, etc..

4 First photographs: the moon

Next you are going to take your first astro-photographs. We'll start with a nice, big, bright target: the Moon. Again it is possible to take photos of the moon during the day, although the contrast will be lower and the seeing is likely to be poor. If the moon isn't visible, you can start with one of the other observations from later sections.

First get the moon in your sights using the finder scope and the optical eyepiece. Then replace the eyepiece with the QuickCam CCD camera. This camera is literally a webcam cracked open and put in a box. It is not as sensitive as the SBIG ST-7 camera (which can't cope with the moon) and it is also a LOT cheaper! The demonstrator will show you how to hook the camera up to the PC, take photos and movies.

Take photographs of several areas of the moon. What you can see will of course depend on the phase of the moon. You will find that the best images are obtained near the terminator (the boundary between daylight and lunar night) because the long shadows make features a lot easier to recognise.

If you can, take photos of one of the lunar maria (the smooth, dark plains- these are relatively young, formed by basaltic lava flows towards the end of the moon's formative period) and of the lunar highlands, the broken, brighter, mountainous regions in between the maria.

Ensure you have some nice photographs of craters and take some images near the centre of the lunar disk because these are easiest to interpret- the craters will appear circular, whereas towards the limb of the moon they will be foreshortened and tend to appear elliptical.

You will probably find that the seeing varies from instant to instant. It is probably best to take a series of snapshots of the same region, say, 10 or 20 of each, and pick the best.

Save your images in your own folder on the dome PC. Make sure you use meaningful file names, and write down in your lab book what each picture corresponds to- the object you are observing, its coordinates (RA, dec) and the time at which the observation was made. You will be glad of this when you come to analyse them!

If you end up with lots of time looking at the moon, you can even attempt to make a mosaic image of the whole lunar disk and stitch the images together afterwards using a program such as Paint Shop Pro.

Lunar data analysis

After the observing session, get your images onto a CD so you can analyse them. You are going to measure distances on the image, which you can do with most paint packages, for example Paint Shop Pro tells you the (x, y) coordinates that of the mouse pointer in pixels in the lower left hand corner of the screen. Or you could print out the picture and measure with a ruler and convert that back to pixels by noting the dimensions of the printed picture and the size of the image in pixels.

Select a crater on one of your images from near the centre of the lunar disk. Measure the diameter of the crater in pixels, across several different radii. These will be slightly different, because the crater is unlikely to be perfectly circular. Make several measurements, find the average, and calculate the standard deviation. You now know how far across the crater is in pixels. This isn't much help, since we want to know how far across the crater is in kilometres!

The first stage in finding this out is to figure out the angular size of the crater. You can work that out by knowing that the telescope has a 2.5 m focal length, which means its plate scale, p, is given by

$$p = 206265/F \ ,$$

where p is the plate scale in arc seconds per mm and F is the focal length of the telescope in mm. 206265 is a numerical constant (the number of arc seconds in a radian).

To get the angular size of the crater, we need to know the size of a pixel in the CCD chip. For the QuickCam, the chip is about 3 mm $\times$ 4 mm and contains 480×640 pixels (or effectively 240×320 if the camera is used in medium resolution mode). From this you can work out roughly the size of a pixel and therefore the angle that it subtends.

A more accurate method will be to take a picture in which you have two well known stars in the field of view. Then with a program such as ImageJ you can measure the distance in pixels between the stars. You can then look up their actual angular separation using a program such as Starry Night, and from this you can find the angular separation per pixel. Try both methods and see that they give roughly the same result.

Now we know what angle is subtended by our crater at the telescope. To convert this to a physical distance, we need to know how far away the moon is: $384,400$ km on average. Simple trigonometry should now allow you to calculate the diameter of the crater in kilometres, and the uncertainty on that diameter (which comes from the uncertainty on the measured crater diameter in pixels, and is represented by the standard deviation on the mean of the measured diameters).

This basic procedure, going from measured pixels to angular size, and angular size to physical size once you know the distance, is the most basic analysis technique and will be used in most of the other observations as well.

4.1 Further work

If time permits, try to determine the diameter of the smallest distinct and recognisable crater on your image. That will give you some idea of the size of the landscape features you are observing.

For the exceptionally keen, try to estimate the number of craters on your images. You can do this by printing out the images, drawing over each crater and counting the number you get. Do this for both the lunar maria and the lunar highlands. You should discover that the highlands are much more heavily cratered than the maria- this is because they are significantly older.

