Laboratory 1: Observations and the Telescope
Coordinates & Introduction to the Planetarium

When the Earth turns away from the Sun, night falls and the Universe opens up. Looking at the dark sky, an observer in a good location can see 4,500 stars with their bare eyes. With a telescope, that same observer could see millions. Also, the oldest and most complex structures in the Universe can only be seen with a telescope.

Pictured above are some of the Radio Telescopes at The Very Large Array in Socorro, New Mexico.

From the above picture, it's clear that telescopes are more than two lenses in a tube. There are special telescopes to view every part of the light spectrum. There will be more information about the light spectrum in Exercise 3, but for now more about telescopes...
Important Telescopes

Earth's atmosphere prevents astronomers from observing light in most regions of the spectrum. Even in those regions of the spectrum called atmospheric windows where the light can get through, there is still considerable distortion of the light. To avoid the distortion and observe in the restricted parts of the spectrum, we have launched telescopes into space.

![Spitzer-Infrared](image.png)  
![Hubble-Optical](image.png)  
![Chandra-X-Ray](image.png)  

Launching observatories into space is in some cases necessary, and provides observers with a unique perspective on the Universe, but can be prohibitively expensive. For those wavelengths that can be viewed on Earth's surface, astronomers use ground-based telescopes. The largest ground-based telescopes are radio telescopes. The Very Large Array in New Mexico has over 25 dishes each 20 meters in diameter that can be arranged to electronically produce a telescope kilometers across. Most students will be familiar with optical telescopes, like the ones pictured below. Optical telescopes can range from foot-long manually operated models available from any store for $50, to the two ten meter-mirrored Keck telescopes pictured below that cost millions of dollars to build and are controlled by an intricate computer system.

![Twin Keck Telescopes](image.png)  
![UTK's Meade 8-inch LX 200R Telescope](image.png)  

The Astronomy Department has a fleet of 10 optical telescopes for student use, like the one pictured above. The purpose of this lab is to familiarize you with the telescope and prepare you for the night time observation required of all astronomy students.
Our Telescopes

In front of the classroom should be a real telescope that everyone should look at closely and handle. This is what you will need to operate on the roof when you do your night-time observation.

Anatomy of the Meade 8-inch LX200R

Finder Scope

Eyepiece

The finder scope is a much smaller telescope aligned with the main tube to provide a larger field of view for finding objects in the night sky. The object is actually seen through the eyepiece.

The hand controller, pictured below, is the keyboard and monitor to operate the computer that directs the telescope.

The 'SPEED' key also labeled as '1' controls the speed at which the telescope moves. Options are 1 as the slowest and 9 as the fastest. A speed has to be chosen before the telescope will move.

The four opposing arrow keys in the middle of the hand controller move the telescope to look at an object.

Use the bottom two arrow keys to scroll through the list of displayed options.

'ENTER' key - select an option.

'MODE' key – go back to a previous menu, also used to find coordinates.

'GO TO' key – point the telescope to the selected object

'LIGHT' key – also labeled as '0' shines the red light at the top of the hand controller.

The computer requires that every action finishes before the next action can start. Mashing buttons will not make the telescope go faster, it will freeze the computer.
Now that you are familiar with the outside of the telescope, it's time to use it to find celestial objects. While the actual telescope laboratories will be conducted on the roof of the Physics Building, experience has taught the organizers that going through the motions in the classroom first can only help.

Night-time Telescope Observations
The goal of the night labs is to familiarize students with real astronomy and the night sky. The telescope is a good tool to access the night sky, but only if students learn how to use it. The first t-lab is designed to teach students how to use the Meade telescopes by finding stars and solar system objects. The second lab uses a ccd camera to take a series of images of a distant celestial object such as a galaxy or nebula. The final in-class lab of this course will be when those images are manipulated to produce a single picture of the celestial object.

Written by Meagan K. White
T-1 Part 1

For five bright celestial objects: use the hand controller to move the telescope to each object, record each object's right ascension and declination, identify the object with the telescope database.

