Astronomy Labs Supporting Manual

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Preface

This manual was written primarily for use with the Observational Astronomy (ASTR 105L) laboratory course at Cerritos College. It should be used as a reference that provides background information for the lab activities for that course. The actual lab activities will be given by your instructor – either in-person, through Canvas, or a combination of both. Please see the syllabus for your class to determine how your instructor will use this manual in conjunction with your class.

This manual is meant to be used as an electronic document. You should use an online version so that you can follow hyperlinks. It will still be useful as a printed document, but it will lack the connections to related and supporting material if you only use it that way.

Written and compiled by Thad Szabo
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All pictures taken by the author unless otherwise noted.
All diagrams created by the author unless otherwise noted.

Introduction to Observational Astronomy

From the name of this class, you may think we will spend all of our time looking at the night sky. While this is a component of what this course entails, there is significantly more to it than that. One of the main objectives is for you to recognize patterns in the sky so that you can note how they change. Some changes will be easy to record. When we are outside using telescopes for the lab, you can watch stars and planets move east to west across the sky during that time. You don't even need a telescope for that. You should also look for changes between how the sky appears at the beginning of the semester compared to the end. Some changes are more subtle — wasn't that planet on the other side of that bright star two weeks ago? Wasn't the Moon a different color when it first rose compared with when it was higher in the sky? Other changes are so small that you need a telescope to notice them. The features in Jupiter's atmosphere vary over a span of less than an hour, and its moons change position as you watch through the night. All of these changes reveal something about how our Universe operates and help us understand our place in it.

Another component of this lab course is for you to become more familiar with the physical principles of why the Universe works the way it does. This will give you context for the changes and differences you observe. What can we learn about how the Earth moves from the changes in the sky throughout the night and throughout the year? What can we discern from stars having different colors? You may already know the reason for some of these things from your astronomy lecture class. If you are currently taking an astronomy lecture, this lab course will help reinforce the ideas you learn there.

The last substantial part of this course is learning to make careful records of what you observe. If you are looking for differences, you need to take good notes so that you can compare observations over time. We will learn what details are important for you to always include. You should also discuss your observations with your lab partner, other students, and your instructor. Talking and writing about what you see in the sky, either with or without a telescope, can help you shape your ideas and improve your understanding. Don't be afraid to ask questions or to make statements you aren't sure of. Learning to correct your own thinking is often the best route to a deeper understanding.

This manual is meant to be used in conjunction with files and software that are available from the Cerritos College Learning Management System (LMS). As of the time of this writing, that system is Canvas. Because each course in Canvas has its own web address, your instructor will need to construct the Canvas site so that you can get to the needed files. Please address any discrepancies between the material in this manual and the material available on Canvas with your instructor.

Learning the Night Sky

Many students who take an astronomy lab hope to learn how to identify what they see in the night sky. Learning to recognize what is visible at night connects us back to our earliest ancestors. People throughout the world have used observations of patterns in the stars to help determine times for planting and harvesting crops as well as for navigation. Even the United States Navy has reinstated celestial navigation as a course for its officers so they understand the basics of how to find their location at sea.

You won't be expected to navigate across the ocean from what you learn in this course, but you do need to know where to look in order to observe stars and planets. There are many apps that can help you identify what is visible in the sky. The primary one you will use for this course is Stellarium. Other options include SkySafari, SkyView, and StarWalk. Lab activities will use Stellarium, but you are welcome to try other apps to help you learn the night sky if you find them easier to work with. Stellarium is available both through the Apple App Store and through Google Play. For the desktop versioin, you can download it directly from the Stellarium website. Several lab activities should help you get more familiar with Stellarium. Ask your instructor if you need help with installing it or learning how to use it.

Before we begin using these apps or any other method of learning the night sky, there are some terms we need to understand. Pointing at the sky and saying, "Look there!" is not sufficient. We need directions to refer to where stars, constellations, and planets appear. If you use a GPS system in your car, you may have heard instructions like "drive *north* for 3 miles." *North* is an example of a ***cardinal direction***. The cardinal directions are *north*, *east*, *south*, and *west*. Even without GPS, these directions can be determined from watching how stars move across the sky throughout the night. You may already know that the Sun rises in the east and sets in the west. If you make note of the positions of objects in the night sky, you will notice that *all* objects rise in the east and set in the west – the Moon, planets, stars, and constellations all do this.

We should also make sure we are clear about what it means for something in the sky to rise or set. We are familiar with the idea of sunrise and sunset. In the morning, it starts off dark outside. The sky begins to lighten and change color, and eventually we see the bright light from the disk of the Sun become visible. This happens as the Sun appears above the *horizon* in the east. At sunset, we watch the Sun go below the horizon in the west, and the process reverses. A basic definition of the horizon is that it is *the line that separates the sky from the land and sea.* This is not a good astronomical definition, but it works to give us the general idea. We can also say that an object is rising as it gets higher above the horizon, and that it is setting as it gets lower toward the horizon. Be careful about the distinction between these two uses, and ask if it isn't clear which meaning is being used.

The last term we will need for finding our way around the sky is *altitude*. You may be used to the idea of altitude from hearing a pilot say that a plane is flying at an altitude of 15,000 feet, or that you are on a mountain that is over a mile high. In those cases, altitude is a measure of distance from Earth's surface, or more precisely, from mean sea level. Because there is no direct way of telling how far away a star or planet is, this definition does not work for astronomy. When we mention altitude in astronomy, we mean *the angle you measure as you move from the horizon directly up to where an object is located on the sky*. Altitude never involves moving side-to-side. To get a feel for this idea, you can point straight at the horizon and then point at an object directly above the horizon. The angle between your arms will approximate the altitude of the object.

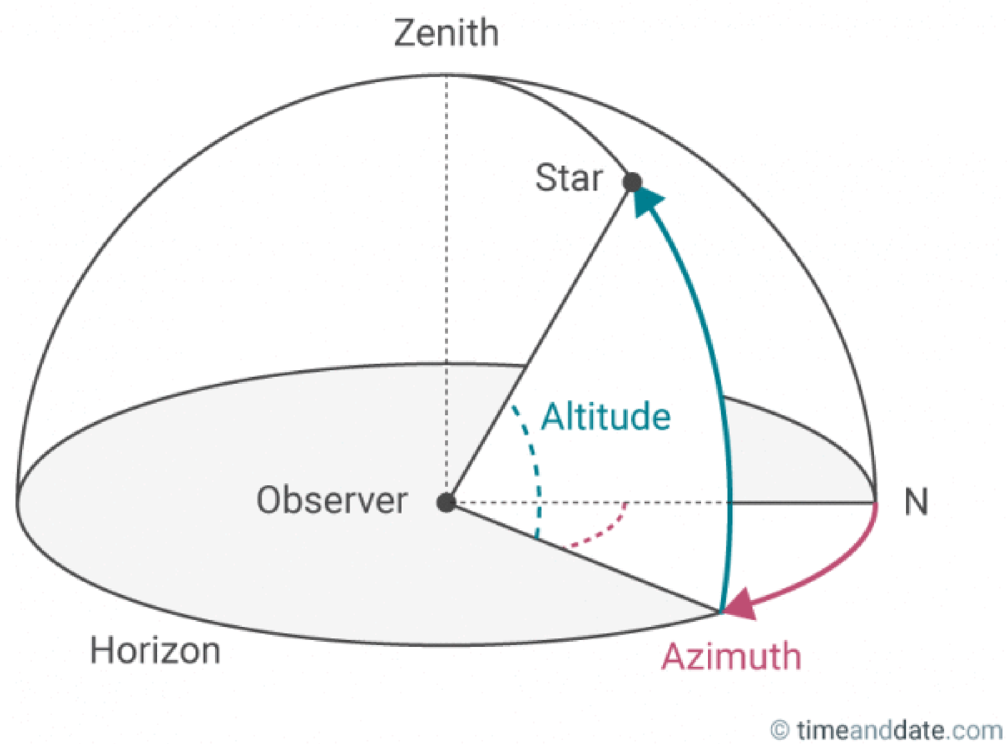


Figure 1 - Diagram showing how azimuth and altitude are measured

Another place we can point to and use for reference is the ***zenith***. The zenith is defined as the point that is directly overhead from your location. It is defined as having an altitude of 90 degrees. If the altitude of the zenith is 90°, what do you think is the altitude of the horizon?

We will make our observations of the night sky from the observatory deck on top of the MCIS building. One thing you may notice from looking at the stars from the city is that you don't see very many of them. This is due to so much of the light that we use at night going upward and brightening Earth's atmosphere. This is known as *light pollution*. In general, light pollution is a big problem for astronomers. However, we can use it to our advantage if you are just starting our learning patterns in the stars. Over the entire sky under ideal conditions, about 9,000 stars would be visible. It would be very confusing to identify patterns in that many stars if you are just starting out! However, only half this number is above the horizon at any time. When starlight has to pass through more of Earth's atmosphere, it becomes fainter. Stars near the horizon have to pass through the most atmosphere, so this removes them from view, even if you are somewhere very dark. At any time of night, typically about 3,000 stars would be visible. That's still too many to learn. Because of how bright the night sky is at Cerritos College, only about 50 stars are visible at a time. This makes recognizing patterns and associating them with the names of stars and constellations much easier.

Notice that as you look around the night sky, some objects are brighter than others. If the Moon is up, it is usually the brightest nighttime object. Generally, planets tend to appear brighter than stars. That isn't always true, but it's a good starting point until we learn more. Some stars are easily visible even with all the light pollution, and other stars appear so faint that you may not be sure you're really seeing them. How bright an object appears is related to its ***apparent magnitude***. Apparent magnitude is a concept that can be confusing because of how it is defined. *Fainter objects have a bigger apparent magnitude than brighter objects.* This feels backwards. It is much easier to see a star with apparent magnitude 1 than it is to see a star with apparent magnitude 4. "A one is brighter than a four?" is probably what's going through your mind right now. It seems backwards compared to how it should be. Unfortunately, it's not going to change. It's based on how Hipparchus assigned magnitudes around 150 B.C.E. This method that seems backwards is over 2100 years old. This trend of lower magnitudes being used for brighter stars continues through zero and into negative numbers. Most of the stars we can see easily from Cerritos College are magnitude zero or one. Magnitude two stars are harder to see, and conditions have to be really good to see any magnitude three stars. If Venus is visible, it is around magnitude -4, and Jupiter is around magnitude -2.5. A full moon has a magnitude of -12.

Here's a quick review of terms we will use when describing the location an brightness of objects in the sky:

- ***Cardinal directions*** refer to north, east, south, and west.
- We will describe the ***horizon*** (for now) as the boundary between the sky and the land or sea.
- The ***altitude*** of an object is the angle that an object is above the horizon.
- The ***zenith*** is the point that is directly above. It has an altitude of 90 degrees.
- We use ***apparent magnitude*** to give the brightness of a star. Smaller numbers (or negative numbers) mean a brighter planet or star. Bigger numbers mean fainter objects.

What Can You Observe?

Constellations

Students sometimes think that you can look at constellations with a telescope. A telescope (or even binoculars) gives a view of the sky that is too narrow to see a constellation. It's not a perfect analogy but think of looking through a paper towel tube. Constellations cover a wide area of the sky, so you can only observe them with the unaided eye. If you are anywhere in the 48 contiguous states in the United States, these constellations will look the same. There is a website which shows views of the night sky from campus that you can use as a reference for learning the constellations and which ones are visible during the time of lab.

Some constellations have many bright stars and are easy to identify. Some constellations have no bright stars, and you need to be under dark skies to have a chance of seeing them. In this class, you will get familiar with brighter constellations. You can use these readily visible constellations and bright stars as guides if you go to dark skies and can see many more stars.

The Moon

The Moon is usually the best place to start if you have never looked through a telescope before. It is the closest object to us, which means that light has to travel the least distance to get to us. This keeps the Moon nice and bright, because light spreads out as it heads away from an object.

The Moon does not produce any of its own light. The only way we see the Moon is when it reflects the light of the Sun. Sunlight falls on the Moon from different directions as the Moon orbits the Earth - this produces the *phases* of the Moon (see page 10). One half of the Moon is always lit by the Sun; the phase of the Moon is determined by how much of the lit side we can see.

Some phases show more detail than others. Most people think that full moon would give the best view, but the Sun is shining very directly on the Moon at that phase. When you look through a telescope, it can make it seem like features lack depth. A crescent moon looks interesting, but there isn't much to study, because there is so little of the lit side facing us. The best phases, from our perspective for this course, will be first quarter and waxing gibbous. You get interesting shadows on the boundary between light and darkness during those phases. That boundary is known as the *terminator*. Plus, there is enough detail to look at. We should plan our Moon observations to be around one of these phases.

Planets

Planets also do not shine with their own light -- they only reflect the light of the Sun. The distances to planets are much greater, so they are fainter.

Some planets show phases because of their relative position to the Earth and the Sun. Mercury and Venus go through a full set of phases. Mars can appear as less than a complete disk. Mars has features on its surface that can be viewed through a telescope or photographed. Mars also rotates once every 24 hours and 40 minutes, so the features that you see can change slowly throughout a night. Jupiter and Saturn rotate very quickly – about once every 10 hours or so. We may track changes in the features in Jupiter's atmosphere as part of this class. Although Saturn rotates quickly, its atmosphere tends to be bland. However, it does sometimes have large storms occur, which gives us something we can watch develop and fade over a span of weeks or months. With Saturn, you can also see how much detail is visible in its rings.

Jupiter and Saturn also have many moons of their own that can be seen with the telescopes we use for lab. If either of these planets are visible during the semester you take this course, you should pay attention to how the moons are arranged around the planet when you look at them through a telescope.

Uranus and Neptune are too faint to see with the unaided eye, even from a dark sky site. There have been students who used a technique called *starhopping* to find them during lab, but they are too far from the Sun to get a good look at them from Earth. Generally, the best you can hope for is being able to say that you saw them through a telescope.

Multiple Star Systems

Our Sun is a little unusual in that it doesn't have any other stars as companions. That's good for us -- I don't think we would be here if the Sun had other stars that orbited it. However, when stars form, they form in groups or clusters, so you usually find more than one star that makes up a system where they are held near each other by their mutual gravity.

You can look for color differences if you see a multiple star system. You can look for differences in brightness. Because of chance alignments, stars may appear near each other in the sky, but be very far apart from each other in space, with one of them significantly closer than the other. If you know that the stars are actually together in space, this lets you compare temperatures and *luminosities* of the stars. There is a difference between brightness and luminosity. Brightness is related to how much of the light of an object makes it to your eye; luminosity is related to the total light output of the star. You can think of luminosity as the power of the star.

Sometimes the separation between stars in a multiple star system is very small, so you generally need good seeing for these. (We will discuss seeing on page 84.)

Star Clusters

We mentioned in the last paragraph that stars form in groups. If the group is young enough, you can see these new stars still hanging around in an open star cluster. These look like a denser concentration of stars on the sky, and they are often blue because of the stars being hot and relatively young.

There are also globular clusters. These are very old, very dense groups of stars. A lot of times, they just look like a fuzzy ball, with almost no space visible between the stars. They often have more of a reddish appearance, because they are made of older, cool stars.

Although these clusters may be thousands of light years away, they are usually relatively easy to see in a telescope from an urban area like Los Angeles. Some of them, like the Pleiades (or Seven Sisters), are visible to the naked eye.

Nebulae

These are regions of gas and sometimes dust that glow because either it is forming hot, new stars that light up the atoms, or there is the hot remnant of a star — called a white dwarf — that provides energy to get the atoms to glow. Thus, some nebulae are stars at the beginning of their existence, and others are lit by stars that recently finished producing new energy.

The hot gases around new stars that are just forming are called *emission nebulae*. Although they would not show color to the eye alone, in true color photographs, they appear reddish or pinkish. This doesn't have to do with the temperature -- this is the strongest color that comes from the element hydrogen. Hydrogen is the most common element in the Universe, and it is a necessary ingredient for making stars. When very hot stars first form, some of the hydrogen can still be hanging around, and it gets lit up by the new stars.

When lower mass stars finish making energy, they throw off their outer layers as shells or rings. These layers of elements are then lit up by the white dwarf. That white dwarf used to be the core of the star, so it is extremely hot. These small, mostly round objects are called *planetary nebulae.* The stuff that got thrown out of the star might make new planets later, but that isn't why they're called that. They got that name because they appear small and round, like a planet.

Galaxies

The most distant objects we will look at are galaxies. They shine with the light of billions of stars or more. However, the closest one is 2.5 million light years away. Because that is a huge amount of space for its light to spread out, it is relatively faint. With the light spread out that much combined with the background light pollution of the Los Angeles area, galaxies are usually extremely difficult to see.

However, if you photograph galaxies, the camera can collect light for a much longer time than the eye can. It is very difficult to do visual observations of galaxies unless you are somewhere that is quite dark. With photography, we can look for a lot more. Because their light has spread out so much over such a long distance, it is best to look for them only when the transparency is very good. A humid night will easily wipe out the view of them, even when taking photos through a telescope. (We will discuss transparency on page 84.)

One event we can look for in other galaxies is a *supernova*. This is what happens when a star explodes violently. One star can shine with as much light as billions of stars combined. This makes it possible to see these events with a telescope even if they are tens or hundreds of millions of light years away. We can try photographing supernovae with the equipment in the observatory. The last time a supernova was visible in our own galaxy was the year 1604 C.E.

The Sun

NEVER LOOK DIRECTLY AT THE SUN WITHOUT PROPER EYE PROTECTION. The front of your eye has a lens which focuses light on your retina. The light from the Sun will focus down to a tiny point and *burn your retina* which permanently damages it.

Eclipse glasses will allow you to look safely at the Sun without a telescope. Eclipse glasses should be certified with the ISO 12312-2 standard. They should also be discarded and not used after a certain amount of time (usually after 1-3 years). Generally, it will just look like a blank disk. There are times that the Sun has enormous sunspots, and they are visible even to the ***properly protected*** naked eye.

There are two types of telescopes that we can use to look at the Sun - white light telescopes and *hydrogen-alpha* telescopes. Using a telescope with a white light filter will allow you to observe sunspots on the photosphere – the visible surface of the Sun. A hydrogen-alpha telescope (or Hα telescope) will allow you to see features in both the photosphere and the chromosphere. In addition to sunspots, you can see filaments and prominences.

Meteors, Comets, and Aurorae

With all of the objects listed above (except for supernovae), we can predict exactly where they will be in the sky at a given time from a given location on Earth. Their motions are entirely predictable. Meteors and aurorae are entirely random. We know when some comets will appear and where they will be in the sky, but we can never accurately predict their brightness. Sometimes, new comets will visit the inner part of the solar system. Astronomers have to determine what their orbits are before we can make predictions about where they will be.

Meteors are also known as *shooting stars*. But stars are huge objects many, many times bigger than the Earth and are made of hot gas and plasma. There's no way they can "shoot" across the sky. Meteors are small bits of rock from space that burn up as they hit Earth's atmosphere at speeds exceeding 20,000 miles per hour. For the most part, they are smaller than the part of your finger after the last joint. At that speed, there is a lot of energy that gets turned into heat, so even rocks that are that small glow incredibly bright as they burn up. Although we can't predict where exactly meteors will appear, there are nights when there can be a *meteor shower*. The typical rate for seeing meteors from a dark sky is about 5 per hour. During a meteor shower, you may see 20 or 30 an hour. During the best ones that happen each year, you may see close to 100 meteors per hour. There will be a direction on the sky that meteors in a meteor shower will appear to come from called the *radiant*. Your best bet for watching for meteors is to get a blanket and lie on the ground or have a chair that reclines and lets you look up. Then, you just have to be patient and watch. Don't use binoculars or a telescope. Definitely get away from city lights. Watch for the colors that meteors might show. It helps to reveal which chemical elements they are made of.

Some comets can get very bright and put on a good show, even to the unaided eye. The two most recent examples for the Northern Hemisphere (as of the end of 2024) are Comet NEOWISE (C/2020 F3) and Comet Tsuchinshan-ATLAS (C/2023 A3). From dark skies, you could see the tail of each comet stretching over a fair portion of the sky – longer than could fit in the view in binoculars. Usually, comets are much smaller and fainter, and you will need a telescope to see them. Comets are unpredictable, so you often have to take advantage of seeing them on a quick basis. They don't move across the sky as you watch, but they do move from one set of stars to another noticeably from night to night. You will need a chart to find where they will be and at what time.

I originally thought there would be no reason to mention aurorae, otherwise known as *Northern Lights*. Typically, you need to be in the Arctic region to see them. You have a better chance of seeing them from northern Alaska, Iceland, Norway, and Finland. However, when the Sun is very active, it can launch huge clouds of plasma into the solar system. If those clouds hit Earth's magnetic field and atmosphere, aurorae may be visible at more southern latitudes. On the night of 2024-05-10, I was able to see them from the mountains north of Los Angeles. They looked like faint, misty curtains of light to the unaided eye, but a cell phone camera set to a longer exposure revealed ribbons of bright red color. You will need to pay attention to *space weather* forecasts, and if a severe geomagnetic storm is happening one night, head out to somewhere dark to enjoy the show.

Moon Phase Review

One of the observations you can do in this class is to sketch the phases of the Moon at different times through its ~~moonthly~~ monthly cycle. This can also be useful to know to determine whether we can see the Moon during a telescope session. We discuss the phases of the Moon based on its position relative to the Earth and the Sun. What do each of these phases look like in the sky?

For the waxing phases, the portion of the Moon closer to the western horizon is illuminated, like this:

Figure 2 - waxing crescent, 2.7 days past new

Figure 3 - waxing crescent, 5 days past new

Note that as the Moon increases in phase, it rises later each night. On average, the Moon will rise about 50 minutes later than it did the night before. How much later the Moon rises from one night to the next can be as short as 30 minutes or as long as 90 minutes. We can discuss these variations when we discuss the celestial sphere and the *ecliptic* later in the course.