You could also try doing this for images of similar terrain types, but compare the results from a region near the terminator with those from a region in full sunlight. Because of the extra information from the shadows, you will probably find more craters on the photos from near the terminator. This is a systematic effect which would have to be taken into account in a full study- but if correctly taken into account would allow one to map the age of the lunar surface, based on the cratering density. The Apollo missions used radioactive decay methods to date the lunar rocks in maria and highland regions and thus calibrated the density of cratering against the absolute age of the surface.

You can also in principle measure the depth of the craters by studying the shadows cast by the crater wall. You will need to know the exact time so that you can work out the position of the sun. For the ultra-keen, you could try to account for the effects of the curvature of the moon on the apparent diameter of a crater seen near the moon's limb, and correct for that effect.

5 Further observations

Now that you have performed these basic observations and know how to record data from the telescope, you are going to make observations of several other interesting objects. The basic aim is to get a good image of the each target, and use your image to make some basic observations.

You should aim to do capture at least three of the following targets, and do the data analysis for each.

5.1 Target 1: Jupiter

Try Jupiter is bright, and easy to find. One could work out where it was in RA and dec and then point the scope... but there is no need. Just press STAR, 905, ENTER, GOTO and the telescope will slew there automatically. The other planet's GOTO numbers are 901 - 909 for Mercury through to Pluto.

Take several images of Jupiter, as before.

5.1.1 Data analysis

Jupiter is a fluid ball, rotating rapidly. This rotation is enough to flatten Jupiter; it bulges at the equator. Measure the maximum and minimum radius of Jupiter's disk and use this to calculate the oblateness:

$$\text{Oblateness} = \frac{R_{\text{equator}} - R_{\text{polar}}}{R_{\text{equator}}}.$$

5.1.2 Further work

If one makes repeated observations over several nights, one can plot the motions of Jupiter's moons. From this one can deduce the periods of the moons, verify Kepler's laws and measure the masses.

5.2 Target 2: Mars

Mars is essentially featureless as seen from our telescope, the angular resolution of the telescope is not good enough to pick out features. However, we can measure the apparent angular size in arc seconds of the planet's disk.

5.2.1 Data analysis

Measure the angular diameter of the planet's disk, in arc seconds. In order to calculate the physical diameter of Mars, one needs to know how far away Mars was at the instant of observation. This can be done in a simplistic way by finding out the RA of the sun on that day and the RA of Mars, and assuming that the orbits of the two planets are coplanar and circular.

5.3 Target 3: Founders' Building

Take a picture of the brick wall of Founder's building.

5.3.1 Data analysis

This will enable you to estimate the angular resolution of the telescope. You should find that the mortar in between the bricks is clearly visible on the photograph. Go up to Founders and estimate how thick the mortar in between the bricks is. From a map of Campus such as the one at

`http://www.rhul.ac.uk/Shared/Maps/Campus.pdf`,

calculate the distance from the telescope to Founders. Calculate the angle subtended at the telescope by the mortar in the brickwork- and compare this with the theoretical angular resolution of the telescope, which is given by $1.22\lambda/D$ where λ is the wavelength of the light being used (visible light is around 500 nm) and D is the diameter of the telescope (254 mm).

5.4 Target 4: Sunspots

WARNING!! BEFORE POINTING THE TELESCOPE AT THE SUN YOU MUST BE FAMILIAR WITH THE SAFETY CODE!!!

Take a series of images of the sun's disk. Try to find a sunspot, or several sunspots.

5.4.1 Data analysis

Measure the angular size of the umbra and the penumbra of the sunspot. (The dark core and the surrounding dark "tendril-like" region surrounding it, respectively.) Given that the Earth is on average 1 AU from the sun, calculate the physical size of the sunspot.

5.4.2 Further work

Repeat this for as many sunspots as you can and plot a histogram of the umbral and penumbral sizes.

See if you can observe the granulation of the sun's surface. You will probably have to take many images and choose the best ones for this. If you can, try to calculate the characteristic size of the "grains".

5.5 Target 5: Double stars

Using Norton's Star Atlas or Starry Night or a similar resource, make images of as many double stars as you can. Start with Epsilon Lyrae, the famous "double double". Each of the two stars, epsilon 1 and epsilon 2, are themselves double.

5.5.1 Data analysis

For each double star, calculate the angular separation of the stars and, where you can, the physical separation (you'll need to know the distance to the stars). You may not be able to resolve all the stars listed in the catalogue- this will give you information about the true angular resolution of the imaging system as a whole, including the atmosphere of the earth above you.

Note any colour differences between the stars in the pairs in your report.

6 References

This script and links to other resources can be found on the PH2900 web page: `www.hep.ph.rhul.ac.uk/~cowan/astro_course.html`

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