

# Physics 344

# Lab 1 Solutions

## Part I:

The purpose of this part of the lab was to become familiar with the planetarium program *The Sky*, which can show the appearance of the night sky from anywhere on Earth over a broad range of times. In this class we will use it to control the pointing of the 0.5 m telescope of the Schommer Observatory. Answers to the questions posed follow.

Q1. The longitude of the Schommer Observatory listed in *The Sky* is  $74^{\circ} 27' 53.6''$  W and the latitude is  $40^{\circ} 31' 23.0''$  N. The elevation is 40 meters. These values were determined using Google maps -- a much easier procedure than in the "old days" (even 15 years ago). One of the first tasks of the historic Schanck Observatory on College Avenue, established in 1866, was to determine the latitude and the longitude of the observatory by making observations of the sky.

Q2. The Object Information for Vega

| Field           | Value   | Meaning   |
|-----------------|---|---|
| Object Name     | Vega  | The common name of the object   |
| Other ID        | HIP 91262                                       | Alternate name: Hipparchos Catalog designation  |
| Alternate Names | HIP 91262<br>SAO 67174<br>GSC 3105:2070         | Hipparcos Catalog (proper motion satellite)<br>Smithsonian Astrophysical Observatory Catalog<br>Hubble Space Telescope Guide Star Catalog |
| Flamsteed-Bayer | 3-Alpha Lyrae                                   | Constellation name and brightness rank  |
| Equatorial RA   | $18^{\text{h}} 37^{\text{m}} 33.980^{\text{s}}$ | Equatorial E-W coordinate at the present time   |
| Equatorial Dec  | $+38^{\circ} 48' 22.810''$                      | Equatorial N-S coordinate at the present time   |
| Eq 2000 RA      | $18^{\text{h}} 36^{\text{m}} 56.336^{\text{s}}$ | Equatorial E-W coordinate on Jan 1, 2000  |
| Eq 2000 Dec     | $+38^{\circ} 47' 01.290''$                      | Equatorial N-S coordinate on Jan 1, 2000  |
| Horizon Azim    | $+157^{\circ} 06' 20.916''$                     | Coordinate along horizon (depends on date & time)   |
| Horizon Alt     | $88^{\circ} 08' 03.381''$                       | Coordinate of elevation above horizon (" ")   |
| Magnitude       | 0.03  | Apparent Brightness – visible in NJ skies!<br>The passband is not stated – probably visual.   |
| Magnitude B     | 0.00  | Apparent brightness in blue filter; does not agree with other catalogs I consulted.   |
| Magnitude V     | 0.00  | Apparent brightness in visual (green) filter; does not agree with "magnitude" above and other catalogs.                                   |
| Spectral        | A0Vvar  | Spectral Type – early A main-sequence star  |
| Parsecs         | 7.7561  | Distance to object in parsecs (don't believe all of those significant figures)  |

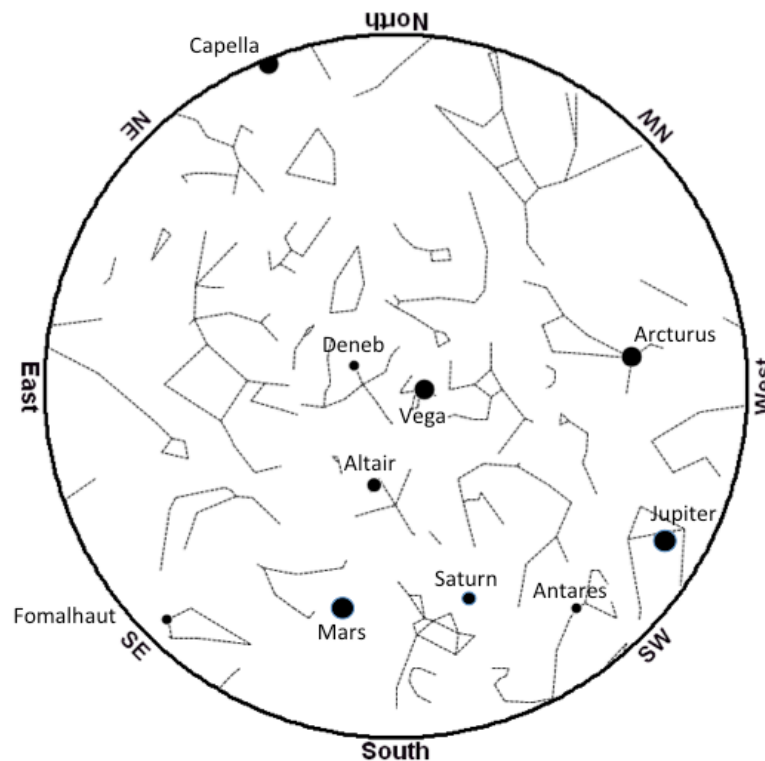
Vega is the brightest star in the constellation Lyra (the lyre, a musical instrument).

