Physics 344 Lab 2
Solutions

Visual Observations with the 0.5 m Telescope

The purpose of this lab was to learn how to initialize and point the 0.5 m telescope. It also explores how angular resolution (i.e., the amount of detail visible) depends on the eyepiece and its magnification. Finally, observations of the open cluster M39 explored how faint a star is visible through the telescope.

The weather was the worst that I can remember and most groups struggled to complete the observing even when given three weeks to do so.

1) Setup

The early group usually started with Arcturus and then a star from the summer triangle: Vega, Altair and Deneb. The later group generally used stars from the summer triangle. If the first star was correctly identified, then the slew to the second star would always put it into the finder, and usually in the main field of view. Two problems with initializing the telescope controller have been noted to occur occasionally: 1) The home position is defined with the telescope vertical on the east side of the pier; in this position, the controller assumes that the telescope is pointing west of the meridian, so if you synch on a star to the east, the controller gets confused and moves the telescope in the opposite direction needed! The solution is to always synch the telescope on a star in the opposite side of the sky from the telescope position. 2) Since the home position is assumed to be vertical, the controller has limits that are about 90º from this position, to prevent slewing below the horizon. If you move the telescope by slipping the clutches, these limits will no longer be at the horizon, and the telescope may refuse to point to some areas of the sky. The solution is to always move the telescope with the hand paddle after homing it and adjusting it to the vertical position.

2) Planets:

Jupiter was visible to the first group of the evening, though its position in the southern ecliptic meant that it was not very high. It was close to or had set by the time the second group began observing. The disk of Jupiter noticeably bulges at the equator because the planet rotates once in 9.8 hours. Some dark belts and light zones, running parallel to the equator, are visible unless the planet is very low and so blurred by poor seeing. Also visible are whichever of the bright Galilean moons (which are 4th or 5th magnitude) are not behind the planet or in its shadow.

Saturn was visible to both the early and late groups, though it was low in the sky for the late group by the end of September. The ball of the planet and the rings were visible, but no details on either. If Saturn had been higher in the sky (say in the northern portion of the ecliptic instead of the southern), then the largest gap in the rings, Cassini's division, might have been visible. Seeing cloud features on Saturn itself is difficult with ground-based telescopes. The planet and rings appeared yellow or even reddish, but this was due to the Earth's atmosphere scattering blue light out of the line of sight. The big moon Titan was easily visible at 8th magnitude unless it was cloudy or Saturn was close to setting. It was the farthest of the visible moons from the planet and started the three weeks of observing north-northeast of the planet. In the first week it moved southward to the east of the planet as the days passed and ended up south of the planet. It then continued swinging around and ended the second week to the northwest and the third week slightly south of east. Sometimes visible were Rhea, Tethys, and Dione, which are about 10th magnitude and closer to the planet than Titan. Rhea was the most often seen of the three, being the most distant (about 1/3 of Titan's distance). Enceladus, at 12th magnitude was generally too faint and close to the planet to be seen. Sky and Telescope magazine has a java applet that predicts the positions of these moons. I find it somewhat more accurate than the positions shown in *The Sky*.

Also visible to both groups was Mars. Still being relatively close to Earth after a favorable opposition last summer (opposite the Sun in our sky, hence closest to Earth), it appeared as a large red-orange disk. At least, a large disk for Mars, which is a small planet compared to Jupiter and Saturn. A planet-wide dust storm that was in progress meant that no surface details were visible, not even the winter polar cap.

The other planets visible were Neptune (both groups) and Uranus (later groups). Both are faint, but noticeably colored: Uranus green and Neptune blue. Uranus is noticeably fuzzier than a star, while it is often difficult to tell that Neptune is extended. An eyepiece of ~20 mm focal length or shorter (magnification around 200× or higher) gave the best chance of resolving these planets into small disks. The moons of Uranus are small and dark, making them hard to see even in our telescope. The brightest are Titania at magnitude 13.7 and Oberon at magnitude 13.9, making them slightly fainter than the limiting visual magnitude (see the final part of the lab). Sky and Telescope has a java applet that predicts the positions of the four brightest moons. The largest moon of Neptune, Triton, is large and reflective, but still is only magnitude 13.5 because of the larger distance from the Sun and us. Again, it is at best just barely visible (I have never seen it).

3) Binary Stars:
It was always easy to resolve γ Delphinus into two stars, one brighter and colored yellow (magnitude 4.4, Spectral type K1IV), and the other fainter and colored blue (magnitude 5.0, spectral type F7V). The stars of this binary are oriented at a position angle of 265°, almost exactly E-W. (The position angle is the angle that the line connecting the brighter to the fainter star makes to the line pointing north from the brighter star, measured from north through east.) The orientations given in this solution are taken from the Washington Double Star Catalog (http://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/wds/WDS). The opinions on the best eyepiece to use were split: some preferred the 26 mm or 20 mm eyepiece, while others found the 10 mm to give better results. The magnification of the 55 mm and 38 mm eyepieces was too low to easily resolve the closer binaries. The Sixth Catalog of the Orbits of Visual Binary Stars (Hartkopf *et al.* 2001, AJ, 122, 3472; http://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/wds/orb6) lists the orbital period of this system as an uncertain 3250 years.

