Guide to Stella

Stella is a simulation where you are an astronomer. There are many flavors of astronomy; you might study the Sun, or planets or galaxies or black holes or the shape of the universe.

Here you're studying stars: stars in our own galaxy, and not too far away. You have a telescope with some instruments attached, and a laboratory for making comparison measurements.

If all that is Greek, we have a few pages of science background at the end of this guide.

Overview of Tools

You can see a field of stars, look at their spectra, and make simple deductions about them. There are three important tabs in the interface: Sky (which has the stars), Spectra, and Results (where you enter your deductions).

You will also see three tables: **Catalog** (a data set about all the stars), **Spectra** (which holds any spectra you decide to save), and **Results**. You get points (and badges!) for Results.

Most of the stars will be within a few hundred parsecs[1].

Astrometry

You will be looking at a square patch of sky 5° on a side. You can read on the telescope where it's pointing, to within 0.000001 degrees, that is, a millionth of a degree or a microdegree. This is a very small angle.

To determine the position of a star very precisely, point the telescope right at it and read off the numbers.

Measuring the positions of stars is called *astrometry*.

Photometry

To measure the brightness of a star, point your telescope at it and use your photometer. You will see a count of how many photons hit your detector within a period of time. The more photons, the brighter the star. You also have three filters to use with the detector, so you can measure the brightness in blue, green, or red light.

---

[1] A *parsec* is a unit of distance, 3.26 light years. Here on Earth, our closest neighbor, Proxima Centauri, is about 1 parsec away.

This lets you be quantitative about a star's color. If you measure a star with the blue filter and get twice as many counts as you do with the red, you could invent a new measure of color: you could say that the "blueness" of the star is 2.0. If a different star has only half as many blue counts as red, that "blueness" might be 0.5. (this is only an example)

Spectroscopy

To get a more detailed breakdown of the light from a star, you can use a spectrograph to separate the light from stars into 100 narrow spectral bands. It's like having 100 filters all at once. That detail will show you the specific shape of a spectrum. You can also see spectral lines, which correspond to particular elements and ions.

Your spectrograph measures the intensity of light at various wavelengths. We will measure the wavelength of light in nanometers (10^{-9}m = 1 nm). The visual spectrum—where we will operate—extends from about 350 (violet) to 700 (red) nm.

Activities

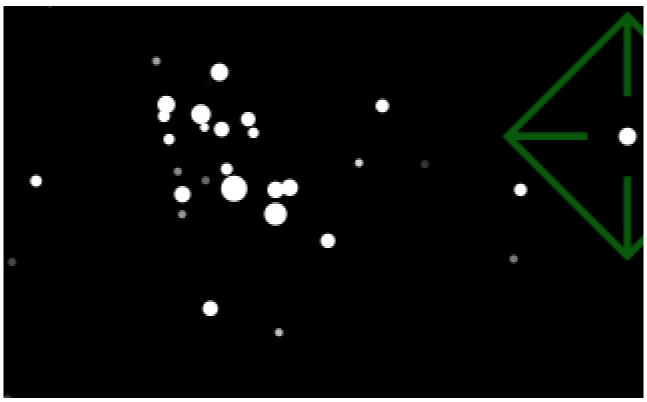
Activity 1	*Stellar Brightness*	*45 - 60 min.*
Activity 2	*Hiding data to clean up a graph*	*50 min.*
Activity 3	*Astrometry*	*45 - 60 min.*

Activity 1: Stellar Brightness

This introduction assumes you are new to CODAP. Let's jump right in.

Click here to start Stella.
Towards the upper right of the star field, you can see a group of stars. Farther to the right, by the edge of what you can see, is another bright star.

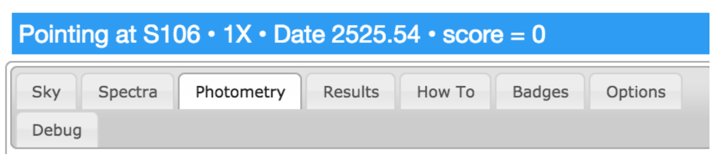
Point the telescope at it by clicking there. It should look like this:



The blue banner across the top should tell you that you are pointing at star **S106**.