Q3. All of Vega, Deneb, and Altair are east of the meridian at 8:00 PM on September 13, 2018. All are high in the sky and Vega is within  $2^{\circ}$  of the zenith. The star Arcturus is west of the meridian and somewhat more than half-way from the zenith to the western horizon. Antares is also west of the meridian and low in the south.

Q4. The brightest star in the box representing the CCD field of view is SAO 47586, with a listed magnitude of 6.93. It is slightly west of the meridian.

Q5. At 8:00 PM on September 13, 2018, there are five planets above the horizon. Venus, though extremely bright, would have been hard to see visually as it is only  $3.5^\circ$  above the west-south-western horizon. It is in the constellation Virgo. The prominent planets are Jupiter, low in the southwestern sky in Libra; Saturn, above the southern horizon in Sagittarius; and Mars, also in the south, but just across the constellation border in Capricornus. Neptune is in the constellation Aquarius, in the southeastern sky, and Pluto (now officially a dwarf planet rather than a planet) is in Sagittarius, just west of the meridian. On this night the Moon, also not a planet, was near Jupiter in the constellation Libra. For astronomers, constellations are regions of the sky rather than patterns of stars. They have divided the entire sky into constellations based on either the classically named patterns or (mostly in the southern celestial hemisphere) more modern creations. When a planet appeared to be between the two patterns of stars belonging to two constellations, it was useful to turn on the actual constellation boundaries. Mars was particularly confusing as it was near the Sagittarius label, but actually in a different constellation

Q6. Your sketch should look something like the figure below. I produced it in *The Sky* after a remarkable amount of messing around with settings. The seven stars brighter than magnitude 1.5 and above the horizon are shown as dots whose size increases with brightness. I labeled the stars and added the planets using a separate program to annotate the Windows bitmap produced by *The Sky*. Capella is *just* rising and was only apparent in the display depending on how the horizon had been set up in *The Sky*. Fomalhaut is so far south that it is always hard to see from New Jersey. So I did not have you sketch those two stars.



| Star     | Magnitude     | RA (2000)  | Dec (2000)     | Sp Type                  |
|----------|---------------|--|----------------|--------------------------|
| Arcturus | -0.05 (-0.05) | 14 <sup>h</sup> 15 <sup>m</sup> 39.67 <sup>s</sup> | +19° 10' 56.7" | K2IIIp (K0III)           |
| Antares  | 1.06 (0.91)   | 16 <sup>h</sup> 29 <sup>m</sup> 24.46 <sup>s</sup> | -26° 25' 55.2" | M1Ib+B2.5V (M0.5Iab+B3V) |
| Vega     | 0.03 (0.03)   | 18 <sup>h</sup> 36 <sup>m</sup> 56.34 <sup>s</sup> | +38° 47' 01.3" | A0V (A0Va)               |
| Altair   | 0.76 (0.76)   | 19 <sup>h</sup> 50 <sup>m</sup> 47.00 <sup>s</sup> | +8° 52' 06.0"  | A7IV-V (A7Vn)            |
| Deneb    | 1.25 (1.25)   | 20 <sup>h</sup> 41 <sup>m</sup> 25.92 <sup>s</sup> | +45° 16' 49.2" | A2Ia (A2Iae)             |
| Jupiter  | -1.9          | 15 <sup>h</sup> 06 <sup>m</sup> 33 <sup>s</sup>    | -16° 39' 05"   |                          |
| Saturn   | 0.5           | 18 <sup>h</sup> 10 <sup>m</sup> 07 <sup>s</sup>    | -22° 43' 54"   |                          |
| Mars     | -1.8          | 20 <sup>h</sup> 14 <sup>m</sup> 51 <sup>s</sup>    | -24° 51' 15"   |                          |