1. Locate and center and object.
   a) Use the speed key with a number 1 to 9 to pick a speed for the telescope to move (slew).
   b) Use the four opposing arrow keys to move the telescope onto a bright star or solar system object. Keep moving the telescope until the object is in the center of the finder scope. Move your eye down to the eyepiece, the object should be very close to the center. Move the telescope until the object is in the center of the eyepiece.

2. Find the right ascension and declination of the object.
   a) With the object in the center of the eyepiece, hold the 'MODE' key down for 3 seconds. When you release the 'Mode' key the screen will display the right ascension and declination of the telescope's current position. Record on the answer sheet.

3. Identify the object with the telescope's database.
   a) Press the 'MODE' key repeatedly until you back to the 'Select Object' screen.
   b) Press 'ENTER' and scroll through the list until you reach 'Identify'
   c) Press 'ENTER' again, and if the object is in the database, the screen will display it's name. Record on the answer sheet.

4. Repeat with four more bright stars or solar-system objects.

T-1 Part 2

Use the telescope's computer database to find 5 stars or solar system objects, record the objects' identification and each object's right ascension and declination.

1. Use the database to find an object.
   a) Press the 'MODE' key repeatedly until you get the screen showing 'Select Object', press 'ENTER'.
   b) Choose either 'Star' or 'Solar System' and press 'ENTER'
   c) Scroll down the list of objects, choose one and press 'ENTER'. The screen will display the object identification, record this.
   d) Press 'GO TO', the telescope will move or 'slew' to the object. Be certain that the telescope has stopped moving and the screen no longer reads 'slewing' before pressing any more buttons.

2. Find the right ascension and declination of the object.
   a) With the object in the center of the eyepiece, hold the 'MODE' key down for 3 seconds. When you release the 'Mode' key the screen will display the right ascension and declination of the telescope's current position. Record on the answer sheet.

3. Repeat with four more stars or solar system objects in the database.

The grade for this night-time lab will come from the worksheet that you will fill out on the roof that night, get stamped by the roof TA, and hand in on that night.
A CCD Camera works via the photoelectric effect. Simply, an incoming photon knocks an
electron from the chip which causes an electric signal. The signal distribution on the chip is interpreted
as an image. These cameras are very sensitive to light and movement. So sensitive that they cannot
take pictures of bright solar system objects. Instead, these cameras are used to take pictures of deep
sky objects like distant galaxies and clouds of gas and dust called nebulae. Also, because the cameras
are sensitive to slight movement and are aimed at such a small portion of the sky, the slightest touch to
the camera, telescope, or tripod while the camera is taking a picture is enough to blur an image.

T-2

Use the telescope's database to find a deep sky object, and take five black and white images to be
processed in the last in-class lab of the semester.

1. Set the laptop to show the telescope view in real time.
   a) On the laptop, the CCDOps program should already be open, put the camera into 'Focus'
      mode by selecting 'Camera' then 'Focus.' In the box that appears, set the exposure time to 1
      second, the Frame Size to 'Full-High', include 'dark frames' and 'filter warm pixels' 'OK'.

2. Use the database to find an object.
   a) Press the 'MODE' key on the hand controller repeatedly until you get the screen showing
      'Select Object', press 'ENTER'.
   b) Choose either 'DEEP SKY' and press 'ENTER'
   c) Scroll down the list of objects, choose one and press 'ENTER'. The screen will display the
      object identification, record this.
   d) Press 'GO TO', the telescope will move or 'slew' to the object. Be certain that the telescope
      has stopped moving and the screen no longer reads 'slewing' before pressing any more buttons.

3. Take the Pictures and Save All 5 of Them.
   a) With the Deep Sky Object that you chose in the center of the main box, press the 'X' on the
      focus box only to stop the camera from focusing.
   b) Select 'Camera', 'Grab' to open the 'Grab' box. Enter an Exposure Time between 1 (for a
      bright object) and 10 (for a dim object). Include 'Dark Frames' and 'Filter Warm Pixels'. Use a
      'Full High' Image size and set Special Processing to 'AutoGrab'. Enter 5 exposures, but don't
      change anything else in the Special Processing box. Save the Images as 'FITS' Files to a
      flashdrive. Keep the camera as still as possible while it is taking the pictures to prevent blurry
      images.