Figure 4 - first quarter, 7 days past new

Figure 5 - waxing gibbous, 9.1 days past new

Figure 6 - waxing gibbous, 12.2 days past new

When the Moon is full, it is opposite the Sun in the sky. It rises as the Sun sets and will set when the Sun rises. The side facing the Earth is fully illuminated.

Figure 7 - full moon, 14.5 day past new

After this, the side of the Moon facing the eastern horizon is illuminated during waning phases.

Figure 8 - waning gibbous, 18.2 days past new

Figure 9 - third quarter, 21.6 days past new

Figure 10 - waning crescent, 26.1 days past new

The only time a new moon is visible is during a *solar eclipse*. This could be a partial solar eclipse, where the Moon only blocks part of the Sun, or a total solar eclipse, where the disk of the Moon completely blocks the bright part of the Sun's surface.

Is there either a solar or lunar eclipse visible during the semester you are taking the lab? Are they partial or total eclipses? What do you expect to see?

Note that, although the amount and direction of illumination changes, it is always the same set of features visible on the Moon. What does this imply about the Moon's rotation?

The Sky Journal

In the introduction to this manual, we mentioned that one of the skills you will develop as part of this course is careful record keeping. You should keep a separate notebook that you use to record your observations of the night sky. You will use this for both unaided observations – sometimes called *naked eye* observations – and for observations using a telescope or binoculars. This notebook will contain sketches of what you see in addition to descriptions and other clues to yourself to help put together how you learn the night sky. Your notebook will not be the same as anyone else's – it is your personal record of your journey of learning the night sky. There may be instances where something you saw through a telescope was of particular significance to you, and you want to note that. This notebook is your ***sky journal***.

Entries to your sky journal will be chronological. Your first pages will be from your first attempts to learn the night sky. You can go back and add additional information later, but when you look through your journal, it should give you a distinct sense of how you progressed from what you knew at the beginning of the semester to what you knew at the end. Hopefully, you continue using it even after the course is over. Maybe you'll be out in the desert on a summer night, and you get to watch a meteor shower. You could record how many meteors you saw, when they occurred, which direction they moved across the sky, and whether they had a particular color. We won't watch any meteor showers from here on campus since the city lights interfere too much, but it's the kind of event that hopefully has you looking at the sky even after the class ends. The key point is that you should be in the habit of recording what you see in the night sky.

If you are taking the astronomy lab face-to-face, you should use a *composition notebook* for your sky journal. The idea is that pages should not be added or removed. Your instructor may have a preference as to whether you should use a lined or unlined notebook. If you are taking the lab online or remotely, there may be other guidelines. Check with your instructor and see what they have listed in the syllabus for your section.

Although this is a personal record of your own learning, it also has scientific value. There is some information that needs to be included with any observation you write in your journal. All entries should include the following information:

- The **DATE**, preferably in a format like YYYY-MM-DD;
- The **TIME**, either in 24-hour format or specifically including AM or PM;
- Your **LOCATION**, which could just be a city and state or something more precise like your longitude and latitude;
- Whether you were observing with the unaided eye or with a telescope or binoculars.

Even if you stay in one place and make several observations, one after another, ***this set of information should appear with each individual observation. Every entry needs to have its own* DATE*,* TIME*, and* LOCATION *listed.*** These three pieces of information uniquely identify what can be in the sky at a particular moment.

Your first entries will likely be sketches and details that help you learn the stars, constellations, and planets that you need to know for the semester. You can use the images from the

Views of the Sky website to get used to what the patterns of stars and constellations look like. *Planets change positions relative to the stars, so you should get information about the location of the planets from your instructor or from a planetarium app like Stellarium.* The position of planets will ***NOT*** match what is in the images from that website. Listen for particular clues from your instructor about how to recognize patterns. There are some tricks and mnemonics that go with the bright stars and constellations for each season. You might find spelling some of the names to be tricky, so you may just want to take some pages in your journal to practice spelling the names of these objects. Had you ever heard of *Alioth, Procyon,* or *Ophiuchus* before taking this course? Most likely not, but repetition can help you get used to words and terms that are otherwise unusual.

Unaided Eye Observations

For observations with the unaided eye, you should include which cardinal direction you were facing in addition to the date, time, and location. If you were looking overhead, you should state that you were looking at the *zenith*. When making sketches of patterns of stars, use a bigger dot for a brighter star. You will likely be doing this under low light conditions, so don't worry about having highly precise drawings. These sketches are mainly a reference for you. By taking the time to reproduce the patterns you see in the sky in a drawing, you will become familiar with them faster. You may also come up with ways to relate stars and constellations to each other that make better sense to you than what you learn elsewhere. Unless your instructor specifically states that you should do things in color, just a pencil should be fine. If you use a pen and you make a mistake, just cross out that page and start again on a new page. You can put color details for stars in the notes on a sketch if it will help you remember the patterns better. If you are sketching objects close to the horizon, you should draw a line to represent the horizon. If a tree is blocking part of your view, make a rough sketch of how the tree is blocking the sky. You don't need to go into great detail with every leaf and branch – just an outline is OK. The same practice also applies to clouds, though I hope you get many clear nights while you are taking this class.

If you want to include weather information, you can. Basic details like temperature and relative humidity are good to include. If you have an idea of wind speed and direction, include that too.

The following picture shows an example of an unaided eye sky journal entry depicting the view to the east (at top) and to the north (at bottom). When you are making your sketches, you will need sketches of the view to the north, east, south, west, and zenith to get full credit. Note that brighter stars have a bigger dot to represent them. I chose not to draw constellation lines on my sketches so that it better represents what you actually see in the sky. The time of night will also advance as you complete your sketches, so you should list the time for each direction if more than 10 minutes pass from the time listed with the sketch in the first direction.

If you are observing from somewhere darker, I do not expect you to sketch every star visible with a roughly accurate position. That would take too long. Focus on getting the brighter stars in your sketch. If the Milky Way is visible, you can use light shading with a pencil to represent where it is. You may even see the general shape of it, and you can include that as well.

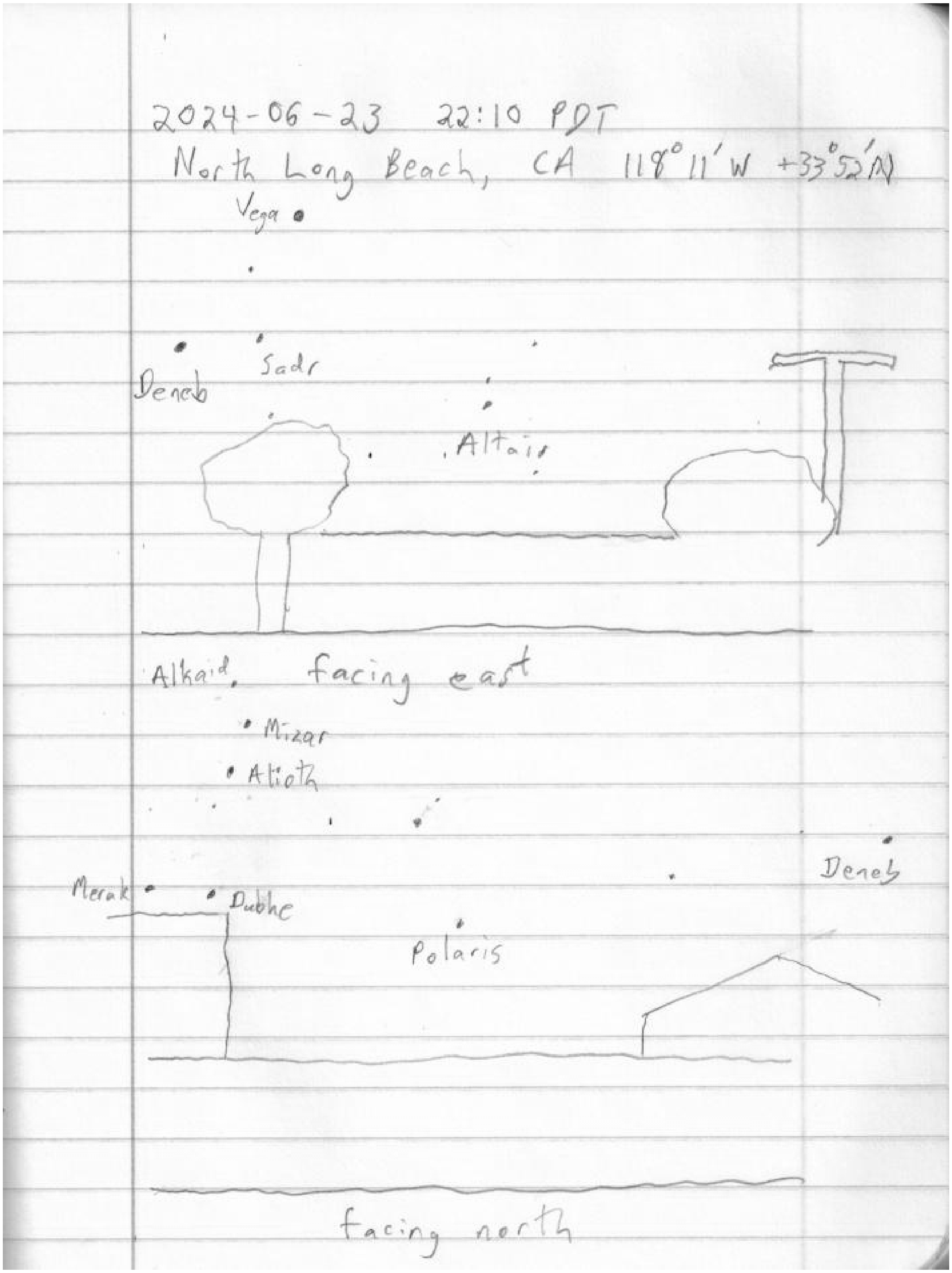


Figure 11 - examples of sky journal sketches for views of the sky with the unaided eye

Telescope (or Binocular) Observations

Getting a careful look at an object through a telescope requires patience. First, it's not something you're used to doing. It will take some time to get used to where to place your eye. There is also the matter of getting an object in good focus. The telescopes that you will use with your group do not track the sky as Earth rotates, so you will need to get a feel for moving the scope as you look. Other factors to consider are seeing and transparency. At first, you should not try sketching objects as you look through the telescope. Look through the eyepiece, take about 20 to 30 seconds to get used to the view, then back away and let someone else have a look. If this is your first time using a telescope, do this two or three times to get a feel for how to be comfortable with viewing before trying to make any sketches. You will need to look for a longer time to make a good sketch.

When sketching planets (or the Moon or the Sun), the view will feel like it shifts or "swims" while you look. Even when the object is in focus, it will get blurry at times. This is due to *seeing* - random changes in temperature and density in Earth's atmosphere that bends light differently from air that is adjacent to it. Your best course of action is to make sure the telescope is in as clear a focus as you can manage and then watch the object for at least a minute. You will see details come into view, disappear, and reappear. If the same features come back clearly a few times as you are looking, they are very likely real and should appear in your sketch.

I used a compass to draw the circle to represent the view in these examples. If you have a wide enough drink container, you can also use the base of the container to make circles. I recommend using something larger than a soda can – you need to leave enough space to be able to draw details. The circle you draw for sketches through a telescope or binoculars should be at least 3 inches in diameter, but preferably larger. If you need a compass for drawing the circles during lab, they should be provided, or you can just ask for one.

The following example shows how I sketched the Moon as it appeared through a set of 25x100 mm binoculars. Even though there are two sides to the binoculars, it gives one image when you look through it. It took me about 40 minutes of careful observing to make this sketch. With every sketch, the ***DATE, TIME, and LOCATION*** are clearly visible. I used either Stellarium or Virtual Moon Atlas to get the percentage illumination of the Moon. With binoculars, the details you need to include are the magnification (25x) and the diameter (100 mm) of the lenses of the binoculars.

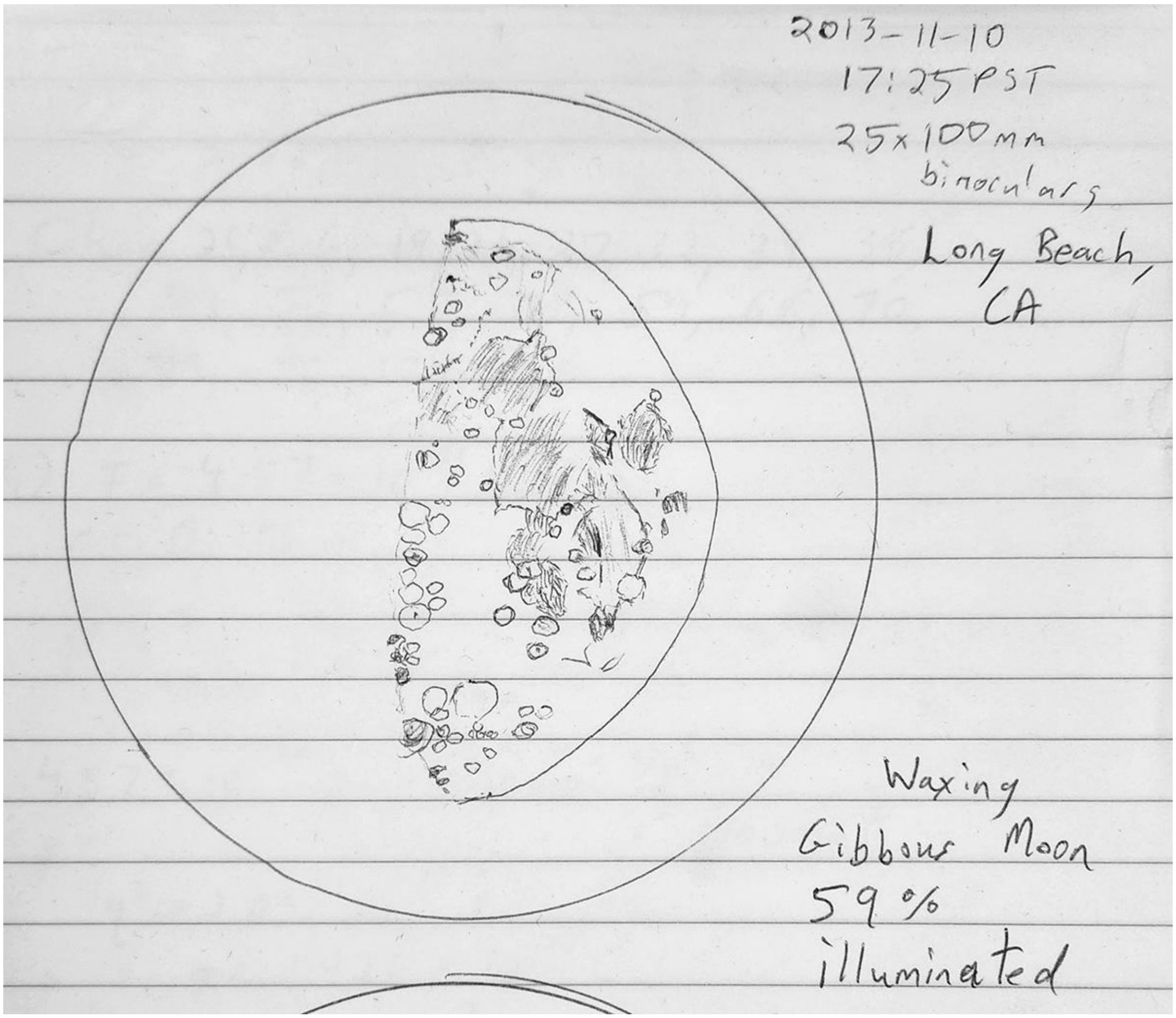


Figure 12 - example of a sky journal sketch made through binoculars

Despite planets being larger than the Moon, they appear smaller because of how much farther away they are. The closest that Venus passes by the Earth is over 100 times farther away than the distance to the Moon, and when Mars is closest to the Earth, it is still over 140 times farther away than the Moon. Unless you are using an eyepiece that gives a high magnification with the 14" telescope, planets will look considerably smaller than the overall field of view. You should draw them so they are sized appropriately for the view. If there are any moons of the planet visible, you should sketch those as well – most likely, they will appear as dots. Any stars within the field of view should also be included.

Below is an example of a sketch of Jupiter. Note that the ***DATE, TIME, and LOCATION*** are listed at the top of the page. There is a large circle that represents the view through the *eyepiece*. The *type of telescope* along with its *aperture* and any additional *accessories* (diagonal) are listed. The eyepiece that was used is also listed. The *magnification* is how many times bigger the object looks through the telescope compared to with the naked eye. The viewing conditions – seeing and transparency – are mentioned. The four largest moons of Jupiter were visible, so they are labeled. This is the minimum set of details that should be included with any sketches you make of planets. If there are stars visible in the field of view, they do not need to be labeled or named.

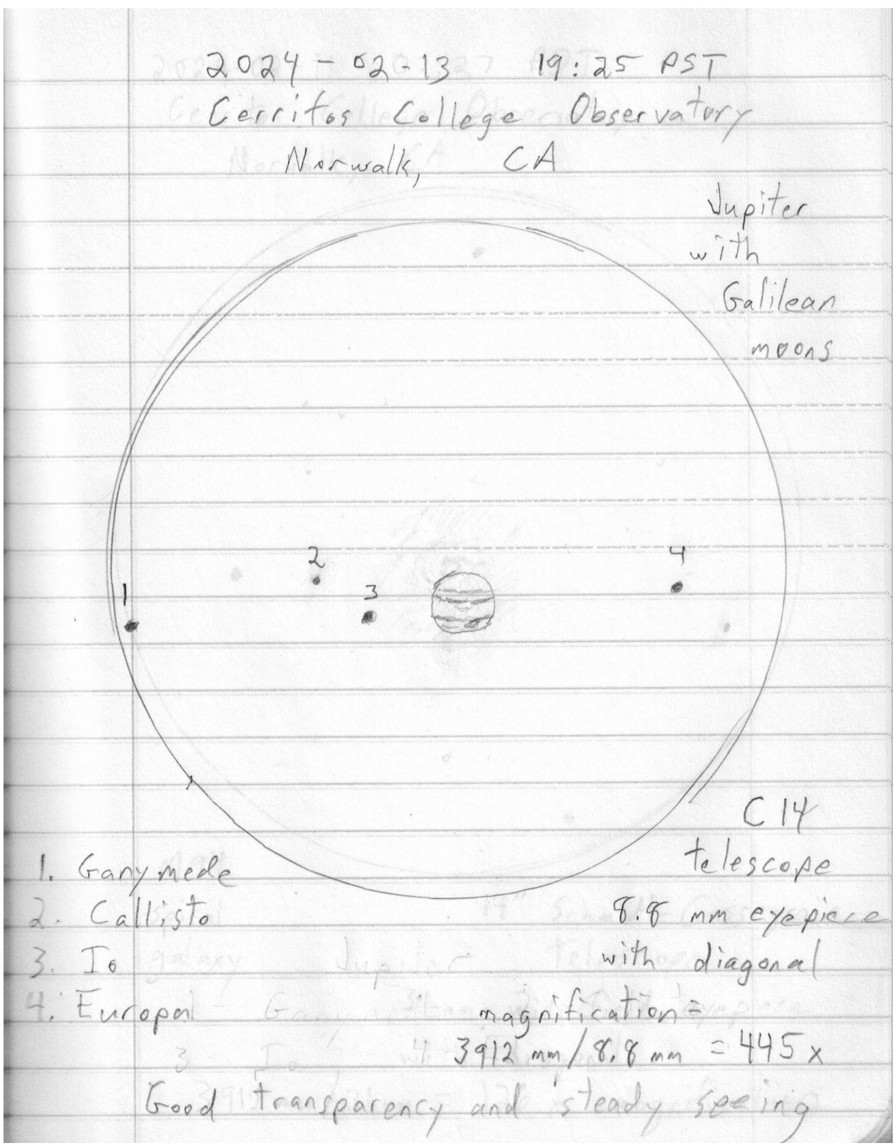


Figure 13 - example of a sky journal sketch of Jupiter; the same format should be used for other sketches of planets

Deep sky objects are much farther away in space than planets in our solar system. When you view planets, you are looking at light that left the object a few minutes to a few hours ago, at most. When you are looking at deep sky objects, you are looking at light that left the object at least hundreds of years ago, and possibly millions of years ago. These objects are much, much bigger in size than our solar system. They will be spread out over a larger portion of the view through the eyepiece. There is an unusual trick for seeing them. After you have a feel for what it is like to look through the eyepiece of a telescope, you can see deep sky objects more easily by *not looking directly at them*. The most sensitive part of your retina – the part of your eye that detects light – is not where you look straight ahead, but off to the side a little. When you look at a deep sky object, you should let your vision wander around the eyepiece. As you do this, the object will suddenly appear a bit brighter and with more detail. When you try to look directly at it, that detail will disappear. This technique is called *averted vision*, and it definitely takes some getting used to. Thus, again, you will need patience. If you are using the telescope that was assigned to your group, you will again need to move it to keep up with Earth's rotation. It is a fair bit to coordinate, so take your time and get some practice to get a feel for how it all works together.

The most common deep sky objects to observe from an urban setting are star clusters. Although the background light of the sky will make them dimmer, they are still relatively easy to see. The fact that the light comes from a set of distinct points helps. Nebulae are harder to see. They will look like a faint cloud, and averted vision is necessary to see details in them. The most difficult deep sky objects to observe are galaxies. As of 2024, the light pollution near campus is so bad that it is probably not worth trying to find galaxies with the 8-inch telescopes. You may be able to see some of the brighter ones with the 14-inch telescope in the observatory.