It was also always possible to resolve the binaries with ~4" separation, either ρ Herculis or 65 Psc. The stars of 65 Psc have equal brightness, are oriented mostly E-W (position angle 115°), and have very similar, yellow-white colors (spectral types F4III and F5III). The ρ Herculis system has stars with noticeably different brightnesses, but with similar blue colors: magnitude 4.6 and spectral type B9.5III *vs.* 5.4 and A0V. The pair has a position angle 322°, so the orientation is SE-NW (SE star brighter). The brighter star has been resolved into a binary with speckle interferometry and was earlier suspected of radial velocity variability. No orbit is listed for either ρ Herculis or 65 Psc, so the periods are probably very long.

The seeing was good enough to attempt ζ Aqr on all of the nights, though it was hard to clearly separate the two stars − most often they looked like a single elongated disk. The two stars of ζ Aqr are very similar, both yellowish F-type stars, of magnitude 4.4 and 4.6 (it is very difficult to discern the small brightness difference visually). They are aligned nearly N-S (position angle 164°), with a separation of 2.2”. The Sixth Catalog lists the period as 490±40 years. This pair has widened significantly from the 1.8” separation that it had when Professor Williams created this lab about 20 years ago. It turns out that the brighter star is itself probably a binary with an angular separation of about 0.4 arcsec (Tokovinin *et al.* 2010, PASP, 122, 1483 and Hartkopf *et al.* 2012, AJ, 143:42).

Albireo shows two bright stars aligned between SW-NE (position angle 55°). The brighter star is yellow and the fainter one is blue. Since both stars are the same distance from us, differences in apparent brightness correspond to differences in luminosity. You would normally expect the blue star, which is much hotter (from Wien’s Law for thermal radiation), to also be brighter since it emits more energy per square meter of its surface (the Stefan-Boltzmann Law). The answer to the puzzle is that the blue star is a smaller, main sequence star, and the yellow star is a red giant star. Thus, although the cooler star emits less flux per unit surface area, it has more than enough surface area to compensate and make it brighter. See http://stars.astro.illinois.edu/sow/albireo.html for a nice description of the system.

Eyepiece Magnification

The telescope is a 20-inch diameter, f/8 optical system, so its focal length is:

$$F_T = 20 \text{ inch } \times 25.4 \text{ mm/inch } \times 8 = 4064 \text{ mm}$$

The magnification is the ratio of the telescope focal length to the eyepiece focal length. The exit pupil of an eyepiece (*i.e.* the diameter of the beam of light emerging from the eyepiece) is the telescope aperture divided by the magnification. The magnifications and exit pupils for the various eyepieces are then:

F_E = 55 mm   mag = 74   pupil = 6.9 mm
F_E = 38 mm   mag = 107   pupil = 4.8 mm
F_E = 26 mm   mag = 156   pupil = 3.3 mm
F_E = 20 mm   mag = 203   pupil = 2.5 mm
F_E = 15 mm   mag = 271   pupil = 1.9 mm
F_E = 10 mm   mag = 406   pupil = 1.3 mm

The high power of the 10 mm eyepiece is often too large to be useful in our observing conditions – it makes the images appear worse, not better. It is hard to get the dome dark enough for the pupil of your eye to fully dilate (to 7 mm), so not all of the light collected by the telescope can enter your eye when using the 55 mm eyepiece. All of the SWA eyepieces have a 70º apparent field of view, while that of the 55 mm eyepiece is 50º; this makes the field of view of the two longest-focal-length eyepieces virtually the same, and the 38 mm is easier to use; the 55 mm seems to have slightly better image quality at the edges of the field.

4) Messier Object:

Most observers found that the Messier objects were not very impressive. Those who looked at M13 on a good-seeing night could resolve the outer parts into many individual stars. The Andromeda galaxy is too large and faint to show any significant detail from our light-polluted site; it is best observed with the low-power eyepiece. It looks like a patch of light that gets brighter towards the center. If the sky is particularly dark and transparent, the NW-SE elongation of the disk is apparent (I did not see any hint of this this during the sessions when I was present). The Ring Nebula is faint but clearly shows the ring structure. It can be instructive to compare the images obtained at good-seeing, dark sites (or from space with the Hubble Space Telescope) to the visual views at our low-quality site. A good resource to explore is http://www.seds.org/messier/.

5) Open Cluster M39:

Depending on which side of the sky the cluster was on when you observed it, the view through the telescope was either the same as that shown in *The Sky* or a mirror image of this. The stars SAO 51001 (6.6 mag) and GSC 3594:2204 (9.6 mag) were easily visible. The star GSC 3594:1276 (10.8) was visible to all, but noticeably fainter, and GSC 3594:2331 (11.0) was harder still. If the conditions were generally good, everyone could detect GSC 3594:212 (11.6) and nearly everyone GSC 3594:86 (12.3). About half the class could see TP C (12.7) and GSC 3594:384 (12.9 mag). The quarter with some combination of good eyes, good conditions, and careful focusing saw GSC 3594:2539 (13.3 mag). One person thought that they could occasionally glimpse TP A (13.6) and no one could see the faintest stars on the list: TP B (14.0). In class I did a simple calculation that estimated that the limiting visual magnitude for our 20-inch telescope should be about magnitude 14.8. We did not get anywhere close to that − the difference in limits is a factor of 4.4 in brightness. A skilled observer comparing two stars in the same field of view can detect a 10% difference in brightness (0.1 mag). As I discussed in class, the brightness of the sky makes the calculation of the limiting magnitude more complicated than calculating the amount of starlight collected. Getting as faint as possible requires complete dark adaption (as little light in the dome as possible) and using "averted vision" – looking at stars out of the corner of your eye. Poor seeing, a less-than-perfectly focused eyepiece, bright moonlight or stadium lights, and clouds can all make the limiting magnitude brighter.