4. Every group member will need a copy of all 5 images to do the last in-class lab of the semester.
The grade for this night-time lab will come from the worksheet that you fill out on the roof that
night, get stamped by the roof TA, and hand in on that night.

Written by Meagan K. White
Coordinate Systems

The earth is divided up into lines of latitude and longitude to find any location on the planet. If you extend these lines to project on the sky, they become Declination (Dec) and Right Ascension (RA). The Right Ascension and Declination system of celestial coordinates is used to chart and find objects on the celestial sphere — our projection of the night sky. Right Ascension and Declination are fixed on the celestial sphere, so that even as the Earth rotates under the stars, the celestial objects keep the same RA and Dec coordinates.

Declination is measured in degrees North or South of the Celestial Equator, a projection of Earth’s Equator. So any point on the Celestial Equator is at 0° Declination. The North Celestial Pole is at +90° Dec (North), and the South Celestial Pole is at -90° Dec (South). Right Ascension is measured in angular units of hours, minutes, and seconds because RA is in the orientation of the Earth’s rotation. There are 24 hours in one day, which is one Earth revolution, which is 360° of rotation.

So 1 hr = 360°/24 hr = 15°

In Earth’s longitude, the Prime Meridian is arbitrarily taken through the city of Greenwich England. Similarly, the zero line for Right Ascension, called the Celestial Meridian, is arbitrarily chosen to be the RA of the Sun at the instant of the Vernal Equinox. Right Ascension then increases from 0h to 24h Eastward from the line through that point.

With this set of Right Ascension and Declination Coordinates, every object in the night sky can be given a fixed set of coordinates so that Astronomers can find the object again every night. On the other hand, it is sometimes more convenient to indicate the position of a celestial object as it appears when it is seen. For a more impromptu coordinate system, astronomers turn to Altitude and Azimuth.

Altitude is the height of an object above the horizon, from 0° at the horizon, to 90° at the zenith, or point directly overhead. Azimuth is the angle in degrees from 0° to 360° starting from North going in
a circle through East, South, West, then back to North. The cardinal directions would have Azimuths in steps of 90°. North is at 0° Azimuth, East at 90°, South at 180°, West at 270°, and back up to 360° at North again. In this way, every object visible in the sky will have an Altitude and Azimuth Coordinate. But the A&A coordinates change rapidly over the course of a night, as the Earth rotates, throughout the year as the Earth orbits the Sun, and varies depending on location. So Alt.Az. can be used to point out objects in the sky in-the-moment. This is the Altitude that the Lunar Observation Lab refers to when it asks you to write the Altitude of the moon at the time you observe and sketch it.

Diagram of Altitude and Azimuth
Image from: http://crab0.astr.nthu.edu.tw/~hchang/ga1/ch02-02.htm
Introduction to the Planetarium Sky

The University of Tennessee Earth and Space Sciences Theatre (TUTESST) can provide students with an unobstructed view of the night sky. In the planetarium light pollution can be turned off, the sky can be changed to match any date and time past and present for many thousands of years, even the atmosphere can be turned off to allow for daytime stellar observations. Make no mistake, nothing can replace looking at the real sky and looking through an actual telescope. The planetarium is another amazing tool that can be used to augment understanding of the night sky.

Part One – The Planetarium Sky

• At this point, the TA should have the planetarium running with the atmosphere and horizon on. As you first see the dome sky, you may notice that our Planetarium is oriented differently from the cardinal directions of the outside world. Traditionally, planetariums are oriented so that the chairs, and therefore the viewing angle, face the Southern sky. This is because most of the objects we studied in the night sky are visible from this southernly orientation, due to our latitude.

• Now the TA should explicitly turn off the Horizon, and atmosphere.