Below is a sketch of the spiral galaxy M94. As always, the observation lists the ***DATE, TIME, and LOCATION*****.**

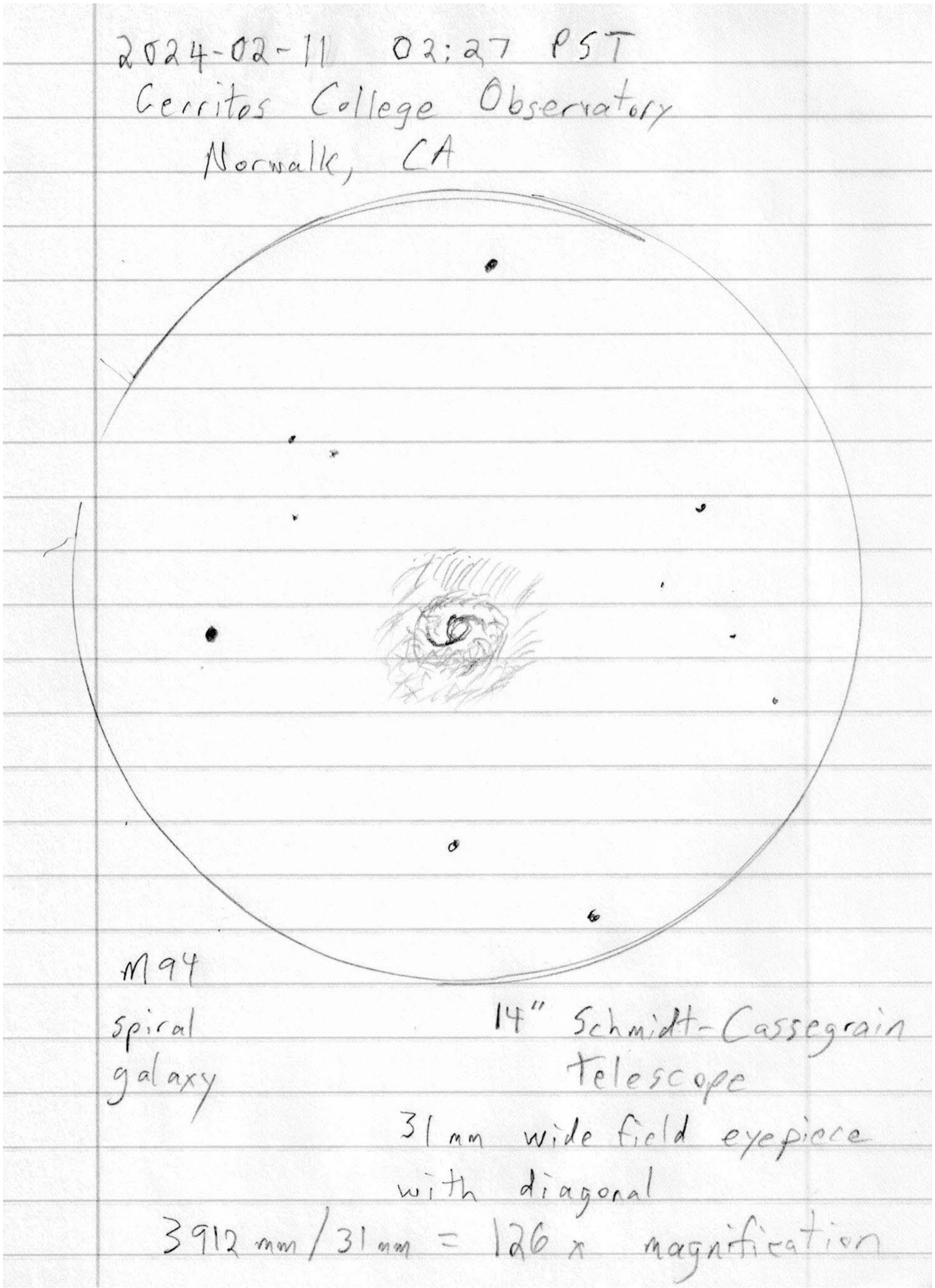


Figure 14 - example of a sky journal sketch of a deep sky object

Systems for Locating Objects on the Sky

When you look at a globe representing the Earth or at a map, note that there is usually a grid of lines printed on it. Most maps are oriented with the north cardinal direction at the top, and most globes are oriented so the north pole of Earth's axis points upward. The grid represents the lines of *longitude* and *latitude*. Longitude is the coordinate to specify how far east or west a location is, and latitude gives a position north or south. They are listed with a certain number of degrees. Questions that should come to mind when you see coordinates like this should include "what am I comparing positions relative to?" and "where is the zero degree mark?"

Latitude measurements on Earth are based on its rotation. The latitude angles don't change with rotation, but when an object spins about an axis, you can show where its north and south poles are. This allows you to determine the location of the *equator*. If you could be placed in the center of the globe of the Earth, you could imagine pointing to its equator and then pointing directly north or south to some location away from the equator. The angle formed by your arms when you do this is the *latitude* of the location. It is the angle between the equator and that location in a north-south direction. You can create this system of latitudes for any rotating object. On a map, lines of constant latitude run left and right across the page when north is at the top. On a globe, the circles that represent constant latitude are parallel to the equator. The equator is defined as having a latitude of zero degrees. The north pole is at 90 degrees north and the south pole is at 90 degrees south.

There is no convenient way to do this for longitude. If you could hover in space above the Earth as it turned about its axis below, you would not see any particular location that indicates where you should measure longitude relative to. There has to be a consensus about a place that will mark zero degrees latitude. The line that runs from the north pole to the south pole through this location with zero degrees longitude is called the *prime meridian*. On Earth, the prime meridian is defined as running through the Royal Observatory in Greenwich, England in the United Kingdom. Lines of constant longitude run north to south on a map, or they make arcs that are part of a great circle going from the north pole to the south pole on a globe.

The observatory on the roof of the MCIS Building on Cerritos College campus is at longitude 118° 5' 51.3" west and latitude 33° 53' 5.9" north. You should record this somewhere in your sky journal, if you make observations from the observatory deck.

Smaller Angles

What are the 5' 51.3" listed with the longitude and the 53' 5.9" listed with the latitude above? In this class, we will typically measure angles with degrees. However, sometimes we need higher precision than that. An angle measurement of one degree can be divided into 60 equal parts called *minutes of arc* or *arcminutes*. There are 60 arcminutes in one degree. Similarly, an arcminute can be divided into 60 equal parts known as *seconds of arc* or *arcseconds*. There are 60 arcseconds in an arcminute, or there are 60 x 60 = 3600 arcseconds in one degree. We would read the longitude and latitude of the observatory as "118 degrees, 5 arcminutes, and

51.3 arcseconds west, and 33 degrees, 53 arcminutes, and 5.9 arcseconds north”. West and north can be abbreviated as W and N, respectively, when you write longitude and latitude.

Horizon Coordinates

In any coordinate system that we use, we need at least two numbers to specify a position. Horizon coordinates indicate where something is on the sky based on your local horizon. Since your local horizon is determined by your location on Earth, along with the date and the time, horizon coordinates also depend on these factors. We already encountered one horizon coordinate - *altitude*. If you measure the angle from the horizon directly up to an object, that gives its altitude.

Earlier, we saw a loose definition of the horizon as the apparent boundary between the land and the sky, or of the sea and the sky. If you have mountains or other uneven features located on the horizon, how do you know where it really is? A precise definition of the horizon is the great circle on the celestial sphere defined by the set of points that are 90 degrees away from the zenith.

While altitude tells us how high in the sky an object is, *azimuth* tells us where to point along the horizon so that we are directly below the object. There are a few different conventions for how azimuth is specified. If you are using new astronomy software or reading a chart where the convention is not clear, see if you can find how north and east are labeled. The system we will use in this course will have the north cardinal direction at 0° with angles increasing as you head to the *right* of north. That would make east equal to 90°, south equal to 180°, and west equal to 270°. This is the most common convention, but you cannot assume that it is the one that is always used. Look for other information that lets you confirm the convention.

To summarize, any position on a sphere can be specified by two angle measurements. On the sky, you can use *azimuth* for the angle around the horizon and *altitude* for the angle above the horizon. One thing to be aware of: because of the Earth’s rotation about its axis, the azimuth and altitude of any object on the sky is continually changing. Earth’s motion around the Sun also causes some change. ***The azimuth and altitude of an object are entirely dependent on the date, time, and your viewing location on Earth.***

Celestial Coordinates - Equatorial System

The idea of coordinates changing continually may make them seem less useful. Can we come up with a system where stars are “fixed” on the sky? On Earth’s surface, we use longitude and latitude for specifying coordinates and positions. Can we construct something similar for the sky?

Yes, but the system is no longer called longitude and latitude. Some terms will look familiar. On Earth, the equator has a latitude of 0°. The north pole is at 90° N and the south pole is at 90° south. What if we stretch these features away from the Earth so that they “touch the sky”? Going back to the ideas about the cosmos from Ancient Greece, most philosophers at the time

believed that Earth was within a *celestial sphere*. Since all the stars moved together across the sky throughout each night, it seemed as if they were painted on the inside of a transparent sphere of immense size. As the sphere rotated, it caused the stars to rise and set.
This view of the cosmos is not at all correct; however, it is useful for specifying a coordinate system. Above Earth's equator, we find the *celestial equator* on the sky. The Earth's north pole points to the *north celestial pole*, and our planet's south pole points toward the *south celestial pole*. On the celestial sphere, we use *right ascension* (RA) to measure angles to the east and west and *declination* (DEC) to measure angles north and south.

Declination is a bit easier to describe, so we'll start with it. The celestial equator has a declination of 0°. The north celestial pole has a declination of +90°, and the south celestial pole has a declination of -90°. We use "+" and "-" instead of north and south, but otherwise, it follows the same convention as latitude.

To discuss right ascension, we need to introduce a feature that is unique to the celestial sphere. Unlike a globe of the Earth, the celestial sphere has another curve that arcs across the sky: the *ecliptic*. The Earth's axis of rotation is tilted relative to its orbit around the Sun (from our point of view, it's the orbit that is tilted). It is along this line in the sky that you find the Sun (by definition). The Moon and planets are also always found near this line. When the Moon crosses in front of the Sun you get an eclipse, hence, the name ecliptic. The plane of the ecliptic is determined by the path the Earth takes around the sun -- the Earth's orbit. Anything along that plane in space appears to lie on the line of the ecliptic on the sky. The constellations that lie near the ecliptic make up the *zodiac*. Which zodiac constellations do you need to be able to identify this semester?

As you trace the path of the ecliptic around the sky, there is a point where the center of the disk of the Sun crosses the celestial equator moving from south to north. This is called the *first point of Aries*. It no longer appears within the boundary of the constellation Aries. The moment this happens is the time of the *vernal equinox* for that year. This is an important point to remember: while we associate equinoxes and solstices with times of the year, they are also associated with a particular location on the sky. The right ascension of the first point of Aries is defined as 0h 0m 0s (zero hours, zero minutes, zero seconds). Right ascension then increases eastward across the sky, with 24 hours to cover the entire 360°. The beginning of spring in the Northern Hemisphere occurs when the Sun has a right ascension of exactly 0h. The autumnal equinox occurs when the Sun has a right ascension of exactly 12h.

There is another effect to consider in thinking about how right ascension and declination are measured. As the Earth rotates around its axis and revolves around the Sun, the direction that its north pole points in space slowly wobbles. For now, the Earth's north pole nearly points to the star Polaris (in the constellation Ursa Minor). Over hundreds and thousands of years, this will change. If for some reason you are still using this manual in the year 13,640 C.E., Vega will be much closer to the location of the north celestial pole than any other bright star. This means that the right ascension and declination of stars change over time. This wobble of the Earth's poles is called *precession* or *precession of the equinoxes*. One complete cycle takes about

26,000 years. If you are still (incredulously) using this manual in 27,100 C.E., Polaris will again be the North Star.

Because of precession, it is also necessary to specify the *epoch* used for right ascension and declination. You will often see "*J2000.0*" appear with a set of coordinates. That means that we are using positions as they would have been in the year 2000 C.E. Another way to see this is to check if coordinates specify an epoch (like J2000.0) or they state "of date". If they are indicated as "of date", this means the coordinates were adjusted for precession for that particular date. Any time you are using a set of coordinates to aim a telescope or record an object for scientific purposes, you should make it clear which convention you are using. Generally, we will not need this level of precision for this course, but there are more advanced astronomical observations where it becomes quite important.

Other Celestial Coordinate Systems

For measuring positions within the solar system, or for solar system objects, you may see the *ecliptic coordinate system* used. This system uses *ecliptic longitude* and *ecliptic latitude*. While precession affects the ecliptic longitude of an otherwise "fixed" star, the ecliptic latitude does not change due to precession. This coordinate system is aligned to the plane of the solar system.

There are two other coordinate systems that you may see while using Stellarium – the *galactic coordinate system* and the *supergalactic coordinate system*. The galactic coordinate system is based on how our galaxy, the Milky Way, appears from Earth. It wraps around the sky at a different angle than both the celestial equator and the ecliptic. The point of zero galactic longitude and latitude is toward the direction of the center of the galaxy in the constellation Sagittarius. The galactic north pole is in a direction that allows astronomers to look deep into space, in the constellation Coma Berenices.

Based on the arrangement of galaxies out to distances of about 50 million light years making a flat plane in space, the supergalactic coordinate system is based on the orientation of that plane.

Astronomical Data

Before we discuss astronomical data, I want you to think more generally about information and how information is structured so that we can pass it from one person to another. As an example, let's consider the following question:

How do we know what words mean?

I don't just mean looking up the definition of a word in a dictionary. A word could be used one way in a story, a different way in a news report, yet another different way in a joke. A word may have no meaning to us, even after reading the definition. There needs to be some context -- some other information around the word to give it meaning.

How do we know what information is in a picture? Or in a sound?

Maybe it's something we've seen or heard before. What if you were just given the ability to see? How do you make sense of all the new information that comes at you? What if you've never heard a sound before? Suddenly, there's this huge input of different noises, and you have no context for what is happy or what is a warning or what is just background noise.

Part of what gives information meaning is context.

If you are conducting scientific research, you take notes on every step that you do. It gives you a way to help recover the meaning of your results once you are finished with the experiment. You know what to do if you try to repeat the experiment, and you can also know if you do something different.

We don't really have a laboratory in astronomy. I know that sounds strange as you are currently enrolled in an astronomy lab course. The difference is that in chemistry, physics, and biology, you can control some portions of the experiment directly, then measure what the outcome is. In astronomy, we take in light that comes from space and try to interpret it. What can we possibly control about things in space from here on Earth's surface?

One thing we might have control over is the size of the telescope that we use. Or, we might have a choice of cameras to attach to the telescope to record images. There might be different color filters for allowing some light through and blocking other types of light. Are we getting a wide view that takes in much of a constellation, or are we focused on just one star and its surroundings? Maybe we want to look at the entire disk of the Moon, or maybe we want to focus on just one crater.

Any observation we make needs to have the context of the observation provided with the observation itself. Someone might take a gorgeous picture of part of the sky or make a very detailed sketch of the bands of clouds in Jupiter's atmosphere. They need to provide context for anyone who looks at those images so that they can be interpreted for what is in the photo or sketch. Anyone might have an opinion about whether a picture or sketch looks pleasing, but does that convey the meaning that the person who took that photo or drew that sketch intended?

Professional astronomy is now done entirely through digital files. These files are created by sending light through a lens or telescope to a camera that has an electronic sensor. The sensor is similar to the one in the camera on a cell phone. As light hits the sensor, it gets recorded as data. For the data in these files to be useful to someone else, there needs to be information about how it was produced.

Data Calibration

It may seem that astronomers sometimes take pictures of nothing. There are plenty of images available showing beautiful galaxies and nebulae, but to get those, a photographer has to understand how their telescope, camera, and filters are working together. You may see an astronomer cover the opening to the telescope or put a white panel over the opening. They are taking the images needed for preprocessing their data. Preprocessing data removes noise and artifacts so that what remains is astronomical data. The three types of files used for preprocessing are *bias frames*, *dark frames*, and *flat frames*.

Bias frames are needed because all modern astronomical cameras are electronic devices. There is a sensor that takes in the light, and merely running an electric current through the sensor causes the pixels to brighten a bit. These extra detections of light need to be removed from any data we want to use. To take bias frames, set the camera to its fastest possible exposure, cover the aperture of the camera, and take a few images. No light can enter the camera from the outside, so these would show up in an image even if you were not shooting anything, so they should be subtracted from a final image.

Star clusters, nebulae, and galaxies are generally very faint. Sometimes, you want to record exceptionally faint stars. To take images of these objects, the camera shutter needs to be left open for seconds or even minutes as you try to collect enough light to make a photograph. While you are doing this, the CCD or CMOS sensor is "on". If any of the pixels are bad, they will light up even without having light shining on them. You will also need to deal with cosmic rays and other high energy radiation affecting your images. To take dark frames, you cover the aperture, but now you make the exposure for the same amount of time as you used for the exposure of your regular images.

If all of your optical elements had perfectly clear glass that did not warp incoming light at all, these would not be necessary. But there is no way to get rid of every speck of dust, or maybe there's some residue from the last glass cleaner you used on a filter. With flat frames, you can remove the effects of these imperfections. You will need the setup to be the same as when you are taking pictures, including the focus being in the same place. For the Cerritos College observatory, we use an LED light panel to illuminate the camera. Another possibility is to use a clean, lint-free white T-shirt to cover the opening to the telescope. After it is covered and there is still some light in the sky (or as the sky is brightening in the morning), take images of the brightening sky through the t-shirt. Because you should still be focused at infinity, this should imprint a record of any abnormalities in your optics. You can then use these frames to remove those abnormalities. You need to make the exposures long enough that the pixels on the camera sensor only take in about one-third to one-half of their maximum amount of light while you shoot these frames, so pay close attention to the exposure length.

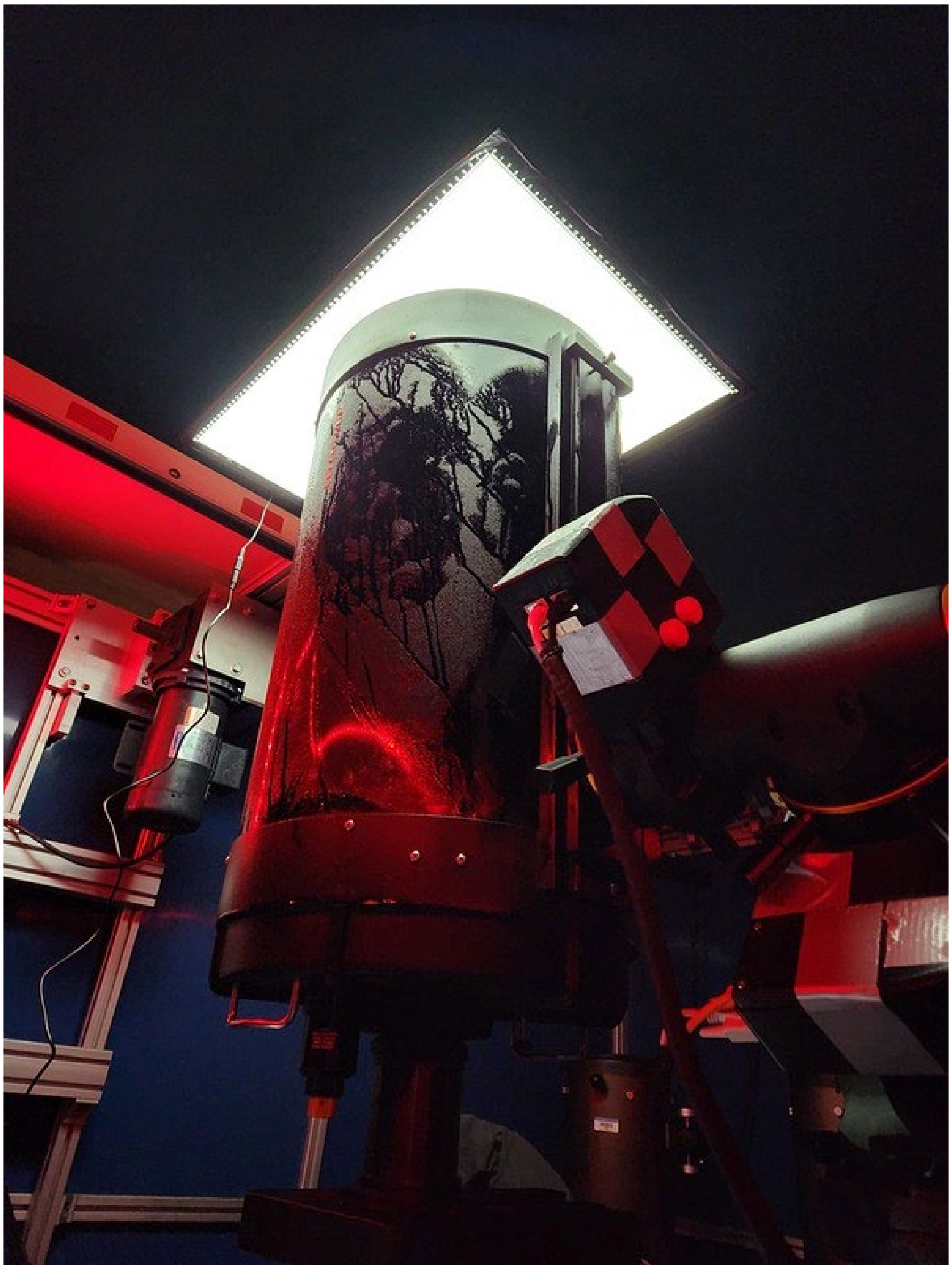


Figure 15 - This is the setup for taking flat frames with the 14" telescope on campus.