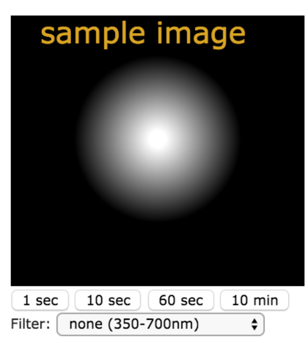
Another way to point the telescope: See the green box above the star field? Type **101** in this box and press TAB or ENTER. The telescope moves over to star **S101**.

Point back at **S106**, over on the right. Let's study star S106.

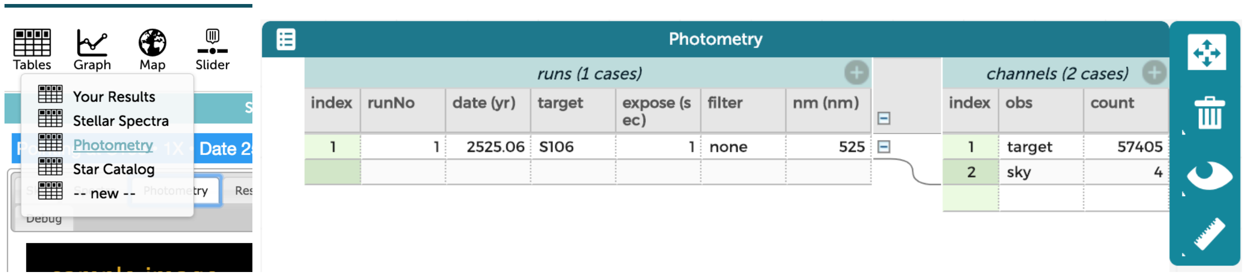


The star we are pointing at appears pretty bright compared to some others. But is it really bright, or just closer to Earth? To find out,C click the **Photometry** tab, and…

...Leaving the filter set at **None**, click the **1 sec** button. You just measured the brightness of S106! You can see the results on the screen. Your measurement has two parts: **S106** and **sky**. Think about what that might mean.



In the toolbar, find the **Tables** button and choose **Photometry**. (See the left-hand illustration below.) A table appears with your measurement. You may have to stretch it to see the whole table. (Right side below.)



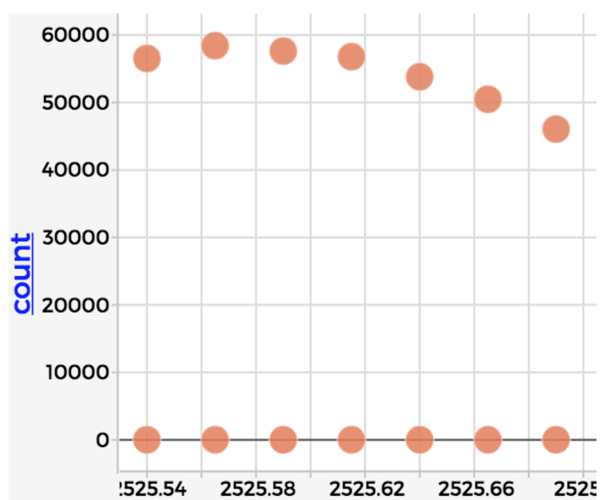
The Photometry table shows that every observation has two parts: we measure the brightness of the "target"—in this case, the star S106—and we also measure the brightness of the "sky" nearby. In this case, S106 is so bright that the sky is almost zero by comparison. For a faint star, these two numbers might be closer, so to get the actual brightness of the star, you would have to subtract.

Take another measurement, again using the **1 sec** button. See how the new measurement appears in the table. Also notice how the date has increased. Time is passing.

Take more measurements (like, 10 of them). Notice how the numbers are changing? Is this a "real" change in the brightness of the star, or a random fluctuation? Let's make a graph to find out.

Click **Graph** in the toolbar. An empty graph appears.

Drag **date(yr)** from the column heading to the horizontal axis and **count** to the vertical. Your graph might look something like the illustration.