In the table, the first magnitude and spectral type are from *The Sky* while the second values (in parentheses) are the V-band magnitude and spectral type taken from the SIMBAD Astronomical Database (<http://simbad.u-strasbg.fr/simbad/>). When two spectral types are given then the star is a binary, with the first type being for the brighter of the pair. The values given in *The Sky* mostly agree well with the most recent values from the database. I also give the right ascension and declination at epoch 2000.0 for each object, though the lab did not ask for them.

The three stars Vega, Altair, and Deneb form the “Summer Triangle”, an asterism that is striking in the summer and fall sky. Vega is the brightest of the three and Deneb the faintest. Arcturus will appear similar in brightness to Vega. Antares and, especially, Fomalhaut are low on the southern horizon and may be difficult to see unless you have an unobstructed view to the South. Capella is just rising in the NNE and will be difficult to spot until later in the evening. The stars of the summer triangle will be blue-white in color, in contrast to the red color of Arcturus (and Antares, if it is visible). Capella is an intermediate yellow shade. The binary companion of Antares has a B2.5V spectral type and, thus, a bluish color. It is 2.9 arcsec distant and about 4 magnitudes fainter than the primary star and so is not visible to the naked eye.

Q7. As time passes, the sky appears to rotate from east to west (counter-clockwise), about a point above the Earth’s north pole (i.e., the north celestial pole). At 6:00 AM, Neptune is just setting (slightly more than 1° above the horizon) and only Uranus is well-placed for observing in the southwestern sky in the constellation Aries. Mercury’s label is visible, but the planet itself is slightly less than 2° below the horizon.

Q8. As the semester progresses, the variable star GK Per rises earlier and earlier in the night because of the westward annual motion of the Sun in the sky. GK Per is first more than 30 degrees above the horizon at 8:00 PM on November 3<sup>rd</sup>, which is the night before the end of daylight savings time on the morning of November 4<sup>th</sup>. When DST ends, the sky is suddenly an hour “later” at a given clock time (clocks “fall back”) and you need to reset the clock from 7:00 PM back to 8:00 PM if you are stepping forward by one day. Note that *The Sky* has an outdated definition of the end of DST – a week earlier, on October 27<sup>th</sup>. To correct for this, you needed to keep the time at 7:00 PM while stepping forward until reaching the evening of November 4<sup>th</sup>. If you did accept *The Sky*’s definition of DST, then GK Per was first 30 degrees above the horizon at 8:00 PM on the night after DST ends: October 28<sup>th</sup>.

GK Per is higher in the sky at 10:00 PM than 8:00 PM and so reaches 30 degrees above that horizon earlier in the semester, on October 3<sup>rd</sup>.

Q6. Jupiter starts out about  $163^\circ$  east of the Sun along the ecliptic on September 1, 2018. As the days progress, Jupiter moves from west to east along the ecliptic with respect to the stars – prograde motion. Jupiter’s motion is noticeably slower than that of the Sun, Mercury, Venus, and Mars. The Sun passes Jupiter on November 26, when Jupiter is in *conjunction* with the Sun. Jupiter’s prograde motion slows until about April 10, when it stops and reverses its direction, beginning its retrograde (east to west) motion. Around August 11 Jupiter ceases retrograde motion and returns to prograde motion. Jupiter is opposite the Sun in the sky (at *opposition*) in the middle of this retrograde loop, crossing the meridian at midnight (well, 1 AM with daylight savings time) around June 10. On September 1, 2019 it is  $174^\circ$  east of the Sun, continuing to move in the prograde direction.