Astrometry

By now, you have probably heard the terms astronomy and astrophysics. Astronomy involves understanding the principles that cause objects to move across the night sky or through space. Astrophysics is more focused on the principles of how things in space have the properties they do -- what are they made of, or how much energy do they produce, for examples. What is *astrometry*?

The change to the ending of the word may provide a clue. Since it ends in -metry, maybe it has something to do with meters or a measurement? This is the correct line of thinking. Astrometry involves the precise measurement of positions and movements of objects on the sky. This would have been accomplished with a star atlas in the past, but now the processing all takes place electronically. There needs to be information about how the image was taken, as well as a way to compare it with known regions of the sky.

Registering Astronomical Images

After an image has been preprocessed, software is used to determine what area of the sky the image represents. This process associates a right ascension and declination with each pixel in the image. The most common tool for doing this is found at nova.astrometry.net. This website will check the pattern of stars in your image against the whole sky to find a match.

When you click the link at the top for the Upload option, you can provide an image in JPEG, GIF, PNG, or FITS format. When astrometry.net solves the image, it writes the data to a new FITS image that includes the right ascension (RA) and declination (DEC) of the center of the image.

Here is an example of what the output from astrometry.net looks like:

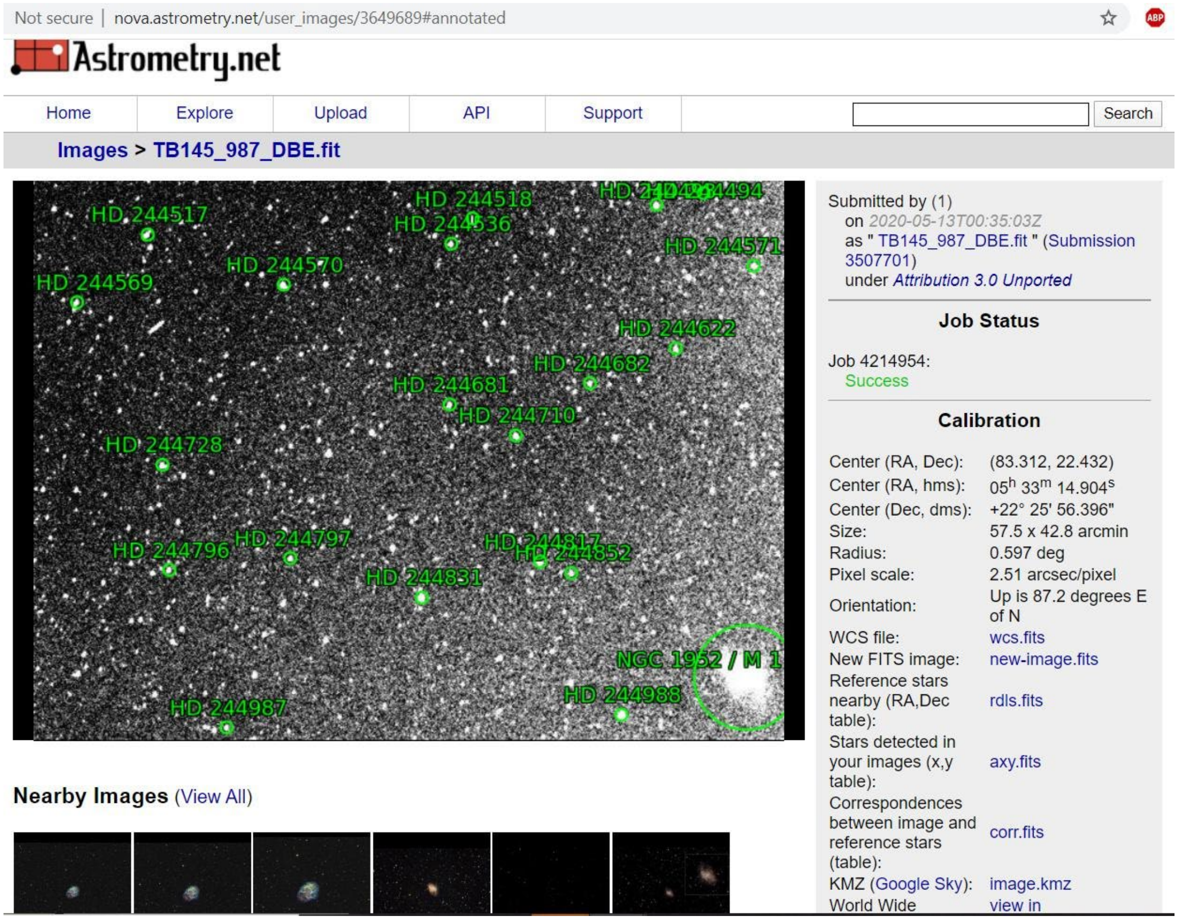


Figure 16 - Example of a solved image from astrometry.net

The image with the new FITS headers attached can be downloaded from the new-image.fits link. This will also include the orientation of the image (which way is north and which way east) and what the scale of the image is, usually in arcseconds per pixel.

The output shown here also includes catalog numbers for bright stars, as well as any labels of deep sky objects that are included. The example above has the Crab Nebula in Taurus, shown as M1 or NGC 1952. There are also many stars from the Henry Draper (HD) catalog. Knowing the catalog number of these stars allows us to look up their magnitude for comparing to an object of interest.

Instructions for Using JS9

To examine FITS files and make measurements from image data, you need software that pairs the data in the FITS header with the geometry of the image. There is software that you can download to do this called SAOImageDS9. For lab activities, we can use a version that runs in a browser as JavaScript called JS9. You can access JS9 online. When you first arrive at the site, it will look like this:

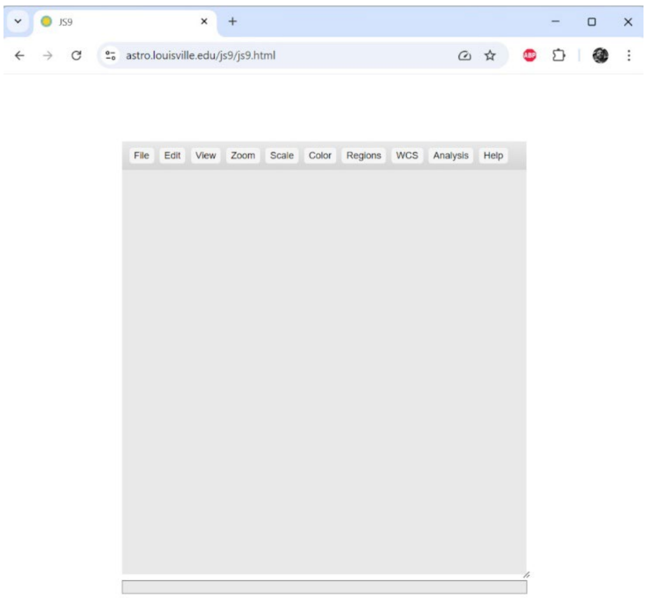


Figure 17 - Opening screen for JS9 web application

We want to examine FITS files within JS9. In the app that loads into your browser, click “File”. Highlight “open …” and choose “local file …”

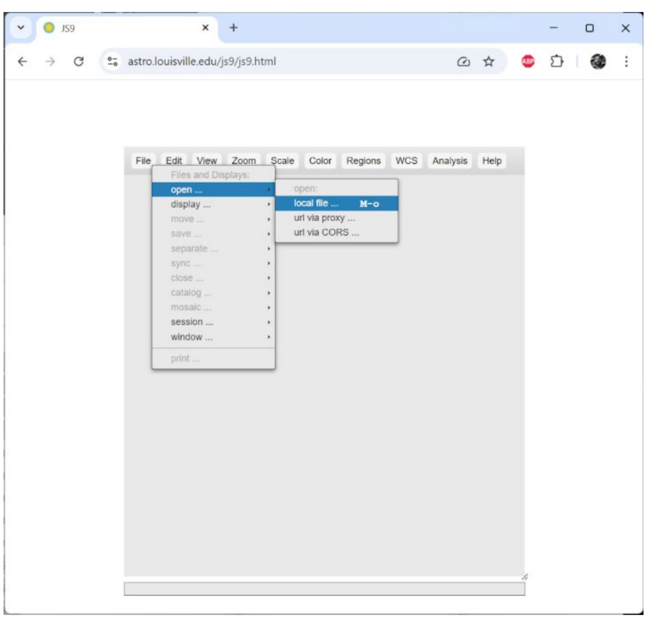


Figure 18 - Selecting a file from your computer to open in JS9

On the selection window that appears, you will need to change the dialog box in the lower right so that it says “All Files” instead of “Custom Files”. Pick the FITS file whose contents you want to read.

To check out the FITS header, click “File”. Highlight “display … “ then “FITS header”. This will open a separate window with the FITS header for that file.

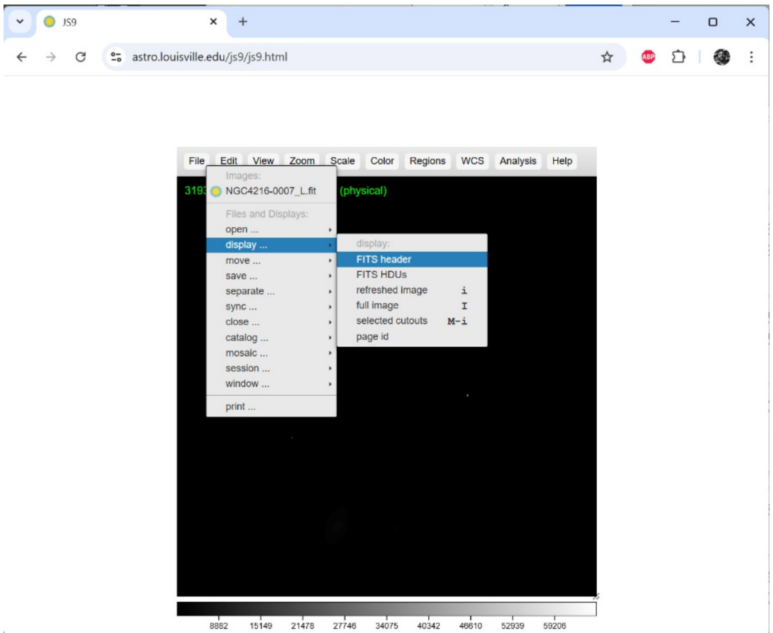


Figure 19 - Examining a FITS header in JS9

Note that as you move the cursor around the image, the position of the cursor on the image is shown in green above the image. The first number indicates how many pixels the cursor is from the left of the image, which is its x-position. The second number tells you how many pixels the cursor is from the top of the image, which is its y-position. If an image has an astrometric solution, you will see a second pair of numbers which show the right ascension and declination of the cursor position.

See the instructions for your particular lab activity to see what you need from JS9.

Photometry

While astrometry is the measure of the position of objects in an image, photometry is the measurement of how much light arrives from an image. JS9 will be the tool you use for photometry as well. To give a thorough discussion of how photometry is done, we need to understand light as well as how the sensor on a camera works. We will revisit how to do photometry as an advanced activity.

Light

Light is one of the strangest phenomena we deal with in everyday life. What is light? It's hard to answer that exactly, as light displays many different behaviors, some of which seem to contradict each other. Let's start with two properties that are fairly straightforward.

First, light can move through empty space. Sound needs air (or liquid or solid) to move through. Water at the beach can come at us in waves. The energy of earthquakes is carried through the layers of the Earth. The energy of light can move with no material to carry it. If there is no material around - no solid, liquid, gas, or plasma - we say that region of space is a vacuum. Don't think of a vacuum cleaner. Imagine a box. Now, take everything out of the box, including the molecules of air. Everything! What is left is a vacuum. When it is said that "light can travel through a vacuum," this is what is meant. Even if there is no matter present, light can still carry energy from one place to another.

The next property of light is that when light travels through a vacuum, it always goes the same speed. The speed of light is the fastest that anything in our universe can travel from one point to another. The exact speed of light has been set as 299,792,458 m/s - scientists base the length of the meter and the amount of time in one second on the speed of light, not the other way around. You don't have to remember that long number - 300,000 kilometers per second works fine. That's seven and a half times around the Earth in one second!

Is Light a Wave or a Particle?

Sometimes, light behaves like a wave. The key properties we are interested in are:

crests and troughs - the high points and low points on a wave
wavelength, λ - the distance between two consecutive crests (or troughs)
frequency, f - how many waves pass a given point each second?
Wave properties - amplitude, wavelength, and frequency

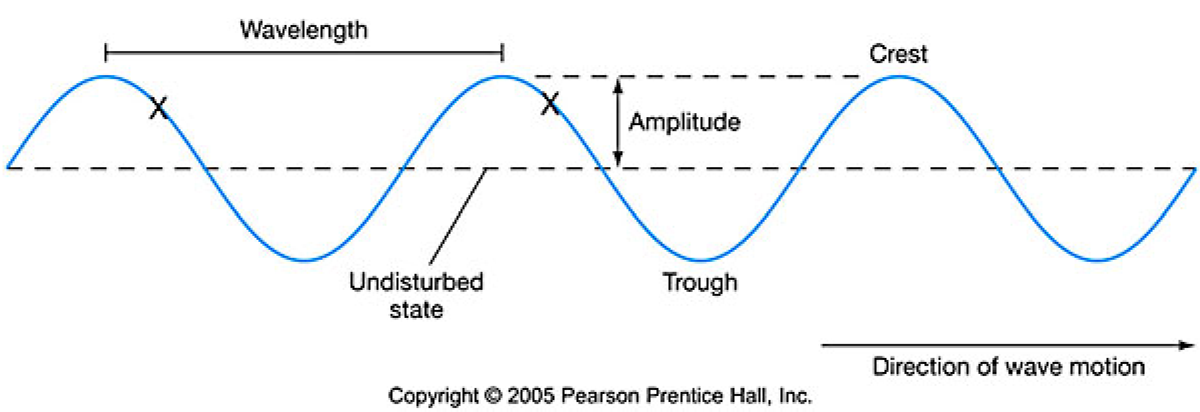


Figure 20 - How to picture the wavelength and amplitude of a transverse wave

What is the wave involved with light? It's called an electromagnetic wave.

The main relationship you will need to remember for waves is that:

wavelength x frequency = speed

You may also see this equation written as:

$$\lambda f = v$$

where λ (pronounced “lambda”) is the variable for wavelength, f is for frequency, and v is for the speed (or magnitude of the *velocity*).

Since light always travels the same speed through a vacuum, this means that light with longer wavelengths will have a lower frequency, and light with shorter wavelengths will have a higher frequency. There is a spreadsheet that goes with this lab that will help you make any calculations related to this equation.

Another variable that you might see related to light is *c*. Physicists and astronomers use c to represent the speed of light in a vacuum. It’s a fairly easy number to remember. If you measure it in kilometers per second, it’s a 3 followed by 5 zeroes: 300,000 km/s or 3×10^5 km/s. If you could get from one side of campus near Studebaker Blvd. over to the stadium in one second, you would be going one kilometer per second (1 km/s). To do this, you would have to go about 2200 mi/hr. Light is 300,000 times faster than that! At the speed of light, you could go from Los Angeles to New York City in under two-hundredths (0.02) of a second. You could get to the Moon in a little over a second, or to the Sun in about 500 seconds (a bit more than 8 minutes). This c for the speed of light also shows up in Einstein’s equation, $E = mc^2$. For light traveling in a vacuum, you may also see the equation relating wavelength and frequency as:

$$\lambda f = c$$

The light we can see covers a very small set of wavelengths, and they are most often measured in billionths (10^{-9}) of a meter, also known as nanometers. A nanometer (abbreviated as "nm") is quite tiny. The smallest details you can see with your eyes are slightly less than a millimeter (mm) in size. A nanometer is a million times smaller than that; it would take millions of nanometers to make an object that is visible to you. Violet light has the shortest wavelengths at 400 nm, and red light has the longest wavelengths - as long as 700 nm.

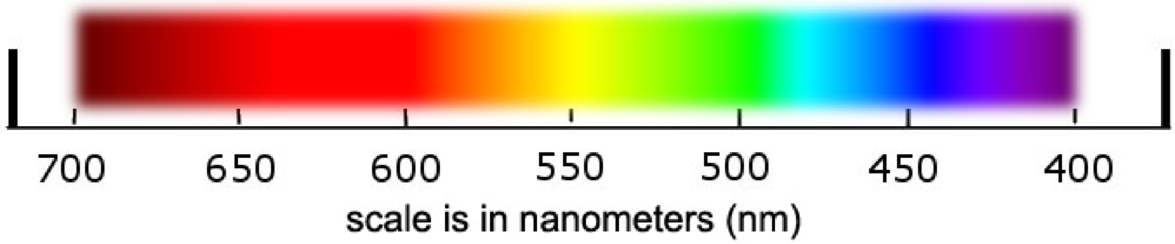


Figure 21 - Continuous spectrum showing wavelength measurements of red, orange, yellow, green, blue, and violet light; colors may not be 100% accurate for their wavelength.

There are electromagnetic waves that are much shorter than violet light -- ultraviolet light, X-rays, and gamma rays. There is also light with much longer wavelengths than red light -- infrared, microwaves, and radio waves.

Other times, light behaves like a particle. We call a particle of light a photon. Each photon of visible light carries a very tiny amount of energy; however, it is enough energy to get the electrons in an atom to jump from one level to another. We will discuss this more in the spectroscopy lab that comes later in the course.

To get the energy of a photon, we use this relationship:

energy of a photon = Planck's constant x frequency

or $E = hf$.

Planck's constant (h) is a miniscule number: 0.000000000000000000000000000000000663 J·s. A much shorter way of writing this is 6.63×10^{-34} J·s. (J·s stands for "joules times seconds.") Think of the energy of photons like the pounding of a hammer to drive a stake into the ground. Red visible light is like a small hammer - you have to hit many times to deliver enough energy to push the stake into the ground. Blue visible light photons pack more of a punch; you don't need as many hits to deliver the same amount of energy. Ultraviolet light photons would be like a sledgehammer - one good hit and that's enough energy to put the stake all the way in. Infrared light would be like tapping on the stake with your fingertips. No amount of taps will get the stake to move.

There is another unit of energy that is better for describing photons of visible light. It is called an eV, for electron volt. Look at the scale below to see how a photon with a given energy in eV matches up with a wavelength in nm:

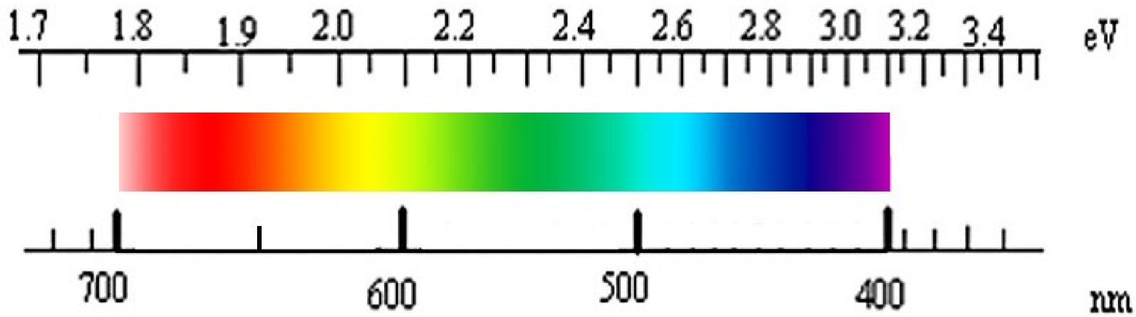


Figure 22 - Visible light spectrum with scales indicating both the photon energy in eV and wavelength in nm; the colors depicted are closer to their actual wavelength in this figure.

The longest wavelength visible light -- red light at 700 nm -- consists of photons that pack about 1.7 eV of punch. The shortest wavelength visible light -- violet light at 400 nm -- is made up of photons that are a bit more than 3 eV in how much energy they pack. A photon from violet light has 75% more energy than a photon from red light. Visible light photons will pack as little energy as 1.7 eV (red), and as much as 3.1 eV (violet).

Temperature Scales

If we want to talk about the photons that an object emits, we have to know its temperature. In particular, if we see all the colors of a spectrum and they change smoothly from one color to the next, we call it a continuous spectrum. You can see an example in the spectrum above that goes with the scale from 700 nm to 400 nm. What temperature should we use for this discussion? The best choice would be a scale where zero temperature means zero energy. Our usual temperature scales don't work this way: although 0°F (Fahrenheit) or 0°C (Celsius) are cold for most people (0°F is significantly colder), but it does not mean there is zero thermal energy present at these temperatures. Let's take the following description as an example. We'll start with steam at a temperature of 300°F. That's the same as 149°C. If we cool this steam down to 212°F (which is 100°C), the steam can begin to condense into liquid water. As we take away more thermal energy, more liquid water forms, and then its temperature will fall. Once the temperature reaches 32°F (or 0°C), the liquid water can turn to ice. At the freezing point, the water is turning into a solid, but it does not mean the water molecules stop vibrating. Zero thermal energy means no extra energy for vibrating molecules or any additional motion. What happens as we try to achieve such low temperatures?

The air you breathe is mostly nitrogen with some oxygen and small traces of other gases. You have likely only experienced air in the form of a gas. I have been to an ice cream shop nearby where they use liquid nitrogen to make your ice cream right in front of you. How cold does nitrogen have to be to turn from a gas into a liquid? It happens around -320°F, which is -196°C. This liquid nitrogen can still flow and slosh around, so it still has thermal energy. If we want nitrogen to turn solid, we have to cool it to -346°F, or -210°C. (Don't worry - you don't have to remember all these temperatures. You only need to be aware of how much colder objects can get.) Even solid nitrogen can still have vibrating molecules. To take away all thermal energy, we have to get much colder still. There is a lowest temperature to which we can cool an object; all thermal energy is gone at -460°F or -273°C. This temperature is known as absolute zero.