Which points are which? You can probably figure it out by looking at the values, but try selecting points in the graph. The table will show you which points you have selected.

You should see that the points around 50,000 are all "target," and the ones near the axis, near zero, are "sky." That is, the star is bright and the sky is dark. Good. Let's see another way to tell.

Drag **obs** from the table's column heading to the middle of the graph. This creates a legend. Now you can tell which are **target** and which are **sky**.

Apparently, S106's brightness is changing over time. It's a *variable star*.

Summary: What Have You Learned?

CODAP skills you've learned so far:

- Make a table by choosing it from the menu in the toolbar.
- Make a graph by clicking on the graph tool in the toolbar.
- Tell CODAP what to graph by dragging column headings (aka attribute names or variable names) to the axes of the graph.
- Make legends by dragging an attribute name to the middle of a graph.

Stella learning:

- Point at a star by clicking on it.
- Point at a star by typing part of its name in the green box.
- Verify what star you're looking at by looking in the blue bar at the top.
- Measure a star's brightness in the **Photometry** tab. The data appear in the photometry table.

Discoveries!

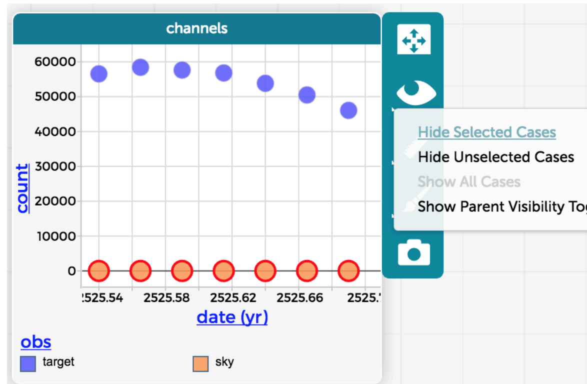
- Some stars—S106, anyway—are variable.

Possible Tasks

- Find another star that's variable, and a star that appears to be constant.
- Figure out the period of S106's variation.
- Figure out the amplitude of S106's variation.
- Find out what happens when you measure S106 using buttons other than the 1 sec button.

Activity 2: Hiding data to clean up a graph

If you have measurements of other stars along with S106, your graph and table are now getting pretty messy. Even if you didn't look at other stars, it might be annoying to see the sky values on the same graph as the target. (If you're thinking that you want to subtract the sky from the target, great! That's coming up in a later lesson. For now, the sky is very dark compared to S106, so we'll ignore it.)



Let's see how to restrict what points appear in a graph.

In the legend of the graph (below date (yr)), click on the box for **sky**. You just selected all of the sky records.

Then, in the panel to the right of the graph, open the "eye" menu (second from the top) and choose **Hide selected cases**.

You should see that the **sky** points disappear and that the graph resizes to show only the **target** data.

Important technique! If you click the top button in that palette, the graph will rescale to show all the data.

Play around with these controls. As you can see, you could instead hide the unselected cases. And if you have hidden too much, you can **Show all cases**. Also, you can just select points in the graph. You don't have to use the legend.

Gotcha: Sometimes you try to get the eyeball and the selection goes away. You can avoid that by clicking in the graph's title bar.

Try all of the controls in the eyeball menu. (**Show Parent Visibility Toggles** may not do anything useful right now, so don't worry about it.)

Practice with hiding and showing…

- Take photometry measurements of some other star.
- Now make a *new graph* that shows shows all of the data since you began.
- Change it so that it shows all the background, **sky** measurements—and only **sky** measurements. Do you think they are random? (Be sure to rescale!)

Additional things to think about and try:

Try dragging **target** (the column heading) to the middle of a graph. What does that tell you?

Investigate: When you hide cases in one graph, do they get hidden in other graphs?

Investigate: The eyeball menu isn't always available. When does the eyeball menu appear?

Summary: What Have You Learned?

CODAP skills:

- When you select cases in graphs or in tables, they get selected in all views.
- The eyeball menu appears when you click on a graph.
- If you click on a graph's title bar, you will not "lose the selection."
- Use the "eyeball" menu in a graph to control what cases are hidden.
- Which cases are hidden is specific to a graph. You can show different things in different graphs.

