Physics 121: Astrophysics
Lab Manual
University of Richmond
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Contents

Lab 4

Daily Motion of Stars (Stellarium version)

This lab has a few purposes:

- To get used to some features of the *Stellarium* program.
- To identify some prominent constellations and asterisms that can be seen from our location.
- To see how stars move in the night sky.

A. Messing around.

Start up *Stellarium*, and spend a few minutes playing around with some of its features. Appendix B lists a bunch of things you can do. Here are some specific things you should try. Refer to the Appendix for details about how do do these things.

1. Adjust the time and date. When you first start the program, it will show the sky at the current time. It's much more interesting to see the sky at night. You can also examine what things look like at different times of year.
2. Speed up the flow of time by a large amount, so that a day goes by in just a few seconds.
3. Initially, the program is showing you the view of the sky from here in Richmond. Switch to some other locations.
4. Click on a star or other astronomical object. Information about that body should appear on the screen. Some of that information may not make sense yet, but it will!
5. Drag the image around (hold down the left mouse button and move the mouse around) to look at different parts of the sky.
6. Zoom in to look at a small patch of the sky, then zoom back out (using the mouse wheel or the page-up/page-down keys). Note the display at the bottom that says "FOV." This stands for "field of view," and it indicates the size of the patch of sky that's visible on the screen at that moment. Watch how the FOV changes as you zoom in and out.
7. Click on the "find" icon and search for various celestial objects. Try Mars, for example, or Polaris (which is the name of the North Star).

8. The pop-up menus in the lower left contain a bunch of buttons you can click to change the appearance in various ways. I've listed the ones I think are most useful in the Appendix. Try these out. Some are harder to understand than others.

B. Big Dipper, Mizar, and Alcor.

Once you're done messing around, set your location back to Richmond, looking north, with a nice, large field of view (say 90° or so). Set the time to 10:00 tonight.

You should see the Big Dipper in the northeast. Turn on the constellation labels and lines. Notice that the Big Dipper is not a full constellation; it's just part of the larger constellation Ursa Major (the Great Bear). A group of stars like the Big Dipper, which is easily identifiable and has a name, but which isn't a whole constellation, is called an "asterism."

The second star in the handle of the Big Dipper is called Mizar. Click on this star to select it, and move it into the center of the field of view. Then zoom in on this star until you can see another star called Alcor right near it. Find the angular separation between these two stars. What is the angular separation?

This separation is visible to the naked eye, if you have good eyesight. Next time you're out on a clear night, look to see if you can spot both Alcor and Mizar.

Zoom in on Mizar still further, and you'll eventually see that it splits into two stars. Amazingly enough, although *Stellarium* might not tell you this, each of those two stars is itself a double star system. Unfortunately, these two pairs are too close together for us to see them separately, even with our best telescopes. (How do we know that they're there, then? Good question! We'll answer it eventually.) In fact, in 2009 it was discovered that Alcor is actually a double star system as well. So when you look at Mizar you're really seeing four stars, and if you look at both Alcor and Mizar, you're seeing six stars.

What is the angular separation between Mizar and its companion (not Alcor – the closer one)?

Select Mizar by clicking on it (if it's not still selected). You'll see some information about it in the upper left corner, including the distance to the star in light-years. Use the small-angle formula to determine the separation between Mizar and its companion. The small-angle formula will give you an answer in light-years. Convert this to meters and to astronomical units.

Zoom in on Amazingly enough, each of these two stars is itself a binary star system! So when you look at Alcor and Mizar in the night sky, you're really looking at at least five stars.

Zoom back out to the largest field of view, look toward the north again.

C. Other Constellations.

Identifying constellations isn't a big part of this course (after all, there's no physics involved in constellation-spotting). Still, it's good to know where a few prominent constellations are.

The two stars at the end of the bowl of the Big Dipper (Merak and Dubhe) are called the pointer stars. Draw an imaginary line from Merak to Dubhe, and extend it about six times the separation between those stars. You'll hit the star Polaris, which is the tail end of the Little Dipper (the constellation Ursa Minor). Polaris is also known as the North Star. Polaris isn't a terribly bright star – in fact, none of the stars in Ursa Minor are very bright – but it's still important. It's the one star in the sky that all the others seem to rotate around. (More on this later.)