To put all this information together:

- Water boils at 212°F or 100°C or 373 K
- Water freezes at 32°F or 0°C or 273 K
- Nitrogen boils at -320°F or -196°C or 77 K
- Nitrogen freezes at -346°F or -210°C or 63 K
- Absolute zero is -460°F or -273°C or 0 K

Wait - what's this new temperature scale on the right? This is known as the Kelvin scale. It is very useful in astronomy and physics because absolute zero is zero Kelvin. At this temperature, there is zero thermal energy.

Continuous Spectra

Wien’s Law

At absolute zero, an object cannot emit any light. As an object heats up, it will emit higher energy photons. Higher energy photons mean higher frequencies, which also mean shorter wavelengths. An object at a specific temperature will be most likely to emit photons at a specific wavelength called a peak wavelength. Some higher energy/shorter wavelength photons will be emitted; many more lower energy/longer wavelength photons will be emitted. The "X" marks in the diagram below show the peak wavelength for stars of the temperatures listed.

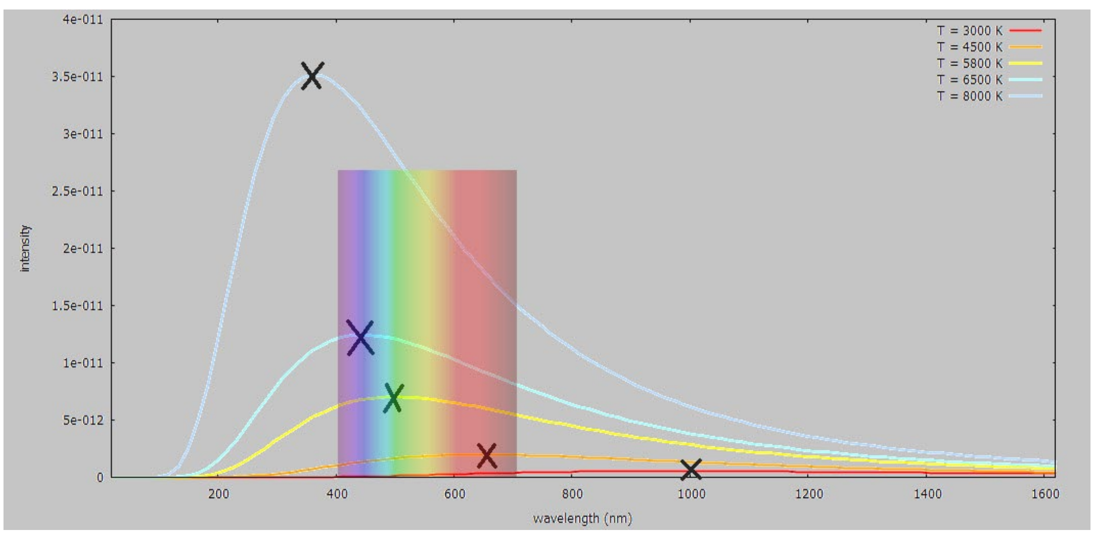


Figure 23 - Peak wavelengths for stars of different surface temperatures are indicated by the position of the 'x's; note how this peak wavelength is shorter for hotter stars

To get the peak wavelength, we use Wien's Law (pronounced *Veen's Law*). This law states that

peak wavelength (in nm) = 2898000 nm·K/temperature (in K)

We will use a spreadsheet to determine the peak wavelength of stars of different temperatures. To see how wavelength, photon energy, and temperature of an object determine which type of light will be produced, see the diagram below.

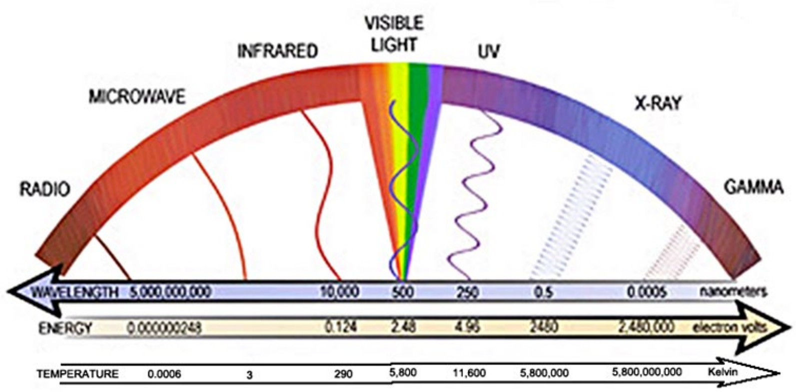


Figure 24 - Names for the ranges of electromagnetic waves (by wavelength in nanometers) or photons (in energy in eV). There is also a scale showing the light that peaks at certain temperatures.

Stefan-Boltzmann Law

The last relationship we need to discuss is how bright an object is, or how much power an object that is at a specified temperature will produce. Imagine that we have a metal ball that is currently sitting at room temperature. On the Kelvin scale, room temperature is about 295 K (72°F). What if we make it twice as hot? Twice as hot does not mean 72 x 2 = 144 degrees Fahrenheit; it means 295 x 2 = 590 K. (Remember: the Kelvin scale is directly related to how much thermal energy an object has.) 590 K is about 600°F -- much hotter than the oven in your house usually gets.

First, what happens to the peak wavelength as the temperature increases? Does it get longer or shorter? (Remember that we are now dividing by a bigger number in Wien's Law.)

What about how intensely the metal ball will glow? The Stefan-Boltzmann Law will tell us the power produced by the ball at a given temperature. This tells us the intensity of the light. The Stefan-Boltzmann Law states that

power emitted is related to the temperature (in K) to the fourth power

You don't multiply by the temperature to get the power; you multiply by the temperature times the temperature times the temperature times the temperature ($T \cdot T \cdot T \cdot T = T^4$). If we double the temperature (in K) of our metal ball, the intensity of the light doesn't double -- it goes up $2^4 = 16$

times! If the Kelvin temperature goes up 10 times, the object glows 10^4 = 10,000 times brighter. The most massive stars have surface temperatures that are 10 times hotter (on the Kelvin scale) than the coolest stars. If the stars are the same size, the hotter star will glow 10,000 times brighter. In the diagram below, the area that is shaded represents the power emitted by a patch of the surface of a star with the listed temperature. Look at how much more area is shaded light blue compared to what is shaded orange. This gives an idea of the power each portion of the surface of a hot, blue star compared to a cool, red star.

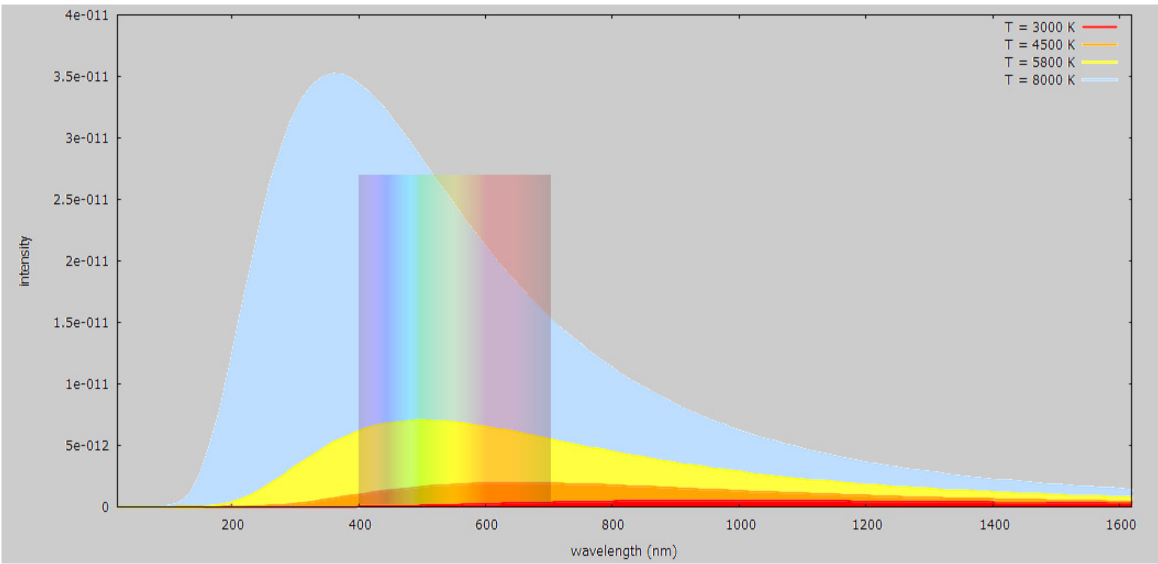


Figure 25 - The total area under each different color plot shows the total power output per square meter of a star with that surface temperature; hotter stars have a much higher power output per unit of surface area compared to cooler stars.

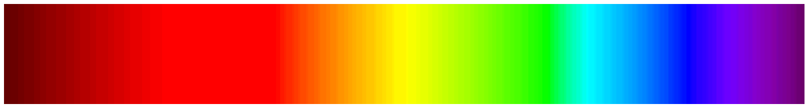
Kirchoff’s Laws

Spectroscopy was advanced by two chemists in the mid-1800s: Robert Bunsen and Gustav Kirchhoff. They - primarily Kirchoff - discovered that heated objects give off light in three very distinct ways:

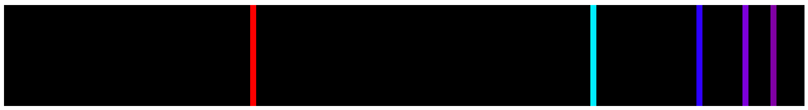
- If the object is hot and dense, like the core of a star or the filament of a lightbulb, the spectrum is continuous.
- If the object is hot and rarified (or sparse or low density), like a gas, the spectrum is discrete. This is also known as an emission spectrum.
- If the object is cool and rarefied, it doesn't emit light: it absorbs discrete spectra. This is called an absorption spectrum.

(The missing alternative, cool and dense, doesn't allow light to pass through it, so we can't observe a spectrum.)

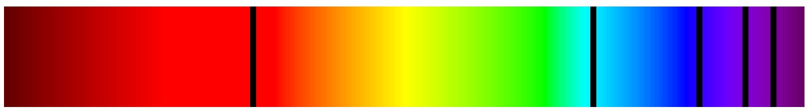
The spectrum of an element is a luminous fingerprint, unique to that element. It takes the form of many-hued light. Continuous spectra are like a rainbow:



A discrete spectrum, also known as an emission spectrum, are like a series of bright lines against a black background:



Absorption spectra are like a rainbow with thin black lines in it:



Emission (or Discrete) Spectra

How can this be a fingerprint? Because of the process involved in making the spectrum. Take, for example, emission spectra. An atom of hydrogen has a single electron orbiting the nucleus of a single proton, making this the simplest example. The electron, because of something called quantum mechanics, can only exist in certain, specific energy levels within the atom. This is because the electron behaves like a wave instead of a particle when it is in the atom. As we saw in the light lab, waves can have constructive or destructive interference. The allowed levels for the electron correspond to where it has constructive interference. Destructive interference would mean the electron ceases to exist, and that is not allowed. Neils Bohr is a Danish physicist who first discussed the hydrogen atom this way. In the Bohr model of the atom, the energy levels are denoted with the letter n where n = 1, 2, 3, 4.... The level n = 1 is the lowest state, called the ground state. Most of the time the electron is in the ground state, but if a certain amount - and just the right amount - of energy impinges on the atom, the electron can jump to a higher level.

What it shows is that the electron can jump from n = 1 to n = 2, 3, 4, 5, 6 or beyond. It then orbits from a short time farther away from the proton than usual. But eventually it drops back down. In order to do this it gives up the energy it absorbed in the form of a quantity of light called a photon. The bigger the drop, the more energy is released, and the shorter the wavelength of the photon. In visible light, long wavelengths are red and short wavelengths are violet. Red light has lower energy photons than violet. You can think of this as red photons not having as strong of a punch as violet photons do.

But wait, there's more! See how sometimes the temporary "landing zone" is not n = 1? The temporary landing zone denotes a series. When you do the calculations, if n = 1 as an endpoint, the energy changes make photons with too much energy to see -- the photons are in the ultraviolet part of the electromagnetic spectrum. If the landing zone if n = 3, 4, 5... the energy changes make photons with too little energy to see -- these photons are infrared photons. So all we can see is when the landing zone if n = 2. This is called the Balmer Series.

So, each jump down to n = 2 generates a color of light unique to hydrogen. Voilà! A fingerprint. Sodium has its own energy levels, helium its own, etc. We can identify a substance at a distance by the colors of light it emits.

The following diagrams were created using the ophysics site. If it is still available, you should use it to try simulating different energy transitions within the hydrogen atom.

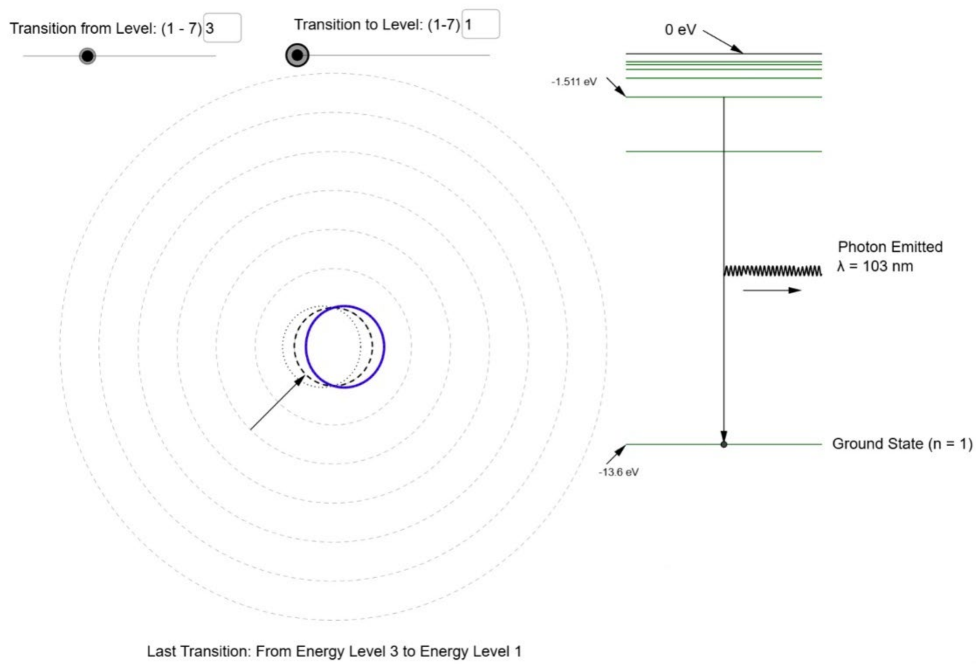


Figure 26 - When an electron moves from the n=3 energy level in a hydrogen atom to the n=1 energy level, an ultraviolet photon with the corresponding amount of energy is created.

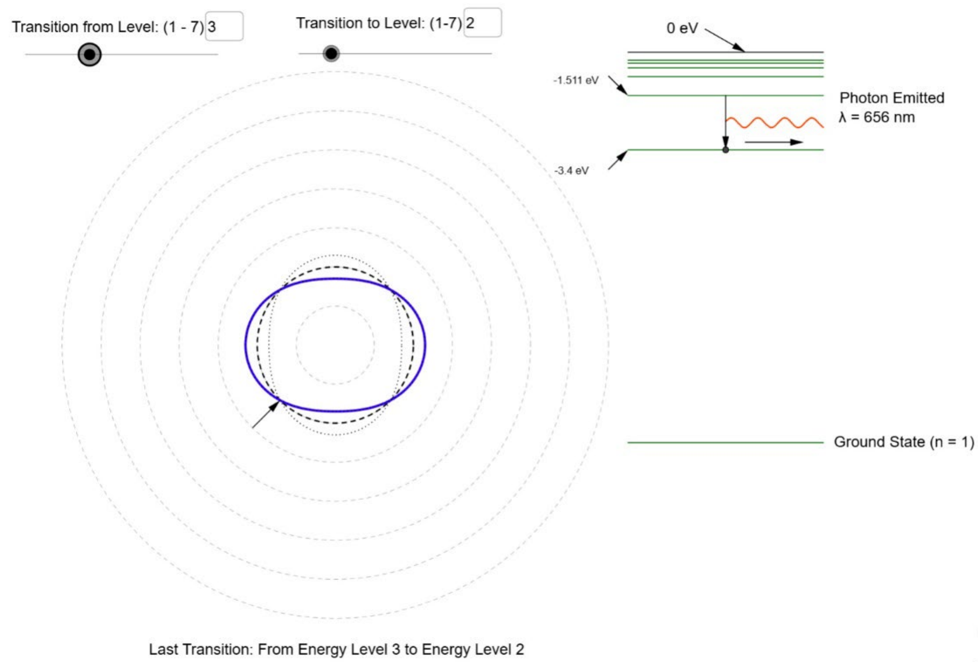


Figure 27 - When an electron moves from the n=3 energy level in a hydrogen atom to the n=2 energy level, a visible light photon is created. The light has a wavelength of 656 nm and appears red.

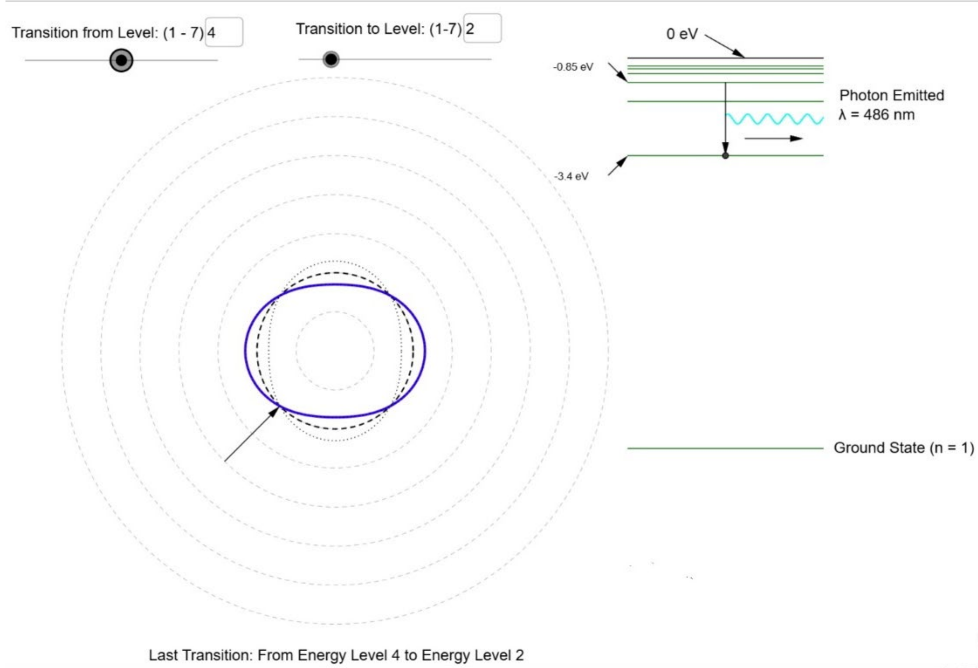


Figure 28 - When an electron moves from the n=3 energy level in a hydrogen atom to the n=2 energy level, a visible light photon is created. The light has a wavelength of 486 nm and appears blue-green.

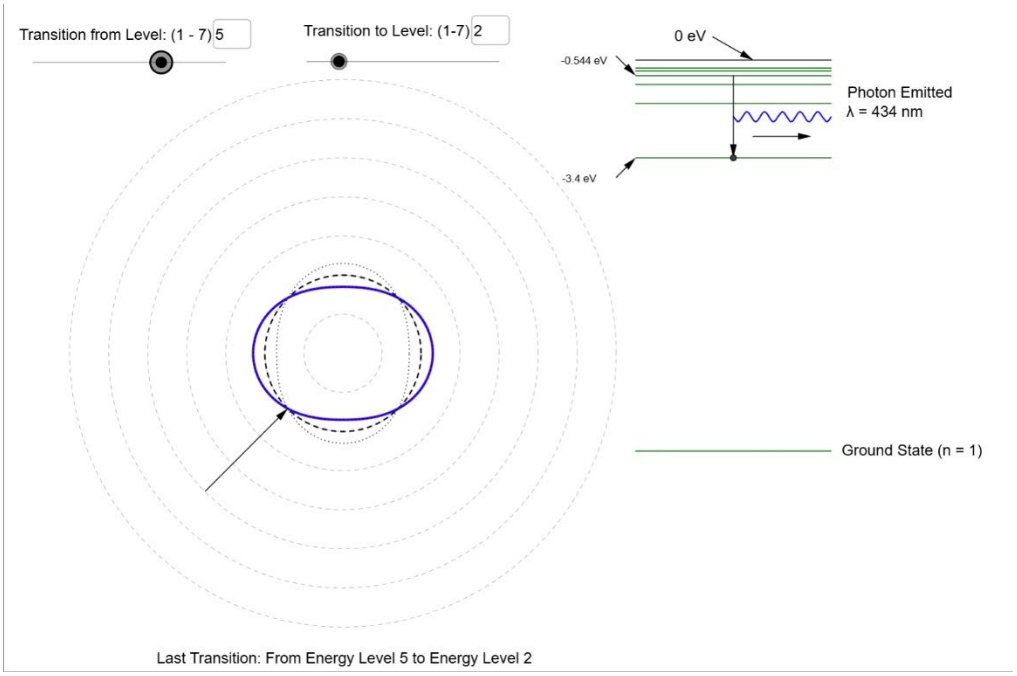


Figure 29- When an electron moves from the n=3 energy level in a hydrogen atom to the n=2 energy level, a visible light photon is created. The light has a wavelength of 434 nm and appears violet.