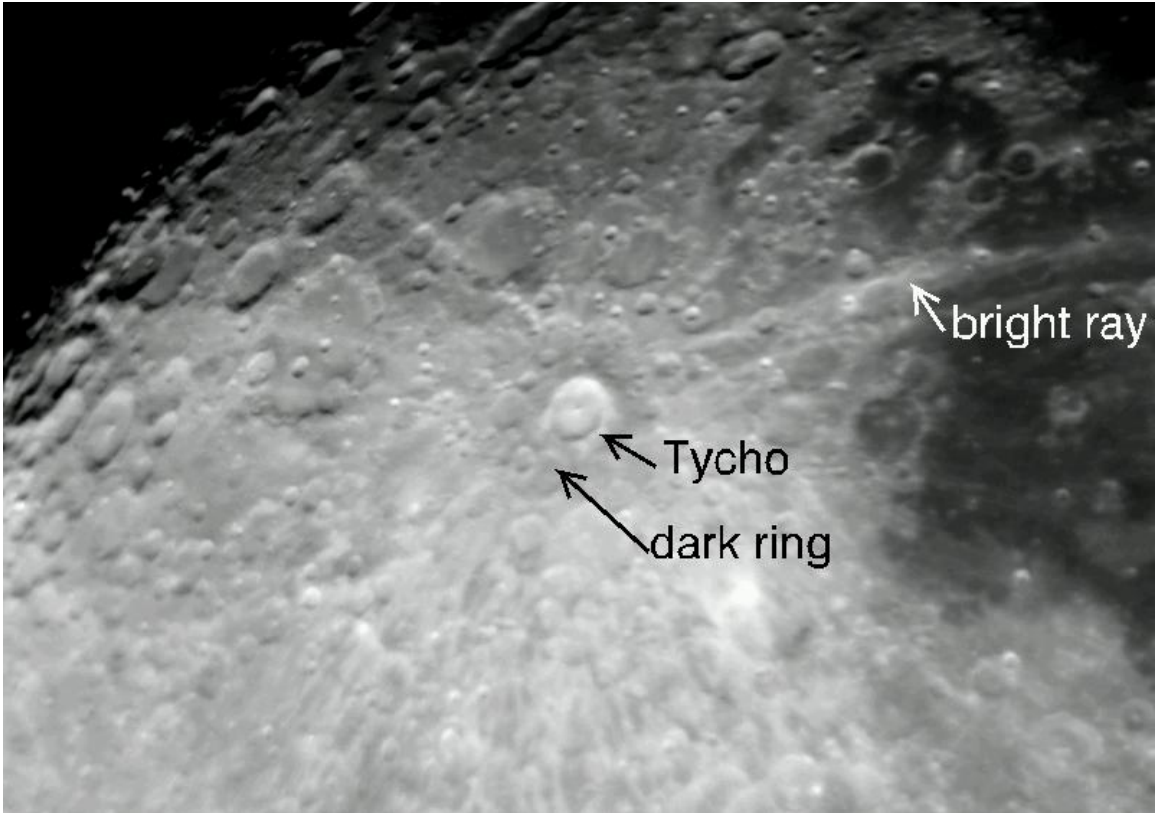
The stars do not move when stepping by one sidereal day because this is the rotation period of the Earth with respect to the stars. So the stars return to the same place with respect to the horizon.

## Part II

The purpose of this part of the lab was to learn how to connect to the astrolab computer using VNC and then to become familiar with the Interactive Data Language (IDL) and its interface. The initial steps had you start the IDL Developer’s Environment (idlde), which is really overkill for what we do in this course, and set up the path which makes available a large number of existing programs useful for astronomy. Most of the steps involved using the RUPhAst image display tool to display and examine two images.

In RUPhAst, the r key plots the pixel values along a row going through the current position of the cursor. The c key plots a column through that position and the i key gives the minimum value, maximum value, mean, median, and standard deviation around the mean for the pixels in a region around the cursor.