Look to the West from Polaris to find the constellation Cassiopeia. It looks like a W (on its side at the moment). The stars in Cassiopeia are quite bright, and Cassiopeia is easy to spot in the night sky pretty much all the time. Cassiopeia and the Big Dipper are probably the most useful constellations to use when orienting yourself to the night sky.

In the winter, the other easy constellation to spot is Orion. Find it in the southern sky.

That's enough with constellations for now; we'll do more when we actually do some observing.

D. Daily Motion of Stars.

Make sure you're looking North, with a large field of view (at least 90°). Turn off the effects of Earth's atmosphere. This will make it so that the sky is dark during the day, so that you can see the stars all the time. (Astronomers would love it if this were possible in real life!)

Set time to go at much faster than the normal rate, so that a day takes only a a few seconds. Observe how the stars move. The stars move in circles, with the star Polaris at the center. Note that some of the stars move in circles that always stay above the horizon, while others rise and set below the horizon. Stars that never set below the horizon are called "circumpolar."

Of course, whether a star sets below the horizon or not depends on the exact shape of the horizon. To keep things simple, let's assume that we're looking at the stars from a location with a nice, flat horizon (no hills or trees to get in the way). Here's one way to make this happen in *Stellarium*: click on "Sky and viewing options", then the "Landscape" tab, then check the "Ocean" box. As you'll see, that shows you what things would look like if you were surrounded by a nice, flat ocean.

How many of the seven main stars in the Big Dipper are circumpolar? (Here I'm counting all of Alcor and Mizar as one star.)

Now change locations to Boston, Massachusetts. How many of the stars in the Big Dipper are circumpolar when viewed from Boston?

When Santa looks at the stars from the north pole, how do they appear to move? What percentage of the stars he sees are circumpolar? Make a prediction first, then try it.

Now switch your location to Santiago, Chile. Find the center of the circles that stars appear to move in from this location (hint: look South). What constellation is this in?

Note that there is no bright star right at the center of these circles: Polaris is the North Star, but there is no South Star.

Go back home to Richmond. Pick a star that's not circumpolar (that is, one that rises and sets). Record the time that this star rises on one day, and the time it rises on the next day. Make sure your times are accurate to the minute. How much time elapses between successive risings of the star?

Repeat for a few other stars. Is the result always the same?

The length of time between successive risings of a star is called a "sidereal day." How different is a sidereal day from an ordinary day?

Lab 6

Celestial Navigation (Stellarium version)

In the old days, before GPS, sailors figured out where they were by looking at the positions of the stars. In this lab, you'll see how that worked. To be specific, you'll look at the question of how to use the positions of celestial objects to determine your latitude and longitude.

Our reason for doing this is not that I expect you to find yourself lost at sea without access to GPS (although anything's possible, I guess). It's because figuring out how celestial navigation works is a good way to make sure you understand how things move in the night sky.

Latitude

As it turns out, determining your latitude (i.e., how far north or south of the equator you are) is much easier than determining your longitude. The easiest way is to observe the location of the star Polaris. As you know, Polaris is very close to the North Celestial Pole, or in other words almost directly above the Earth's North Pole. For purposes of the questions below, you can assume that Polaris is exactly at the North Celestial Pole.

Suppose you were standing at the Earth's North Pole, which is at a latitude of 90° north. In which direction would you have to look in order to see Polaris?

Now suppose you measured the *altitude* of Polaris. As we've seen, the altitude of an object is the angle that describes how far above the horizon that object is located. To be specific, draw an imaginary line from you to Polaris, and draw an imaginary horizontal line (pointing toward the horizon) directly below Polaris. The altitude means the angle between those two lines.

If you were at the north pole, what would the altitude of Polaris be?

Now suppose you were at the equator (which is at a latitude of 0°). In which direction would you have to look in order to see Polaris?