Activity 3: Astrometry

Astrometry is the science of stellar positions. We talk about the "fixed stars" but in reality, they move — or appear to move — in the sky.

Star Positions (Astrometry)

The results you can record include temperature and radial velocity, of course, but they also include some that depend on careful measurement of star positions:

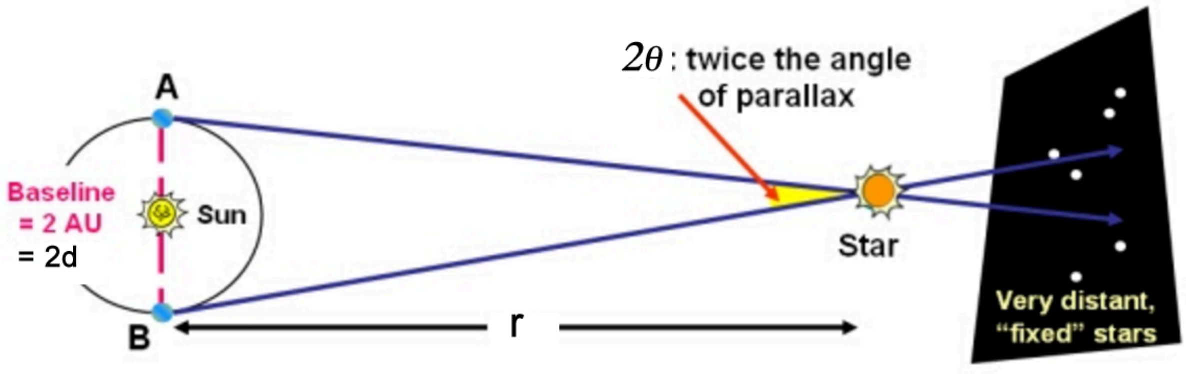
- **Position** itself, in x and y. These are measured in degrees, to six decimal places (i.e., microdegrees). If you are a fan of arc minutes and arc seconds, you may still agree that those are too esoteric for students who will not be reading Ap.J. To save you working out the conversions:

microdegree world	**arc second world**
1° = 1,000,000 μ°	3600" (" = arc seconds)
1,000 μ°	3.6"
278 μ°	1"
214 μ°	0.7716" (parallax of proxima Centauri)
105 μ°	0.379" (of Sirius)
~0.5 μ°	2 milliarcseconds, about the best parallax measurements
57 μ°	0.000001 radians (1 μr)[2]

- **Proper Motion** in x and y: this is the speed, in microdegrees per year, that a star moves across the sky. Abbreviated **pm**. The coordinates in the catalog are "epoch" 2500. That is, they are positions as of 2500. But we are in 2525. So the stars have moved. How far? You can measure and find out. Note: when you select a star in the catalog or by clicking in the sky, the telescope points at the *catalog* coordinates.
- **Parallax**: this is the payoff. Over the course of a year, nearby stars appear to wobble back and forth, because our planet is moving around the Sun. The amplitude of that wobble is the parallax, measured in microdegrees. And by amplitude, we mean half the peak-to-trough distance. Why is this important? Because we can do (simple) trig to calculate the distance to the star. If d is the distance to the Sun (one astronomical unit, 1

[2] Consider the implications of this for parallax. One microradian is the angle made in a triangle with a hypotenuse of 1,000,000 inches and a base of 1 inch. So it's the angle subtended by a quarter at about 15 miles. That's what 57 microdegrees looks like.

AU, in our solar system about 150 million km), r is the distance to the star, and θ is the angle, then the relationship is $d = r\theta$. (Because theta is so small, $\theta \sim \sin\theta$.) Here is a picture swiped and modified from Swinburne:



Of course, just looking at the sky, there's no way to see angles anywhere near as small as a microdegree. Remember our patch of sky is 5° square.

So on the **Sky** tab, you can zoom in with the orange buttons to get a more accurate reading. At small zooms, we display the direction the telescope is pointing. At larger zooms, that seems to be broken in Chrome. No matter. When you switch to the Results pane, you can see the current telescope coordinates.