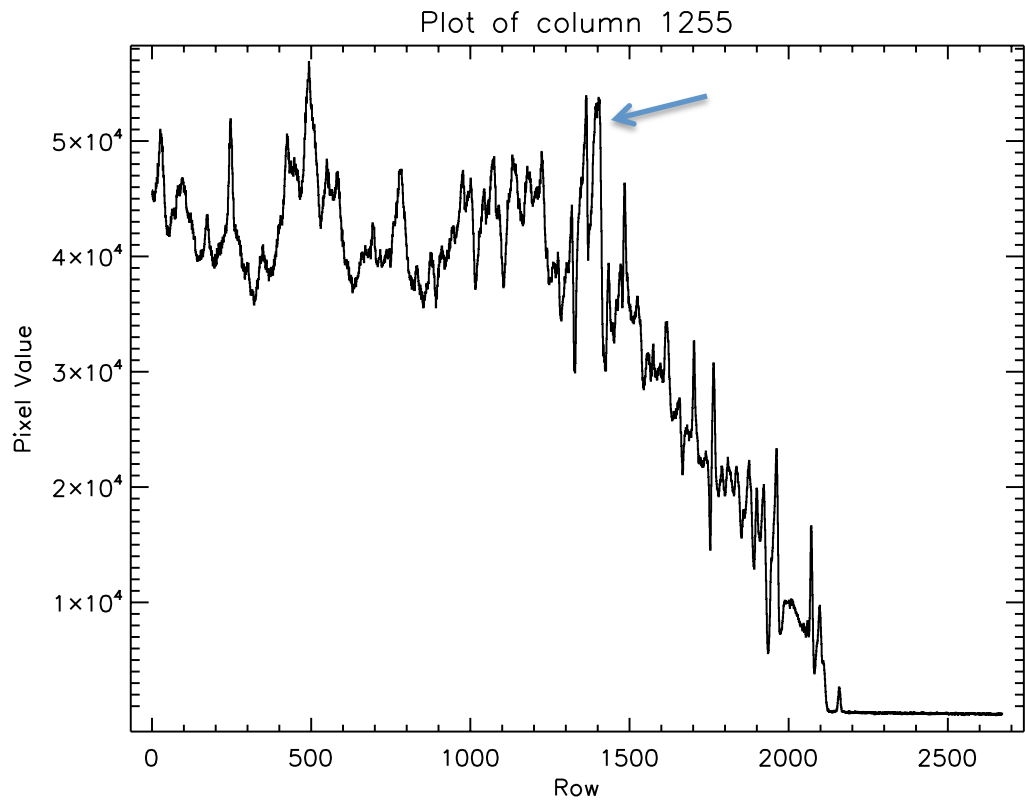
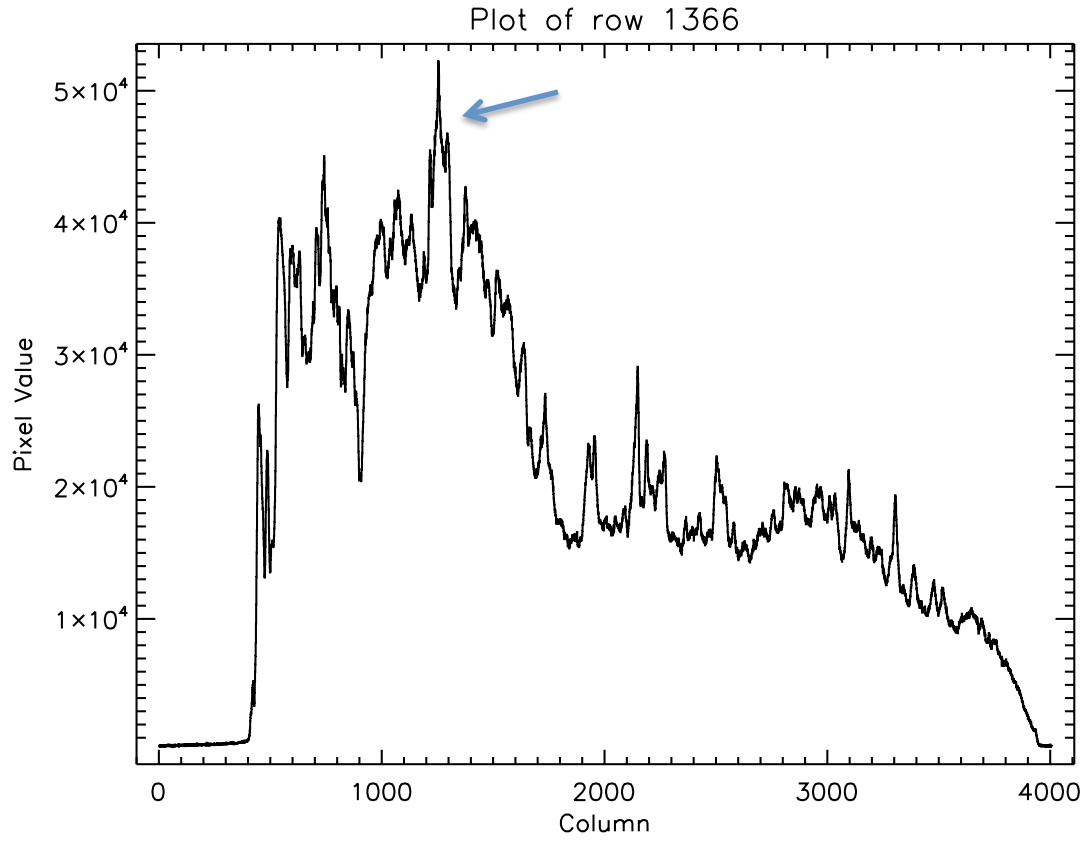
7. With the image of the Moon read into RUPhAst, the easiest way to find the brightest pixel was to set the “Min” value of the display to a high value, say 65000, and then examine the few remaining bright pixels with the “Pixel Table” option turned on. The brightest pixels were near the bottom of the image, with the brightest two pixels having the coordinates (1409, 69) and (1601, 23), each with a value of 65,024 ADU. This value is just below the digital saturation value of  $2^{16} - 1 = 65,535$  set by the analog-to-digital converter in the CCD.