Absorption Spectra

An absorption spectrum occurs when a continuous spectrum from a hot, dense object shines through a cooler, thin gas. The elements in the gas remove spectral lines that correspond to the ones for the elements in that gas. Let's get an idea of how this looks by comparing the emission spectrum of hydrogen to the absorption spectrum for that element.

Figure 30 - Emission spectrum of hydrogen

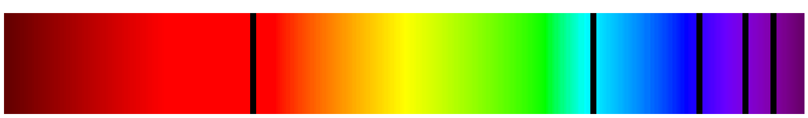


Figure 31 - Absorption spectrum of hydrogen

Note how the colors that are missing in the absorption line spectrum occur at exactly the same wavelengths as those that are present in the emission spectrum. If we examine the spectrum of a star and we observe the pattern above, we can infer that the star has hydrogen in its atmosphere.

The absorption spectrum from a star is not as neat as the graphic above. Any elements in the atmosphere of the star may contribute to the spectrum, meaning that there could be contributions from hydrogen, helium, calcium, sodium, magnesium, iron, and others piled on top of each other in the spectrum. A group of women working at Harvard University in the early 1900s worked to decode the various spectra and what they mean. This group included Henrietta Swan Leavitt, Annie Jump Cannon, and Willamina Fleming. Throughout their careers, they examined hundreds of thousands of spectra, and they found the spectra could be identified as belonging to distinct categories. When Cecilia Payne – an astrophysicist – arrived to work with the group, she demonstrated that the different types of spectra were related to the different surface temperatures of stars.

In the following images, the wavelength in nanometers is plotted along the horizontal axis in the top part of the plot. The intensity is plotted along the vertical axis. The taller the graph, the more intense the light is. At the very bottom of the images, it shows how the spectrum would appear. Where there is a dip in the intensity plot, a dark line appears in the spectrum. The pattern of how strong these dips are along with how wide they are reveal information about what is happening in the atmosphere of the star. Cannon, Leavitt, and their colleagues worked with spectra that looked similar to the pattern of intensities shown underneath the intensity vs. wavelength plots.

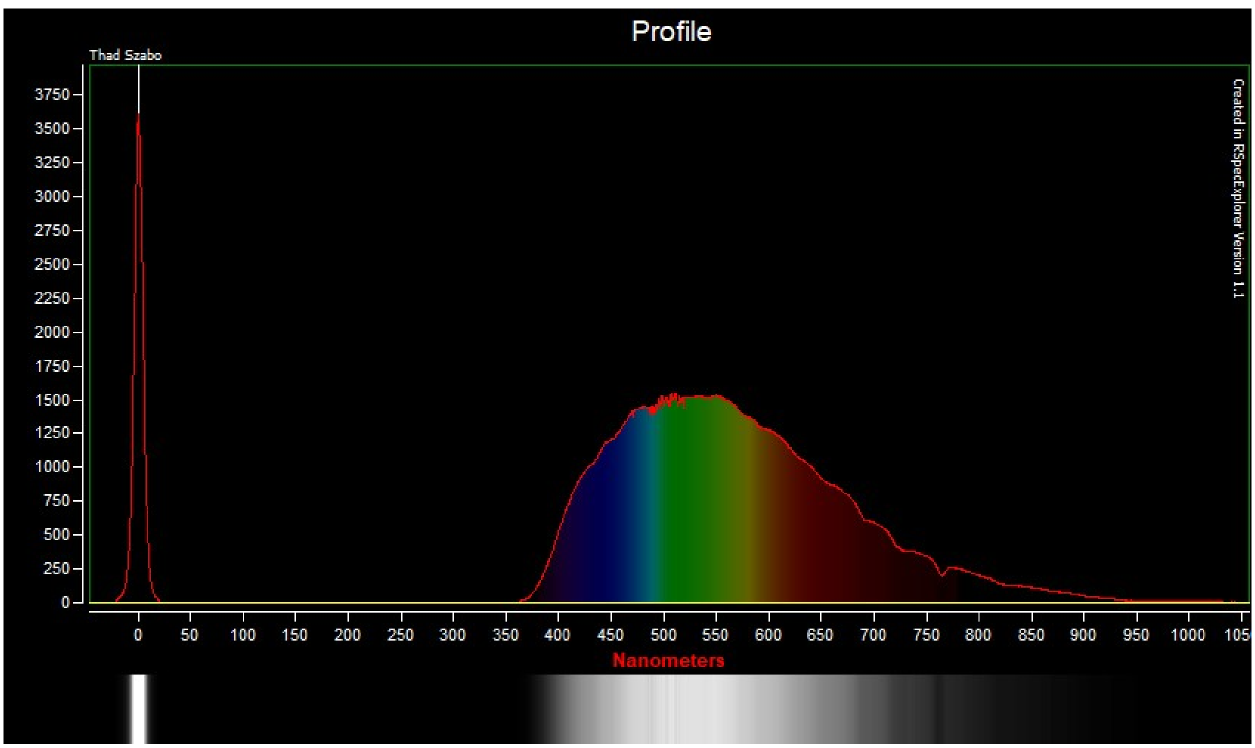


Figure 32 - Spectrum of the star Deneb, a supergiant star with a surface temperature of 8700 K

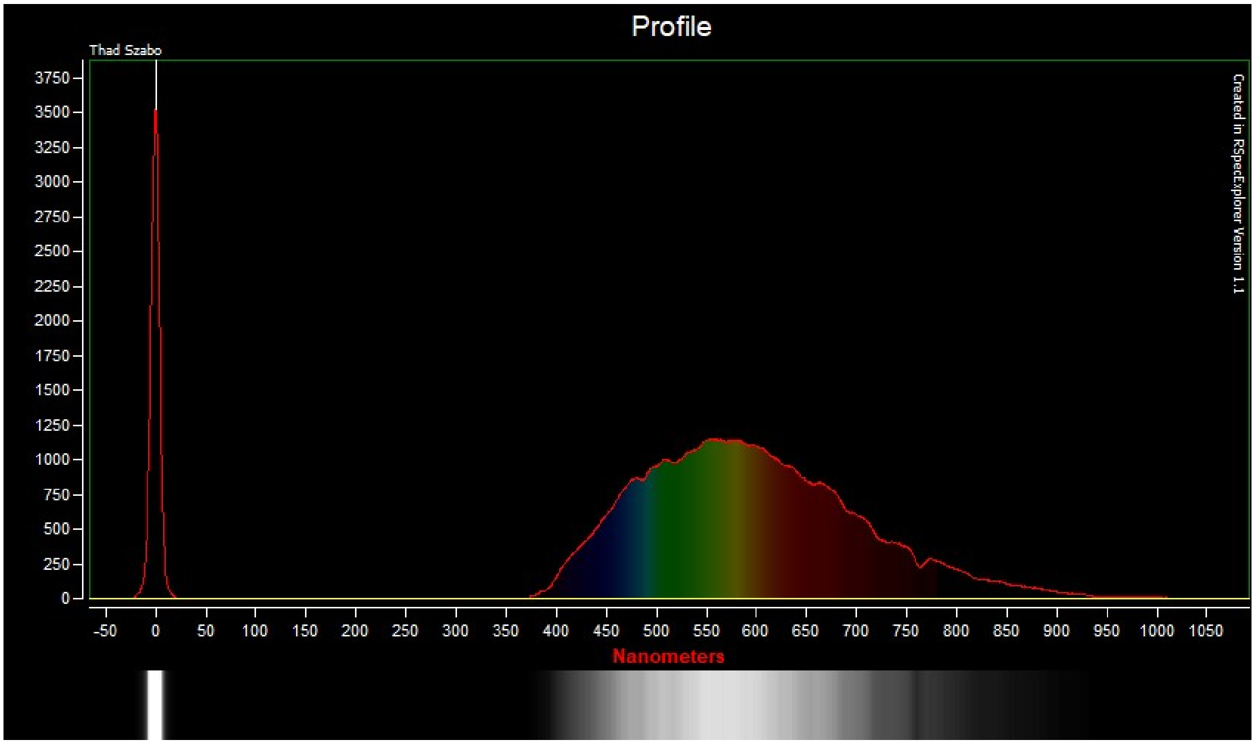


Figure 33 - Spectrum of the star Sadr, a supergiant star with a surface temperature of about 6000 K

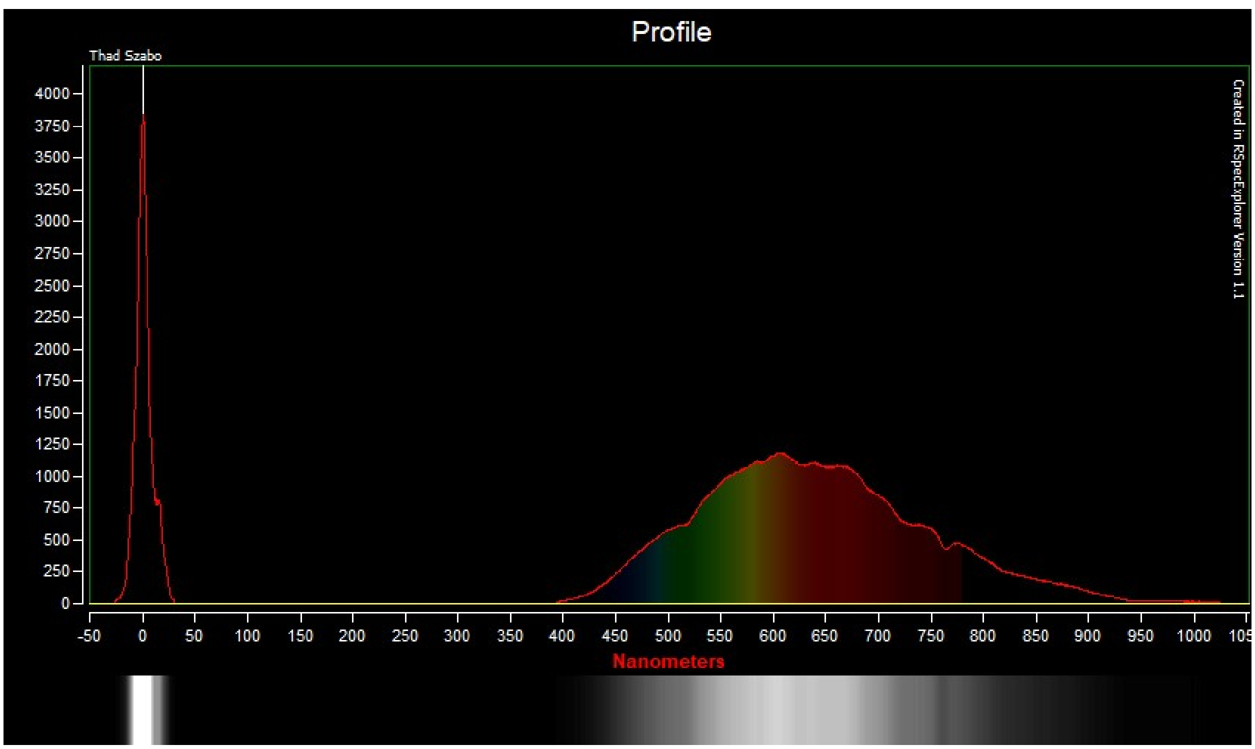


Figure 34 - Spectrum of the star Tarazed, a bright giant star with a surface temperature of 4100 K

Optics

Now that we have some idea of the information that we can get from the light from astronomical objects, we need to gather and concentrate that light as much as possible so that we can study it. We can do this either by directing the light into our eye or onto a camera sensor. We need to know a bit about how lenses and mirrors work in order to understand how telescopes and binoculars are used in astronomy.

Reflection and Refraction

The two principles that form the basis of this understanding are the *law of reflection* and the *law of refraction*. The law of refraction is also known as Snell's Law. To examine these laws, we need to know a little more about light.

Light travels in a straight line from one point to another through empty space. We usually represent this as *rays* of light. If you have a small light source, like an LED, you can draw this as rays moving directly away from the source in all directions.

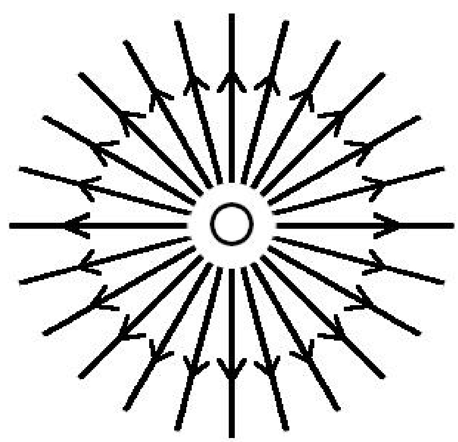


Figure 35 - Light rays emanating straight from a point or a small, spherical source.

If you have a laser, you can represent the rays as all traveling in the same direction.

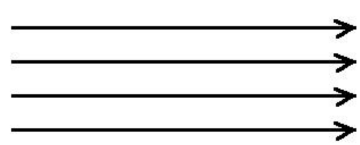


Figure 36 - Light rays moving parallel to each other.

Astronomical objects are so far away and our telescopes and cameras are so small that we say the rays from an astronomical object are parallel to each other. They aren't highly concentrated, like they are from a laser, but when we want to figure out what happens when they hit a mirror or pass through glass or water, we can approach the problem the same way.

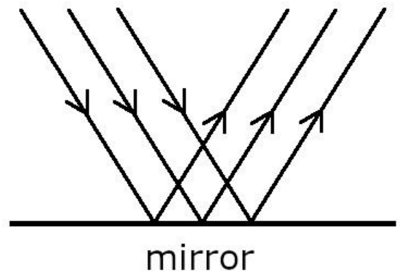


Figure 37 - Multiple light rays reflecting off a flat mirror

When light passes from one substance to another, two things happen: the light changes speed and if it passes through at an angle, the path bends. The bending of light is also called refraction. The amount that it bends depends on how much the speed changes. We measure this value for different substances and relate it to the *index of refraction* of that substance. The slower that light moves through a substance, the higher its index of refraction is. The fastest that light travels is in a vacuum (empty space), so all values are compared to that. Air has very little effect on the speed of light; it has an index of refraction just a tiny bit more than one. Water slows down light more; its index of refraction is 1.33. Glass tends to slow down light more than water, so it has a higher index of refraction – typically around 1.5 to 1.8, depending on the type of glass. Diamond has one of the highest indices of refraction at 2.42.

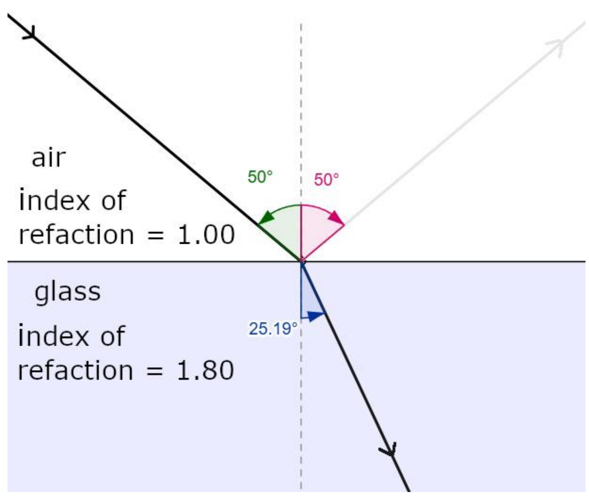
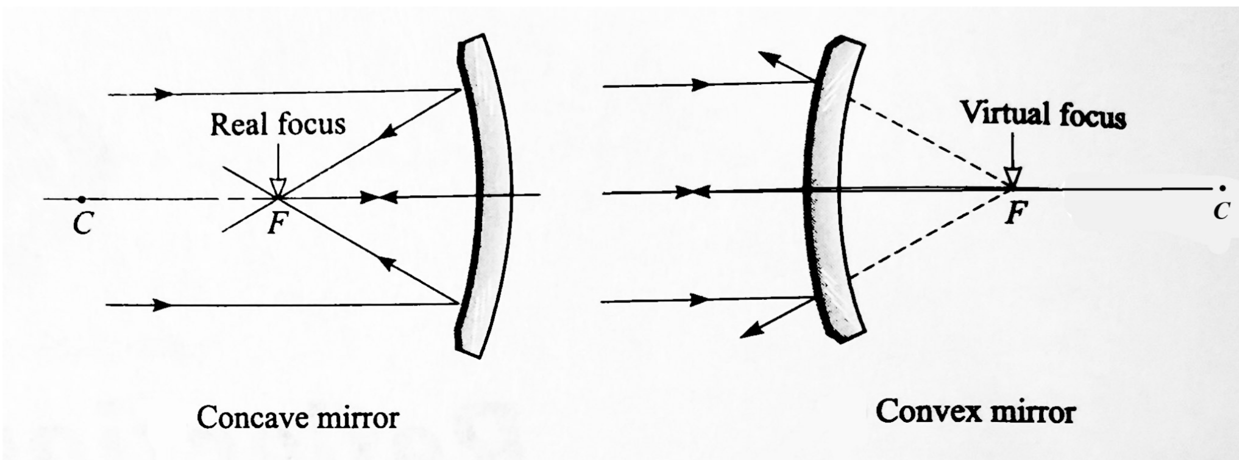


Figure 38 - Reflection and refraction of a light ray at the interface between air and glass

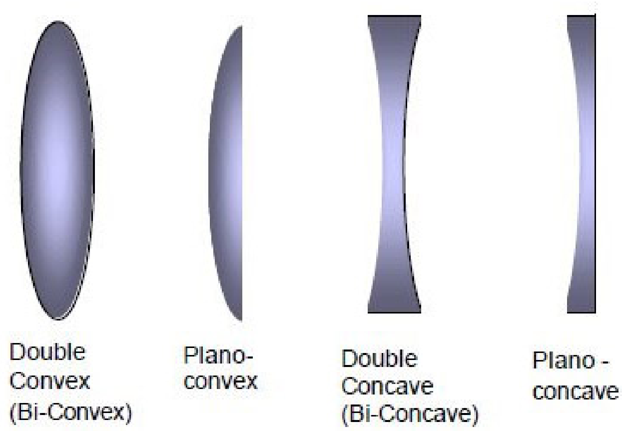
The larger the difference in the index of refraction between two substances that are in contact at an interface, the more the light changes direction as it passes from one to another. Also, the bigger the difference, the more light is reflected from the interface. Both of these aspects need to be considered in designing a telescope or other optical instruments.

Curved Mirrors and Thin Lenses

Mirrors and lenses can be flat or curved. If they are curved, they can be used to focus light and possibly produce an image. If the curve of the mirror or lens brings light rays together, the mirror or lens is *convergent*. If the curve of the mirror or lens spreads light rays apart, it is *divergent*.



The curvatures of lenses and mirrors can be either convex or concave. See the picture below for examples of each.



To make light rays converge, use a convex lens or a concave mirror. To make light rays diverge, use a concave lens or convex mirror. Since we want to concentrate the light that comes into a telescope, the primary optical element is either a convex lens or a concave mirror.

When viewed face on, mirrors and lenses in our labs usually appear circular. When you look at them from the edge, lenses show a cross-section that is either convex or concave. A concave lens or mirror looks like it is "caved in" a bit at the center, or that the light has to go into a bit of a "cave."

Astronomical objects are at such a great distance that light rays from them are all parallel to each other when they strike the Earth. The diagrams and pictures below show what happens when parallel light rays encounter a concave mirror:

The next picture shows what happens when parallel light rays encounter a convex mirror:

In the schematic at the top of each image, F represents the focal point of the mirror, and C is the center of curvature. The radius of the mirror goes from C to the mirror, and F is half the distance from the mirror to C.

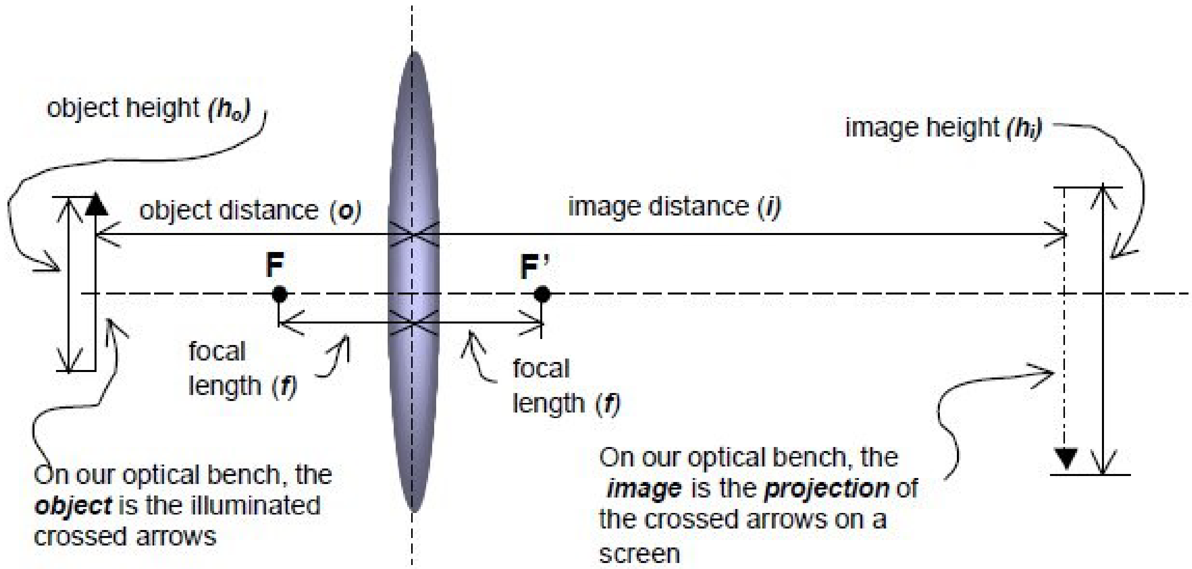
A small section of a sphere will bring light to a focus for a concave mirror, but if it is too large of a portion of the surface of a sphere, there will be distortions at the edges. Using a *parabolic mirror* eliminates these distortions.