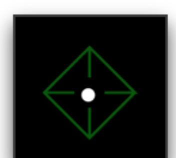
New, essential feature: when you are zoomed in, you can pan the field by dragging. For now, if you click on a star, it will move the telescope to its catalog coordinates. This is undesirable at the highest zooms.

Just as we did with photometry, we will point at a star, and then take measurements. For this lesson, we will focus on star S107, which is near the left edge of our star field.

Point at S107. (By now you know at least two methods!)

Zoom in 5x by pressing the orange 5x button at the bottom of the window.

Zoom in 30x. Now notice that the star is no longer perfectly centered in the green reticule. Close, but not quite.



Why is it not centered? The coordinates (the x and y at the bottom of the window, in green) are from the star catalog, and that was from the year 2500. The year is now at least 2525, so the star has moved. Maybe not a lot, but a little.

Drag the *sky* to center it better. Notice how the coordinates change.

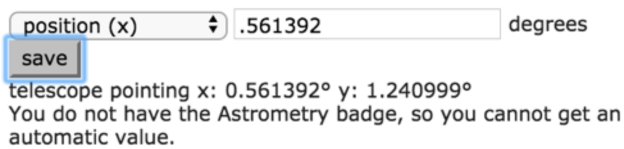
When it is centered at 30x. It's probably no longer at the center. Center it again to get the best, most accurate position you can.

Example: 

Now we will record the current position of the star.

Click the Results tab. It will have a menu that should say position(x). Enter the x-coordinate the telescope is pointing at in the box. (Notice that you don't have to go back to the telescope to get the number — it's just below the save button.)

Click **save**. It should look something like this:



If your result is "close enough" to the truth, you'll get some points!

Do the same for the *y*-coordinate. Change the menu to **position(y)** and enter the value. Then click **save**. This will probably give you the **Astrometry badge, level 1**.

Return to the SKY tab, you should now see 100x and 10000x magnification.

There are orange buttons that control time. 0.001 0.01 0.1 Click the 0.01 button three to five times to advance the time, (The value 0.01 is in years. So five clicks is about two weeks.)

Take a new measurement for *x*-position and record it. VERY IMPORTANT: un-zoom the telescope, at least as far as 100x, then zoom back in before re-centering the telescope on the star. Then enter the data for x-position and press **save**.

(We will not be recording any more y-coordinates for now.)

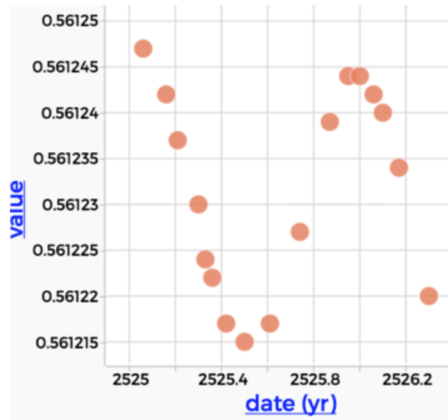
Note: if you press the auto button (which would exist because you earned a badge), Stella will type the current telescope position into the box, saving you typing.

Make a graph that shows how the x-position of S107 changes with time.

- To make a graph, you will need a table. **Get the Your Results** table from the **tables** menu in the toolbar.
- You will need to hide extraneous points.

- Don't forget to use the "scale" button in the graph palette to rescale your data.

Continue to collect data until you have what amounts to a complete cycle of *x* positions. Your graph might look like this: What's going on with this star?



In the "hamburger" menu, upper left, **Save** your document. Google Docs is a good place. Give it a location and a name you can remember.

Summary: What Have You Learned?

CODAP Skills:

- Saving a document
- Practice in hiding unwanted data points
- Practice using the auto-scale button

Stella Skills and Findings:

- Stars' positions change; in fact, S107 seems to go back and forth.
- You can zoom in when you're on the Sky tab.
- Use 10000x for positions (but back off to 100x between measurements)
- You can record positions in the Results tab
- Badges can save you trouble in entering results
- You can control the passage of time using the orange time buttons.