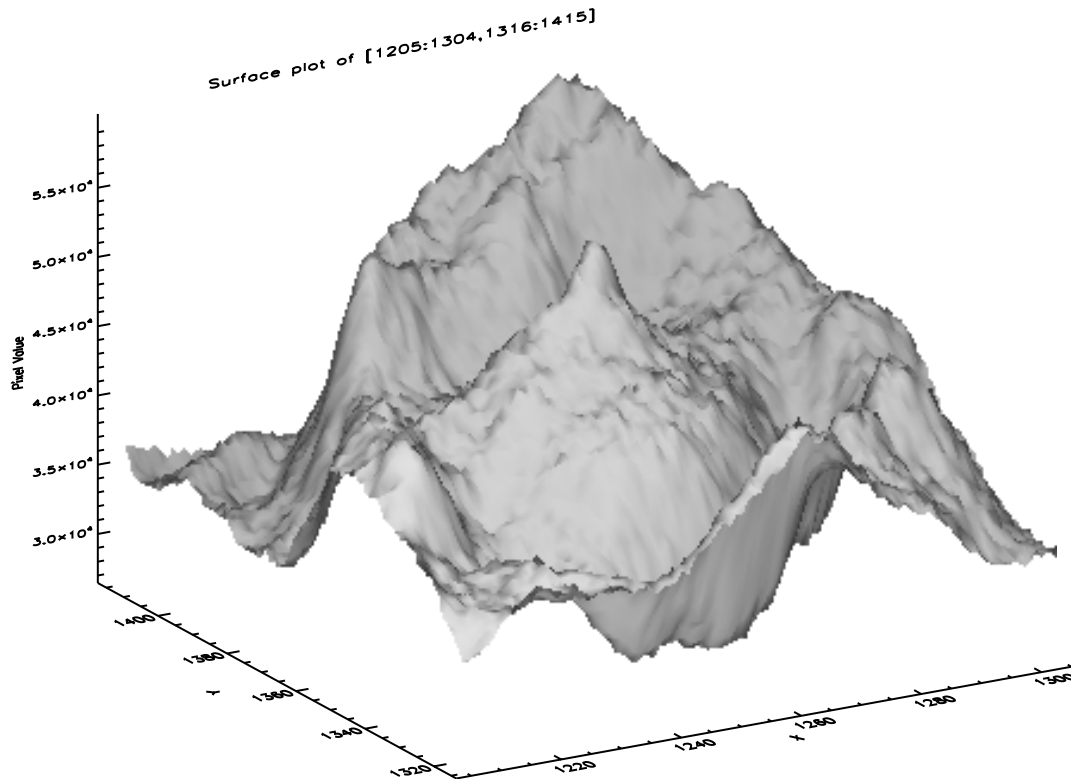
A region of the image of the Moon centered on the crater Tycho is shown above. Tycho is the youngest large crater on the lunar nearside and has a well-defined raised rim and a central peak. It is the center of a prominent system of bright rays created by the impact of the 8-10 km wide asteroid which formed the crater. A darker ring surrounding the crater is a coating of dark, glassy impact melt. Tycho's age of 109 million years is too short for the constant rain of small impacts which pulverize and mix the lunar surface to have eliminated the ring and rays. Young lunar craters also tend to be bright because there has not been enough time for the energetic particles coming from the Sun (the solar wind), which directly strike the lunar surface, to darken the surface materials