(diagrams of examples with a concave mirror showing object distance, image distance, and focal length)

The Lens Equation and Magnification

For this course, the main thing to remember is that the distance from the object to the lens or mirror is called the *object distance*. To talk about this mathematically, we will refer to it as d_o – pronounced “d sub o”. The distance from the lens or mirror to where a clear image forms is called the *image distance*. The variable we will use for this is d_i – pronounced “d sub i”. It isn’t too important what we call them, and different texts use different variable names. What is important to us is the relationship between the object distance, the image distance, and the focal length of the mirror or lens. This relationship is given by the *lens equation*.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$



Object and Image distances

Earlier, we said that light rays from astronomical objects arrive parallel to each other. One way of working with this in an equation is to say that *the object distance is infinite*. Are astronomical objects infinitely far away? No, but the distance is so great that it is fine to work with this assumption. What happens if we put infinity in for the object distance in the lens equation? Don't tell your math professor we did this – they won't like that we tried doing math with infinity. Maybe we'll just say we divided by an incredibly huge number. If you divide one by an incredibly huge number, you get something that is super close to zero. (We could say that one divided by infinity is zero, but that will upset your math professor, and I don't want to do that.) What happens to the lens equation in that case?

We get the result that the image distance is equal to the focal length. This is a way to check what the focal length of a lens or mirror is. It can be tricky, but if you take the light from an astronomical object and focus it through a lens, the distance from the lens to the screen where you display the image is the focal length of the lens. You can try this with the Moon. ***DO NOT TRY THIS WITH THE SUN – YOU WILL START A FIRE.***

Magnification is essentially how many times bigger the image appears compared with the object. If you project an image on a screen, and the image appears twice as big as the object, the magnification is equal to 2. If the image is only half the size of the object, the magnification is 0.5.

To find the magnification of a system that has a thin lens or a curved mirror, take the height (or width) of the image and divide it by the height (or width of the object). You can also find the magnification by dividing the image distance by the object distance.

Our Solar System

WinJUPOS

One aspect of doing astronomical research is precise registration of any images used. This means knowing the exact time, location, and conditions when an image was recorded. For the Sun, Moon, and planets, there is also the issue of knowing what features on the object are facing the Earth. We also need to take into account the telescope, camera, and other optics that was used to take the image. WinJUPOS is a free program that can be used to register images, record the above information, and then make scientifically meaningful measurements on the resulting files.

Jupiter's rapid rotation stretches out regions of high pressure in its atmosphere into belts, while regions with lower pressure stretch out into zones. On Earth, high pressure tends to clear out clouds and bring good weather. On Jupiter, it allows us to see deeper into the atmosphere where higher temperatures make more complex and less reflective molecules. Thus, the belts appear darker. On Earth, low pressure allows clouds to build to high altitudes. The same thing occurs on Jupiter in the zones, except the clouds contain ammonia, carbon dioxide, and methane, as well as frozen water. The high clouds of simple molecules are more reflective, so zones appear brighter than surrounding belts. See the graphic below for the names of the belts and zones on Jupiter.

Instructions for Using WinJUPOS

There will likely be some initial dialogues when you launch WinJUPOS about choosing a directory or upgrading to the latest version. You can cancel these dialogues. If you choose to download WinJUPOS to use on your own Windows computer, you should get the latest version when it becomes available.

The first task you need to do is set the object that you want to measure positions on. Click the *Program* menu item and highlight *Celestial body*. From there, select the planet (or the Sun or the Moon) – see Figure 32.

If your lab activity requires you to use WinJUPOS to make measurements on an image of a planet or the Sun, choose the “Image measurement” option as shown in Figure 33.

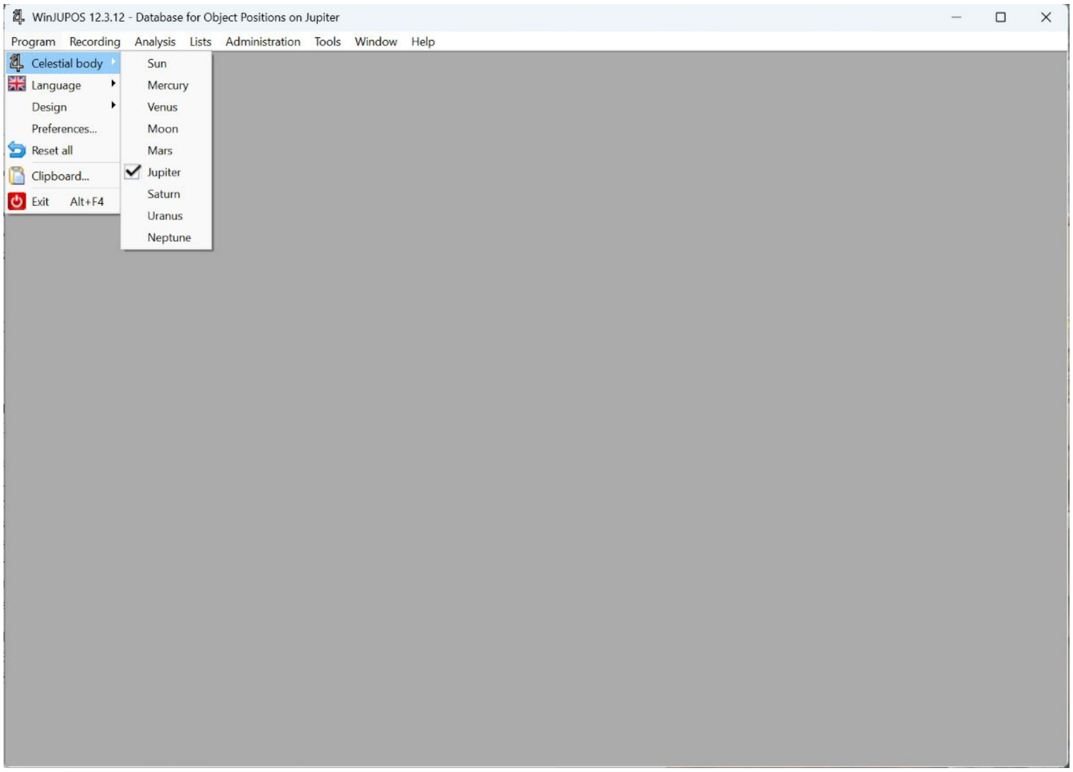


Figure 39 - Choose which planet (or the Moon or the Sun) you are measuring.

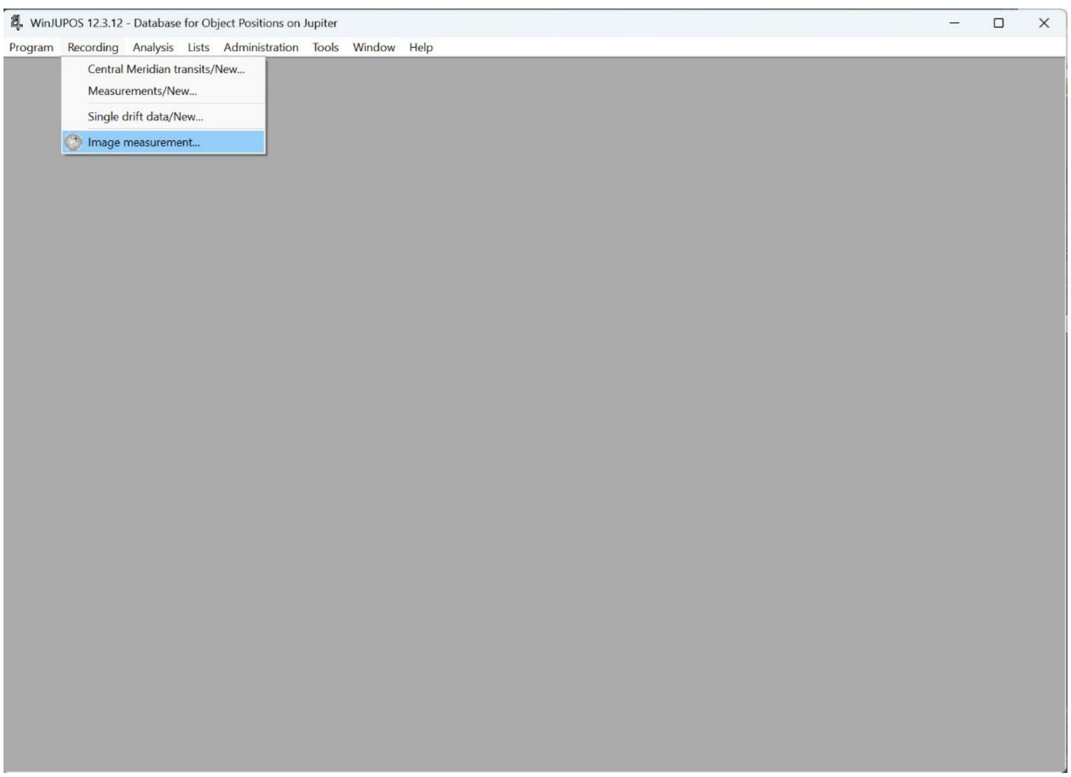


Figure 40 - Use this option to load an image to frame and measure.

Each time you start the image measurement tool, you should make sure the longitude and latitude are set correctly. The image shown in Figure 34 has them set properly for images taken from campus. Some images will automatically update the date and time, but not always. Use ***Universal Time (UT)*** if you need to input the date and time here. Remember that you add 8 hours to Pacific Standard Time to get UTC, or 7 hours to Pacific Daylight Time to get UT.

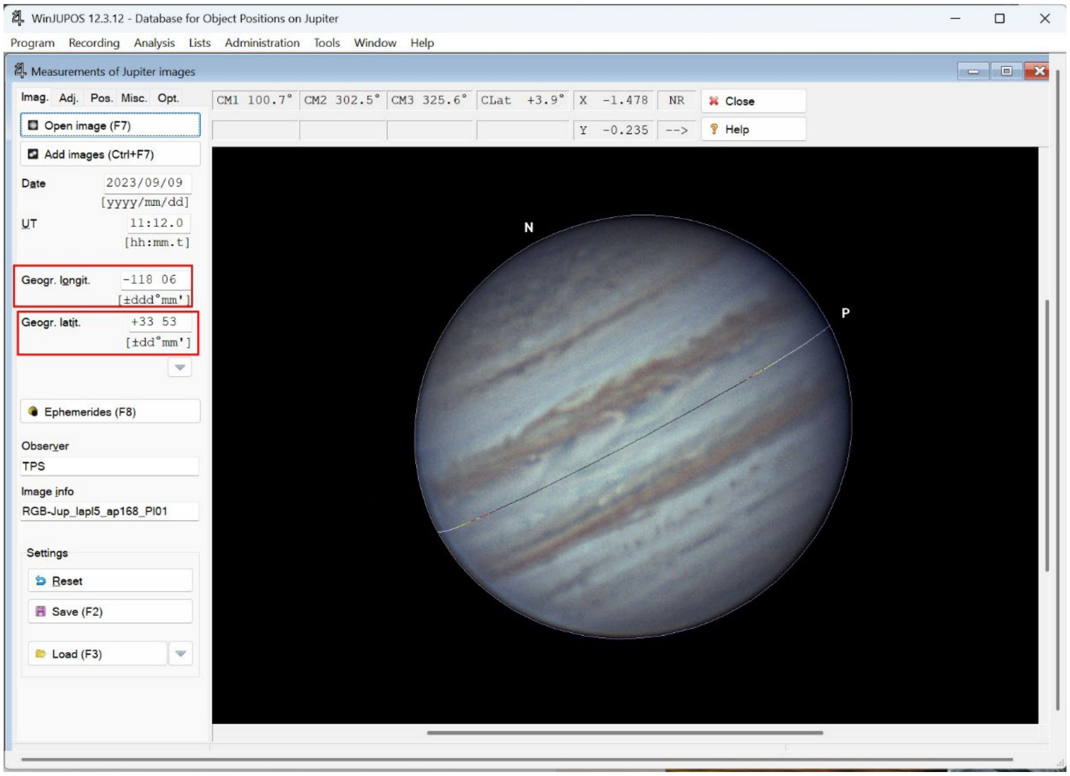


Figure 41 - Make sure to set the latitude and longitude of where the picture was taken.

Navigate to the various other views within the image measurement window by the tabs, which are shown outlined in green in Figure 35. The most important step to do from this tab is to fit a frame to the planet or the Sun in your image. For Jupiter, you will likely be able to click “Outline frame” (in a red box in Figure 35) and select “Automatic detection”. For other solar system objects, you will likely need to adjust the frame on your own. Use the “Page Up” or “PgUp” key on your keyboard to increase the size of the frame and the “Page Down” or “PgDn” key to decrease its size. Use the “N” key to rotate the outline frame clockwise, and the “P” key to rotate it counterclockwise. Your lab instructor will have more information for using these features if you need them for your particular lab activity.

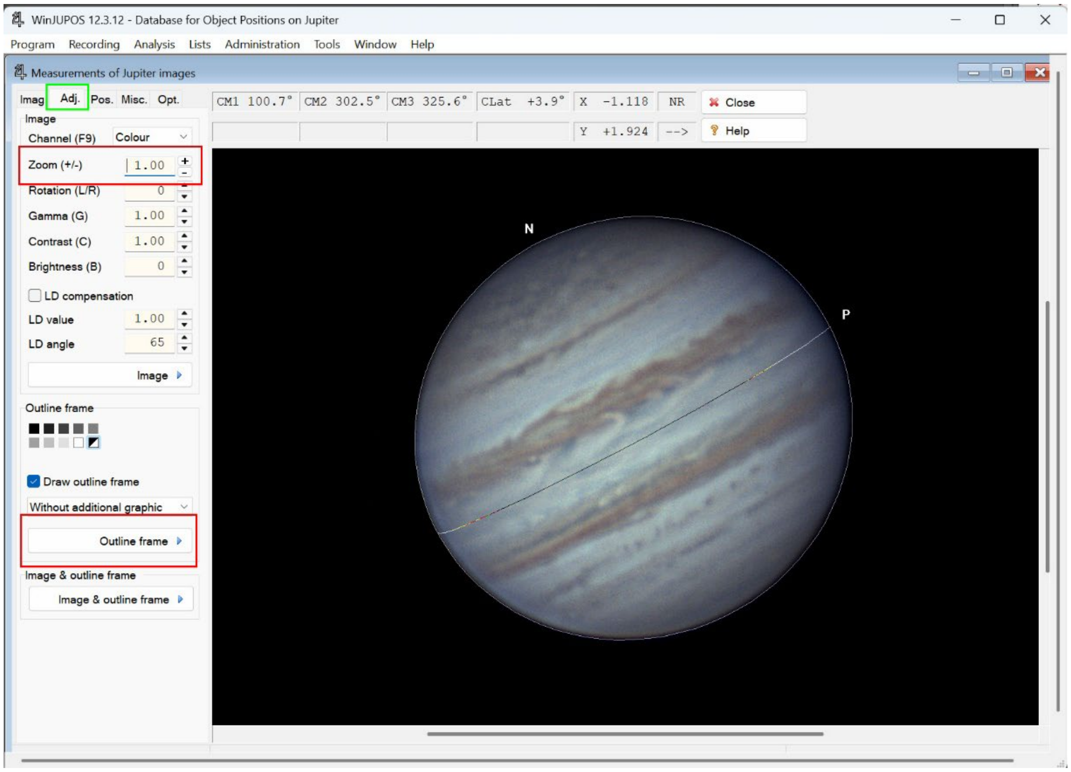


Figure 42 - The "Adjustment" tab for the Image Measurement tool; use this for changing the zoom or placing an outline frame on the object in your image.

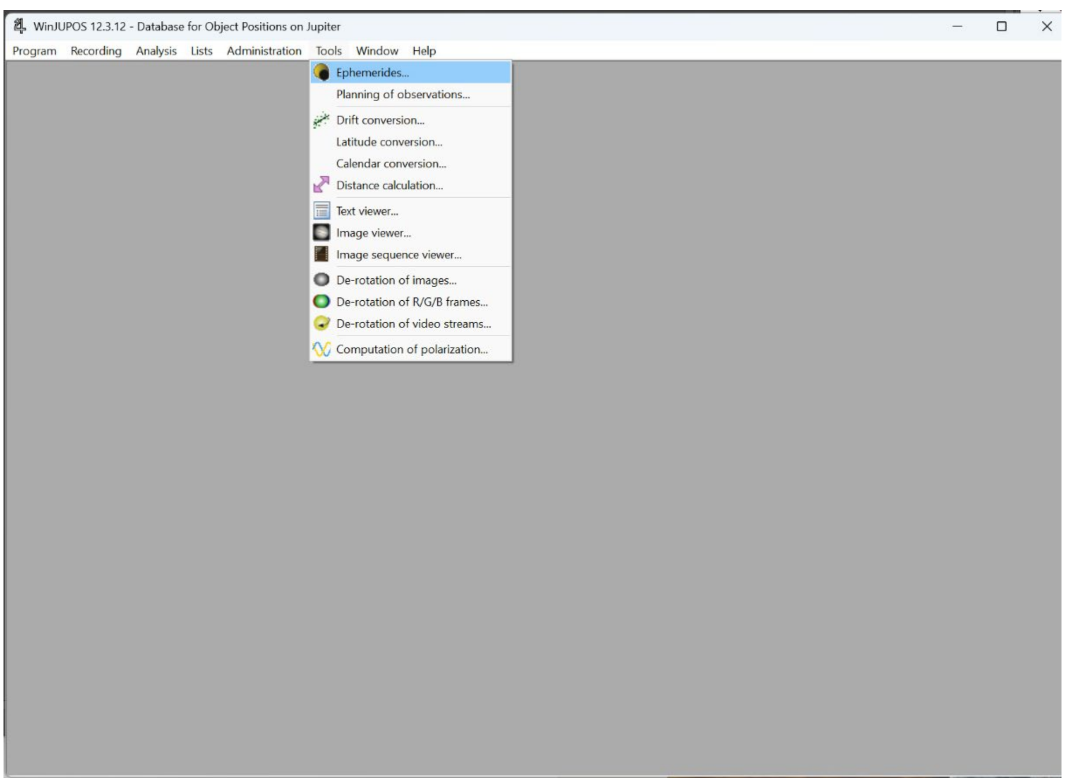


Figure 43 - From the "Tools" menu item, select "Ephemerides" to get information about where an object will be in the sky, and if it has moons, which moons are visible with the planet.

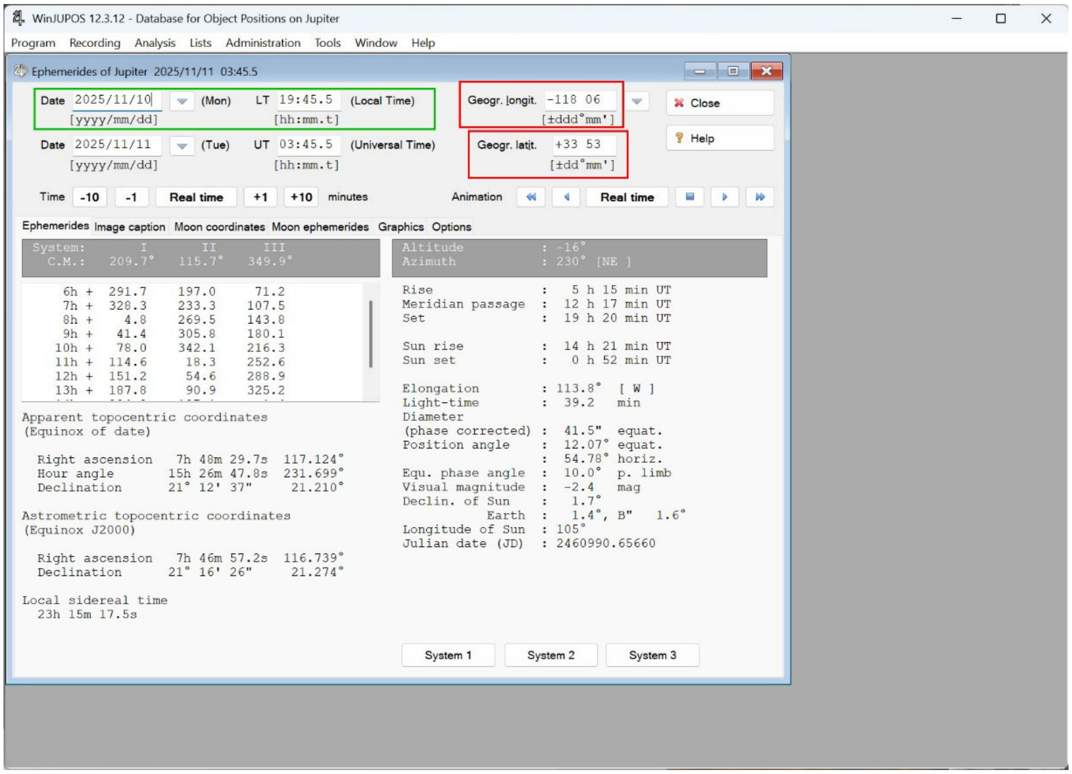


Figure 44 - When you use the Ephemeris tab, make sure that the longitude and latitude match where the observation was taken. You can enter the time as either the local time (above left) or in Universal Time (below the local time entry, on the left).