What would the altitude of Polaris be?

Based on the above considerations, you can guess that there might be a *very* simple rule relating the altitue of Polaris to the observer's latitude. What do you think that relationship is?

We could test this observation using actual observations of Polaris at night, but instead let's test it with *Stellarium*.

Start up *Stellarium*. Find the star Polaris and select it. Look at the information in the upper left, and find the star's altitude. What is the altitude of Polaris?

What is our latitude here in Richmond? (You can find this out by looking at "Location" in *Stellarium*, or I'm sure Google knows it.)

Do the two values you just found agree, at least roughly, with your expectations? (If the degrees agree but there's a discrepancy in the arc-minutes, that's close enough.)

If you're ever lost at sea, you now know how to find your latitude, by observing how high Polaris is in the sky.

Longitude

Suppose you wake up one night and find yourself in a boat tossing about in the middle of the ocean. Using the method above, you figure out your latitude. Now how are you going to find your longitude? As we'll see, this turns out to be a much harder problem than finding latitude.

Suppose your latitude comes out to be 20° north. To keep things (relatively) simple, let's suppose that there are just two possibilities for longitude: either you're at a longitude of 25° west, or you're at a longitude of 55° west.

Set the time in *Stellarium* to about 10:00 tonight, and set your location to be a latitude of 20° north and a longitude of 25° west. (You can type these numbers directly into the Location box. Just enter the number of degrees, and leave out the minutes and seconds.) Orient your view so that you're looking north, with the horizon at the bottom and a pretty large field of view (about 60° or so). Note a couple of landmarks to orient yourself in the sky. You should be able to see the Big Dipper (upside-down) and the bright star Capella, for instance.

Once you've got this set, take a screen shot by hitting control-S. Check that the screen shot was saved. (I think it end up in your Pictures folder.) Open it up and take a look at it to make sure it looks the way you expect. Once you see that the file looks right, go back to *Stellarium*.

Now change your location to 55° west longitude (keeping the latitude and the time the same). Take a screen shot of the sky from this new location.

Now advance the time by two hours, from 10:00 pm to midnight. Take one more screen shot.

At this point, you should have three screen shots.

1. Longitude: 25°. Time: 10:00 pm.
2. Longitude: 55°. Time: 10:00 pm.
3. Longitude: 55°. Time: midnight.

Incidentally, I should mention that the times in *Stellarium* are always times in our actual location (Richmond). That is, 10:00 pm means 10:00 pm Eastern time, regardless of the observer's location.

Two of these three images should look almost identical, and one should look significantly different. Which one is not like the others?

Now, let's get back to your plight as you sit bobbing in your boat in the middle of the ocean. Suppose that you have a timekeeping device (wristwatch cell phone, etc.) that is set to Eastern time. Using this, along with your observation of the night sky, can you tell which longitude you're at? If so, explain briefly how. If not, explain briefly why not.

Suppose that you *don't* have an accurate timekeeping device on board the boat. Can you tell what longitude you're at by observing the sky? If so, explain briefly how. If not, explain briefly why not.

In the 18th century, the British government offered large cash prizes for anyone who could figure out an accurate way to determine the longitude of a ship at sea. In 1765, John Harrison was awarded a £10 000 prize for solving this problem. (It's hard to figure out precise equivalents, but this is equivalent to millions of dollars today.) What do you think Harrison invented?

Back to you on your boat. Suppose that you had a clock with you on your boat, but it wasn't very accurate. Suppose that you use the clock to determine your longitude, but unbeknownst to you the clock is off by two hours. (For instance, you think it's midnight, when really it's 10:00 pm.) By how many degrees will your longitude determination be off?

Suppose that your clock were only off by one minute instead. How far off will your longitude determination be?

One degree of longitude corresponds to an actual distance of about 50 kilometers. If your clock were off by one minute of time, how far off would your determination of your location be (in kilometers)?

If you were a ship's captain trying to avoid hitting undersea rocks and shoals, this level of inaccuracy would be a real problem.