I zoomed in on the crater Tycho and measured a vertical diameter of 83 pixels and a horizontal diameter of 75 pixels. I tried to measure from the lip of the bowl of the crater to the adjacent lip, *i.e.*, using the center of the rim. Larger diameters would have resulted from measuring to the outer edge of the raised rim. The crater is actually nearly circular, but does not appear so in this image because of our oblique viewing angle (we do not look directly down on it). A reasonable average diameter is 80 pixels with an uncertainty of at least  $\pm 5$  pixels.

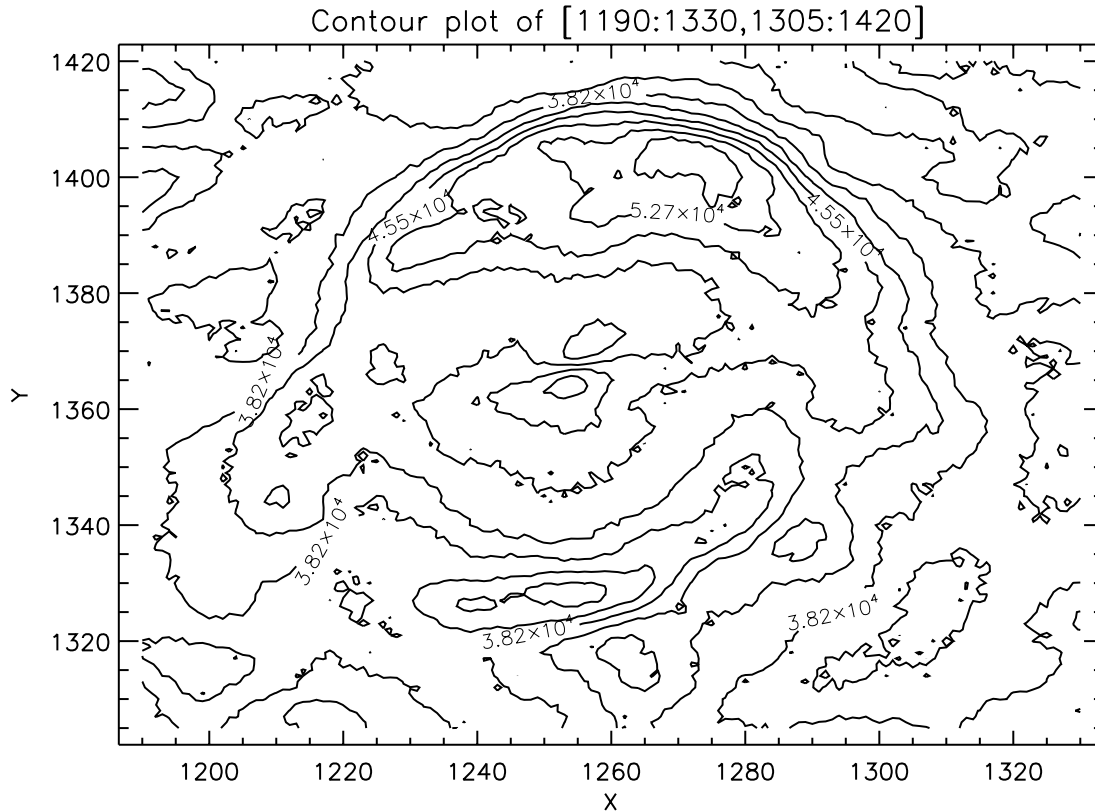
To produce the row and column plots I put the cursor on the central peak of Tycho at about (1255, 1366). The resulting plots are below, with the arrow pointing at the location of the crater. Note that Tycho does have high pixel values and is immediately flanked by the lower intensities of the dark ring.



The s key produces a “surface plot” of the region around the cursor. The example below clearly shows the bright rim and central peak of the crater and its slightly darker interior.