The next thing you will likely notice, is that this sky is vibrant with stars. In fact, it may be totally unrecognizable from the night sky outside. The night sky outside Knoxville may show 25 or so stars on a good, clear night. The planetarium can simulate ideal viewing conditions from any location. So under the planetarium dome, you may see thousands of stars. To be clear, all the stars that you are used to seeing are still visible on the planetarium dome, they may just be difficult to find, because they are lost in the crowd.

• The visible star magnitude (found in Tools, 4. Stars, 4.5 Limiting magnitude) should be set to 7, the highest available.

So why can an observer in Knoxville see 25 stars, but an observer at Big South Fork National River and Recreation Area (Henceforth known as Big South Fork, just two hours away by car) see over a thousand? The answer is primarily light pollution, but other factors can play a big role. Light Pollution is the term used to describe the effect that artificial light has upon the apparent darkness of the night sky. A city like Knoxville has so much artificial light at night from street lamps, field lights, and building display lights, that the dome created by this artificial light goes up nearly to the observer’s zenith inside the city. It is very difficult to see shooting stars inside the city or even comets! As an observer leaves a city, the light-dome created by this artificial light becomes even more apparent. From
the interstate, you can watch as the dome recedes from view at night.

- Now explicitly show the sky with Big South Fork magnitude of 6.5, then Knoxville magnitude of 3.

The additional factors affecting night sky observing are Air Quality, Turbulence, and Cloud Cover. Air Quality in this case refers to the amount of particulate matter in the air. Air Quality affects not only the breath-ability of our air, but also like being surrounded in fog, can limit seeing. Turbulence refers to the massive air motion as air currents flow from hot to cold high above. This effect can be seen on a smaller scale on the air above asphalt on a hot day. The distortions seen by the hot air moving quickly are small examples of turbulence in the sky. Cloud Cover seems like an obvious affect on observing, but not all clouds are dense, close to the ground, or fluffy. High up in the atmosphere cirrus clouds, thin willowy clouds, form that can dramatically change the transparency (or ability to see dim objects from a distance) of the night sky.

- Show the sky with stars of magnitude 7 again, and for the remainder of the exercise.

Part Two – Reference Lines and Locations in the Night Sky

Now is a good time to refresh your memory of the astronomical coordinate systems.

- Put up the lines of Right Ascension and Declination onto the Dome.
  1) Right Ascension and Declination i.e. Equatorial Coordinates- The coordinate system will be projected on the dome sky. You will notice that RA & Dec. are tilted so that Polaris is at the North Celestial pole, and the Celestial Equator is a projection of our equator. As time moves forward, the projected coordinate system moves with the night sky. This is so that every position on the night sky can be given a fixed RA & Dec. coordinate.
  - Set the sky in motion and speed it up so that students can see the stars moving with the grid. Point to bright stars with the laser and follow their motion. Ask for the RA and Dec of a star near grid lines at one point, then again pause the sky's motion 6 hours later and ask again.
  - Now turn off Right Ascension and Declination, and turn on Altitude and Azimuth coordinates.
  2) Altitude and Azimuth i.e. Horizontal Coordinates– The new coordinate system is oriented so that the lines meet at the top center of the dome, the Zenith of the night sky. Also, as the sky moves with time, the Alt.&Az. Coordinates remain stationary, with the zenith at the top of the dome. This illustrates how this coordinate system is useful for quickly finding objects in the night sky, particularly those objects that move rapidly, or for those that you don't know the RA&Dec. Coordinates. This is a good system to use when finding a transitory object at a certain time referenced from your location.
  - Once again, set the sky in motion and follow the path of a bright star on the dome. Point out that the Altitude and Azimuth lines remain fixed to the observer, and then ask for the Alt.Az. Coord.s of a bright object at one point, then 6 hours later.

In addition to the coordinate systems, there are a few celestial lines that are useful for reference on the night sky. You will see in later exercises that these reference lines make organizing celestial objects, and referencing them in the night sky easier.