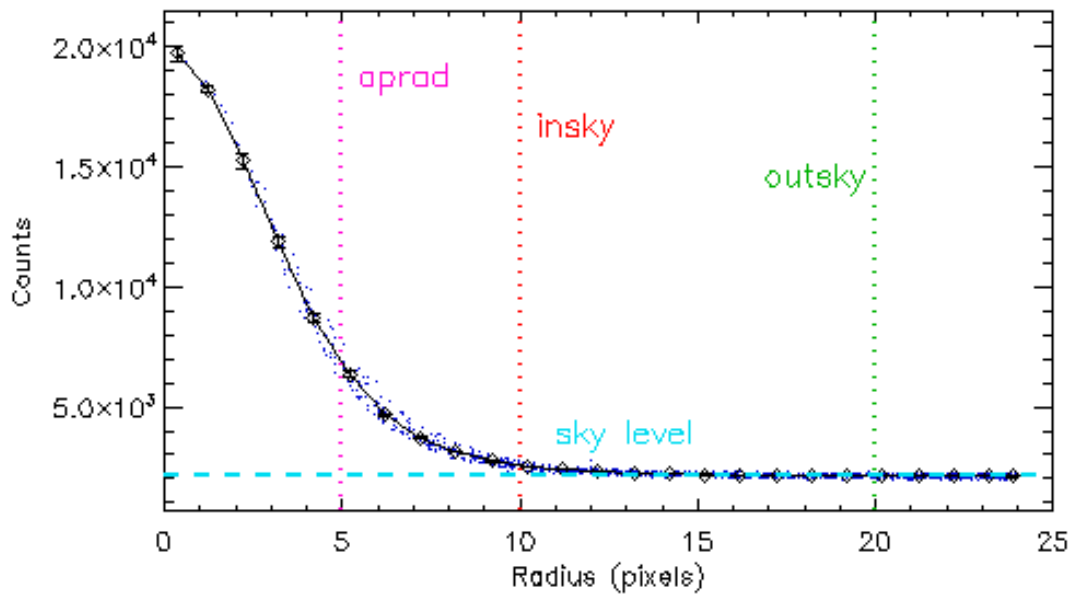
The t key produces a contour plot. Making the size of the region plotted slightly larger than the defaults in order to show the entire crater clearly produced the following. Unfortunately, PhAst does NOT enforce equal scales on the  $x$  and  $y$  axes when making this plot, which is really should do (i.e., one pixel should be the same distance in both the  $x$  and  $y$  directions). I increased the range in  $x$  of the region contoured to approximately produce equal scales, but the two scales are still slightly different.



8. The M31 image had an exposure time of 300 seconds and was taken with the V-band filter. It was taken on October 9, 2011 at 06:31:50.354. This is a Universal Time date and time, corresponding to about 2:31 AM EDT (Professor Pryor was working late that night). This is most likely an exposure end time, though it might also be a start time. Zooming in a few times and centering the image on M31 made it easier to estimate the location of the center of the galaxy. The brightest pixel was at (1240, 1335) and had a value of 19,159 ADU.

9. The p key measures the brightness of objects by performing aperture photometry. For the star at (750,1495) the program chose an aperture radius of 5 pixels and inner and out sky radii of 10 and 20 pixels, respectively. The FWHM is 7.0 pixels, the sky value 2,129 ADU, and the object counts 740,657 ADU. The radial profile plot is shown below. Note that the selected aperture radius does NOT enclose all of the light of the star. The estimated signal-to-noise ratio (S/N) of the measured brightness is 668.9. This is a high value, showing that the brightness has been measured to a fractional accuracy of  $1/668.9 = 0.0015$ . Systematic errors not included in the error estimate make the measurement less accurate than this.





10. The radial profile of the saturated star at (2245, 455) is shown below – note the flat top in the actual profile (the points). The reported FWHM, presumably of the fitted Gaussian profile shown as a line, is 9.1 pixels. This is larger than that measured for the unsaturated star because the maximum value for the saturated star is too low, resulting in too low a value for half of the maximum. This lower value occurs at a larger radius on the profile of the star. The simplest way to obtain a measurement of the brightness of this star would be to reduce the exposure time of the image, so that less light accumulates.