- Turn on the Celestial Meridian line.
  The Celestial Meridian is the great circle passing through the local Zenith and celestial poles.
  - Turn off the Celestial Meridian. Turn on the Celestial Equator.
  The Celestial Equator is the projection of the Earth's equator onto the celestial sphere.
  - Turn off the Celestial Equator. Turn on the Precession Circle.
  The Precession Circle is the circle around which the north celestial pole appears to move over a period of 26,000 years.
• Turn off the Precession Circle, Turn on the Ecliptic, then the orbits of the planets.
  The Ecliptic is the apparent path of the Sun across the sky, which corresponds to the Earth's actual path around the Sun. Insert planets along the ecliptic.
• Clear all dome changes.

Part Three – The Difference Location Can Make
The apparent sky and it's motion change with an observer's location on Earth. An observer in the Southern Hemisphere sees a very different sky than those in the Northern Hemisphere.
• Put the planetarium sky location at Knoxville, TN, then set sky in motion.
• Change the location to be at the North Pole (Tools, 1. Set Location, 1.1 Latitude = 90), set the sky in motion.
• Change the location to be at the Equator, (Tools, 1. Set Location, 1.1 Latitude = 0), set the sky in motion.
Observe the changes in apparent motion the sky makes, and record them on the worksheet.
• Go back to Latitude 35.57 for Knoxville, TN.
Astronomy Lab 1 Worksheet
This worksheet must be completed with a passing grade before a student can sign up for T-Labs.

Short Answer (5pts):
1. What is the finder scope and how is it different from the eyepiece?

2. How are the four opposing arrow keys in the middle of the hand controller different from the bottom two arrow keys?

3. What is the goal of the night-time telescope labs? That is, what should you take with you after its completion?

4. What type of objects should be imaged, and why can't the cameras be used to take pictures of bright solar system objects?

5. What is the celestial analogue of latitude? Longitude? Specify which!

6. If you wanted to find a comet on a particular night, which coordinate system would be used?

7. What is the Altitude and Azimuth of the classroom projector in the astronomy classroom, if the front wall of the classroom points North?

8. What is the Altitude and Azimuth of the top of the planetarium dome, from your seat in the classroom?

9. How does light pollution affect observations?

10. How does the motion of the sky change with position on the Earth?
11. From Knoxville, TN observer's perspective, do the stars closer to Polaris move faster or slower than stars closer to the Equator?

12. What important days in the Solar calendar correspond to the crossing of the Sun across Celestial Equator and Meridian lines?

Fill in the Blank (in random order, 2pts):
13. After you have located an object, hold the _____________ key down for 3 seconds and release to display the RA and Dec.

14. Use the _____________ key in combination with a number key to choose a speed for the telescope to move.

15. Be certain that the telescope keypad indicates that the slewing has _____________ before attempting to do anything else on the keypad.

16. Pressing _____________ repeatedly will take you back through the menu options.

17. To identify an object in the field of view, you should start at Select Object press ENTER, then scroll to _____________ and press ENTER again.

18. After selecting an object, press the _____________ key to make the telescope move to that object.

19. The _____________ is both the monitor and keyboard for the computer controlling the telescope.

20. Keep the camera as still as possible while it is taking pictures to prevent _____________.

21. Save the images as ____________ files.

22. After choosing an object and pressing 'ENTER' the keypad screen will display the _____________. Record This.

23. With the laptop program CCDOps, put the camera into _____________ mode to show the telescope view in real time.

24. Every group member will need a copy of all _____________ to do the last in-class lab of the semester.

25. The grade for this night-lab will come from the _____________ that you fill out on the roof that night, get stamped by the roof TA, and hand in on that night.
Label This Telescope CLEARLY (1pt each):

Planetarium Coordinate Questions (5 points each)

27. 8-21-2013 22:00 hrs. Alt. ~16 deg./Az. 106 deg. What is the object's approximate RA and DEC? What is the object? What phase is it in?

28. 9-15-2013 23:00 hrs. What is the approximate declination of Uranus? Will that change over the next 2 hrs?

29. 9-15-2013 23:00 hrs. Alt ~20 deg./Az. 154 deg. What is the object and what is its' approximate RA and DEC?

30. 9-16-2013 What is the approximate altitude and azimuth of Mars at 5 AM?