As part of the section on Planetary Imaging, we will go over how to use WinJUPOS to register images taken over time. The program can be used with accurate timestamps for your images to “derotate” a series of images of a planet so they can be stacked and averaged. This feature compensates for how the features of the planet change position as it spins while you are imaging it.

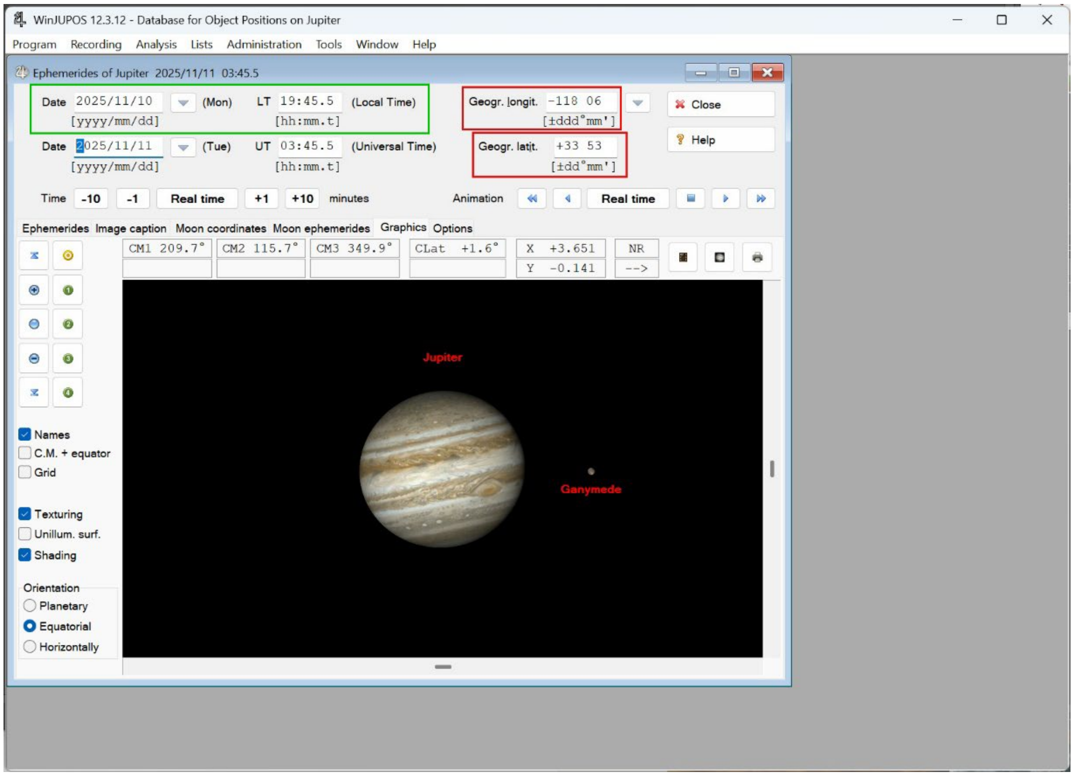


Figure 45 - Again, make sure the longitude and latitude are set properly.

Solar Rotation

As stars and planets form from the gas and dust that their primordial nebula contained, this material begins to rotate. The objects themselves shrink in size as gravity pulls their particles together, but due to conservation of angular momentum the spinning continues. We see this in our solar system with all eight planets traveling in the same direction around the Sun. The Sun also rotates. If you look at the Sun from above its north pole (remember: anything that rotates has a north and south pole), it spins counterclockwise, which is the same direction the planets travel around it.

To measure the Sun's rotation, we will rely on active regions that have origins deep in the convective zone of the Sun. (See the picture of the layers of the Sun.) Why do these active regions exist? The portion of the sun that is visible to our eyes is the *photosphere* – this is where light that was made by fusion reactions in the core of the sun finally escapes the Sun and goes free. Directly below the photosphere is the convective zone. It makes up the outer 30% of the radius of the Sun. In this layer, hotter gases rise, and cooler gases sink. Thus, the gases exhibit convective motion. Because the interior of the sun is so hot, electrons often move around freely, not attached to any particular atomic nucleus. Because the negatively charged electrons and the positively charged nuclei are not bound to each other, as they are in the atoms we are made of, we say that the interior of the Sun is a plasma. Plasma only exists on Earth in extreme conditions, like the air that gets blasted when a bolt of lightning passes through it. If charged particles are free to move, they create magnetic fields. If the magnetic fields concentrate in an area of the sun, they change the flow of charged material and create an active region.

Active regions are assigned numbers so that they can be tracked as the sun rotates. They are not permanent objects. Some will only last a few days, while very persistent active regions can last for months. By studying the sun at different wavelengths of light, we can learn about the structure of active regions and the types of energy they carry. Examine the three pictures of the sun below; each one is taken with a different wavelength of light.

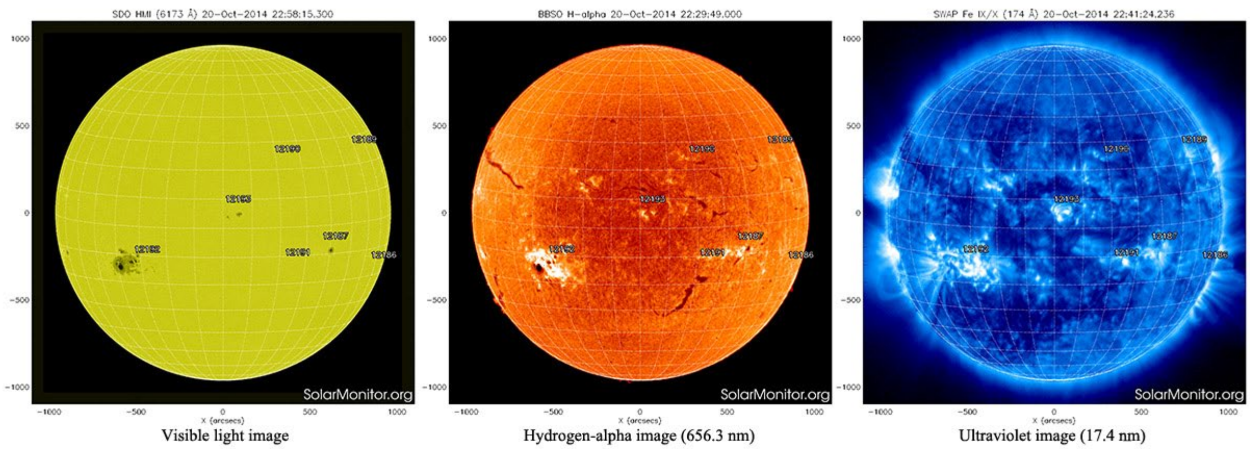


Figure 46 - Images of the Sun from 2014-10-20 in three different wavelengths

The visible light image (left picture) uses a wavelength of 617.3 nm. This shows what the photosphere would look like through a solar filter on the 8" telescopes we use in lab. The middle image detects the wavelength that goes with the red spectral line from hydrogen at 656.3 nm – the Hα line. This shows features in the sun's atmosphere above the photosphere in a region known as the chromosphere. Since these features appear at a longer wavelength, are they associated with temperatures that are higher or lower than those in the photosphere? (Think back to what we discussed in the Light lab.) The image on the right comes from photons that are in the ultraviolet range, bordering on the X-ray range. Do these photons have more energy or less energy than visible light? (Again refer to the Light lab.) There is an enormous active region that appears in all three pictures. This region was about the same size as the diameter of Jupiter! The active region shows a large group of sunspots in the visible light picture. These appear darker because they are cooler (4400 K – remember the Kelvin temperature scale) than the average temperature of the photosphere (5800 K). In the ultraviolet picture, note the large loops that extend above the sun. The light in these loops come from the energy that is produced by electrons moving along the magnetic field of the Sun. Examining the shapes and sizes of the loops reveal details about the structure and strength of the magnetic field.

Finding the positions of the active regions requires a new set of coordinates – coordinates that are associated with positions on the Sun. When we do this for the Earth's surface, we can call them *geographic coordinates*. On the Sun, we use *heliographic coordinates*. As with all our previous systems, finding the north-south coordinate (latitude) is much more intuitive than finding the east-west coordinate (longitude). WinJUPOS can be used to measure these coordinates on the Sun if you have the date and time that the image was taken.

Moons of Jupiter

If we go back to the introduction to this manual, we can recall that there is a lot to learn from watching changes in the sky. The ideas about how the solar system works came from watching changes in the positions of the planets in the sky. The careful observations made by Tycho Brahe in the late 1500s gave Johannes Kepler data that allowed him to formulate his Laws of Planetary Motion. This video from the YouTube channel 3Blue1Brown goes into detail about how Kepler determined that planetary orbits are ellipses. These laws provided the best predictions of where planets would be found in the night sky before Isaac Newton produced his laws of motion – which apply to all objects, not just planets – as well as his law of Universal Gravitation.

Attempting to recreate this with planetary observations is incredibly difficult. It is something for an advanced astronomy course – not this lab. However, a planet with many moons can act like a miniature version of the solar system. Instead of observing planets moving around the Sun, what if we could keep track of moons moving around another planet? Which planet should we pick?

Mercury and Venus do not have any natural satellites (moons), so they are out. Mars has two very tiny moons. They are not even visible with the large telescope we have in the observatory here on campus. Saturn, Uranus, and Neptune all have many moons. None of the moons of Uranus are particularly large, so they are difficult to observe. There is one significantly larger moon of Saturn, called Titan, and one particularly large moon of Neptune, called Triton. Working with Neptune is out because of how far away it is – even its large moon is just barely visible. Saturn is a somewhat better choice. Aside from Titan, there are other decent size moons, so we could run the needed analysis for more than one moon.

However, the best choice is Jupiter. Galileo Galilei was one of the first people to make careful records of what he observed with his telescope. In early 1610 C.E., he reported observations of the four largest moons of Jupiter. He was able to make these observations with a very small telescope that did not have much magnification. It only made objects appear 20 times bigger. That was enough. By March of that year, Galileo published his observations of the moons showing he was aware of their regular motion around the planet.

The four moons he observed came to be named Io (that's a letter "i" and a letter "o"), Europa, Ganymede, and Callisto. If they were in space on their own, they are large enough and reflective enough that they would be just barely visible to the unaided eye. This makes them an ideal system for seeing how Newton's Laws of Motion can be used to measure the mass of Jupiter based on the way its moons orbit the planet.

What principles of physics do we need to do this? First, we need Newton's Law of Universal Gravitation. It says that the strength of gravity that attracts two massive objects to each other depends on the mass of each object and that it grows weaker if the objects are farther apart.

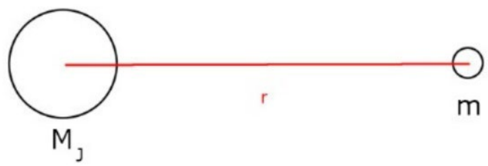


Figure 47 - Jupiter is shown on the left with mass M_J, and one of its moons is shown on the right, with mass m. The centers of the planet and the moon are separated by a distance r.

The formula that tells us how strong the force of gravity is between Jupiter and its moon is

$$F_{gravity} = G\frac{M_J m}{r^2}$$

Don't worry about using this formula, but let's at least make sure we understand what it is telling us. On the right hand side in the top (numerator) of the fraction, you multiply the masses together. If either mass gets bigger, the force gets stronger. In the bottom (denominator), you divide by r times itself (r^2). This means the strength of gravity falls off quickly the farther apart you make the two objects. If you move them to be 3 times farther apart than they were before, the gravity is 3^2 or 9 times weaker.
What is G? It is a constant that describes how strong gravity is in our Universe. Every experiment or observation we have made to measure it has returned the same value. It is a very small number – that means that, unless an object has a lot of mass, its gravity will be too small to notice. If you are interested in the number, it is G = 0.0000000000667 N m^2/kg^2. Another way of writing this would be G = 6.67 x 10^{-11} N m^2/kg^2. Here, "N" is newtons – a measure of how strong a force is. If you have a weight of 200 pounds, the Earth is pulling on you with a force of 890 newtons. Those two different numbers describe the same amount of force. The masses are measure in kilograms (kg), and the distance needs to be measured in meters (m). If you need to do conversions for a lab, most search engines will do them automatically.

The other physics principle we need is *centripetal force*. Most of the idea related to this was known before Newton wrote his laws of motion. Centripetal force is the force you need to apply for an object to go around a circle. In our case, we will consider the moons to orbit Jupiter along a circular path. This is not 100% accurate, but it is good enough for our calculations.

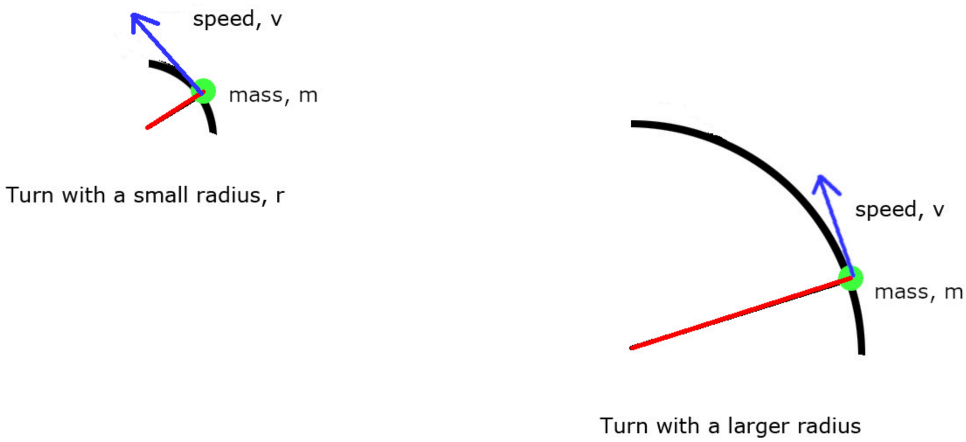


Figure 48 - A portion of a turn with a small radius is shown on the left, and a turn with a larger radius is on the right. Imagine that these turns continue to make a complete circle. The circle on the left would be smaller than the circle on the right. The diagrams also show a mass m in green, and a speed v in blue. The arrow shows the direction the object is moving at the moment the picture is taken.

The following formula would allow you to compute how much centripetal force you need for the object to make the turn (or go around the circle with that radius) shown above:

$$F_{centripetal} = m\frac{v^2}{r}$$

For one of the moons in orbit around Jupiter, r is the same as it was in the equation for gravity. The mass of the moon is given by m. The speed of the moon is given by v. Again, don't worry about computing values with the formula – know what it means for how strong the force is. If you want to go 5 times faster around a turn, you need 5^2 = 25 times as much force. If you make the turn wider (or have a bigger circle), you don't need to apply a force that is as strong as long as you want to go the same speed.

The next point to consider is that centripetal force can't just appear out of nowhere – something has to provide it. If you swing an object around in a circle that is attached to a string, the tension in the string provides the centripetal force. If you go around a turn in a car, the centripetal force usually comes from the friction between the tires and the road.

What provides the centripetal force for Jupiter's moons to move in circles around Jupiter? (Again, OK, I know – they're not quite circles; they're ellipses. But they really aren't too different from circles.) There aren't strings attached to them, and there's no friction in space for moons and planets in our solar system. There aren't tracks for them to follow. If you see pictures of orbits in your text or elsewhere, that's just a representation of the path that is followed. Those lines don't exist as a drawing in space.

If you guessed that gravity provides the centripetal force, you are correct! We can set the two formulas for the force equal to each other (F is the same, even though it is labeled as $F_{gravity}$ and $F_{centripetal}$.) If we do this and rearrange things a bit, we get this:

$$v^2 = G\frac{M_J}{r}$$

The speed that one of the moons goes is squared. That result is equal to G times the mass of Jupiter divided by the radius of that moon's orbit. The bigger that a moon's orbit is, the slower it moves as it goes around Jupiter. In fact, if we measure the speed of a moon and the radius of its orbit, we can use those numbers to find the mass of Jupiter.

Let's stop and think about that for a moment. You could use the motion of the moons of Saturn to get the mass of Saturn. If you can measure exoplanets moving around distant stars, you can get the mass of those stars. This equation gives us a way of measuring how much material makes up objects in space, as long as they have much smaller objects orbiting them.

Also note how the mass of the moon disappears in the equation. Whether its Io, Europa, Ganymede, or Callisto, we don't need to know their mass. However, their speeds can be a little tricky to determine directly. We can use that speed equals distance divided by time. If we can find out the distance they move in one orbit divided by the time for one orbit, we can compute the speed. The distance around a circle is its circumference, and you can get it from two times pi times the radius ($2\pi r$). Let's use T for the time to complete one orbit. We then get these relations:

$$v = \frac{2\pi r}{T}$$

$$\left(\frac{2\pi r}{T}\right)^2 = G\frac{M_J}{r}$$

If you can't follow all the math, that's OK. We just want to see where the result comes from that lets us get the mass of Jupiter. If we rearrange that last equation to get M_J by itself, we get:

$$M_J = \frac{4\pi^2 r^3}{GT^2}$$

Once you have the radius of a moon's orbit (and that has to be in meters) and the time it takes to complete an orbit (which needs to be in seconds), you can figure out the mass of Jupiter! All it takes is watching how the moon moves and some understanding of how to measure things on the sky. Note also how this last expression has the size of the orbit cubed and the period of the orbit squared. We first see this idea in Kepler's Third Law of Planetary Motion, but the equation above shows how it works in general.

Tracking Asteroids

In 2011, an asteroid with a diameter of approximately 400 meters passed closer to the Earth than the average distance between the Earth and the Moon (384,000 km). This provided us with a unique opportunity to attempt to photograph this asteroid. You can see the video made by NBC Los Angeles (Channel 4) of the lab where we photographed it at this link:

http://www.youtube.com/watch?v=urqRB19-rfg

There is also have a video I made of the photographs we took that night:

http://www.youtube.com/watch?v=KMLr22antxI

The asteroid in question is designated as 2005 YU55. It is a carbonaceous asteroid, meaning that it reflects very little light that strikes it. These objects are known to be leftover from the formation of the solar system. At another point in the semester, we examine meteorites closely – one of the meteorites we examine comes from an object like 2005 YU55.

In order to know where to aim our telescope to get pictures, we need to get an ***ephemeris*** for the asteroid. In its most general form, an ephemeris lists the right ascension (RA) and declination (DEC) of an object at a set of specified times. From these coordinates, you can determine where the object will appear in the sky. Since 2005 YU55 has been tracked before, we can rely on the Minor Planet Ephemeris Service from Harvard University. The URL for this service is:

http://www.minorplanetcenter.net/iau/MPEph/MPEph.html

There is software that will allow you to import the information from the Minor Planet Center to show how the asteroid will move across the sky. You can also take a list of times and the RA and DEC coordinates that go with those times to plot the path of the asteroid by hand on a star chart. At this point, we know the positions of stars well enough due to the European Space Agency GAIA Mission along with the positions of some asteroids to be able to predict when an asteroid will block the light from a particular star. This sort of observation is called an *asteroid occultation*, and we have the equipment needed to observe and measure these events here at Cerritos College.

What effects would occur if an asteroid did strike the Earth? As the asteroid enters Earth's atmosphere, the air in front of it would get compressed and heat up dramatically. This heat flows back over the asteroid and causes both the air and the asteroid to glow brightly. This glow transmits heat to everything on the ground that can view the incoming asteroid. For extreme cases, objects on Earth will catch fire. The air that is compressed ahead of the asteroid causes a shock wave to propagate outwards, accompanied by a loud sound. *Even if an asteroid burns up and breaks up before it reaches the ground, the heat and the shock wave can still do damage.*

What if an asteroid doesn't burn up completely? For insight into this situation, we can look at the Moon. It has no atmosphere, so all of the energy that the asteroid has in space is still there when it reaches the Moon's surface. What do you notice about the Moon's surface compared with the Earth? Without the protection afforded by an atmosphere, the Moon is covered in craters.

The craters are not simply from asteroids hitting the surface. If you drop a rock into loose sand, you can make a small crater, but it is missing something important compared to what happens during an asteroid impact. The asteroid brings a huge amount of kinetic energy with it, and that energy turns into heat on impact. The kinetic energy is related to the mass of the asteroid and its speed squared. If you make something move four times faster, it then has $4^2 = 16$ times as much kinetic energy. The amount of heat released *turns solid rock into gas*. It vaporizes the rock, and the gas that results expands in a dramatic explosion. Even though asteroids impact the Moon from all directions at all angles, the craters are all circular, with very few exceptions. The mechanism that makes the crater is the rapid expansion of vaporized rock.

The last two effects to mention are quakes and ejecta. Hitting the solid surface of a planet and creating an explosion will have seismic effects. The explosion from the expanding vaporized rock with throw large quantities of solid rock into the region above the impact. If any piece is ejected fast enough, it may go into space to become a meteorite that lands somewhere else. We have found meteorites on Earth that we can identify have come from the Moon or Mars and even from some asteroids whose surface composition can be verified. Whatever doesn't escape the gravity of Earth will fall back down, potentially causing more damage.

You can ask a dinosaur about the Chicxulub impact and how much fun it was to survive after that event.

Neal Agarwal created a website where you can simulate what sort of damage would be done by an asteroid striking the Earth. The site is called Asteroid Launcher. You can choose the size and density of the asteroid along with the speed and angle of impact. Then you choose where on Earth you want it to strike. The site gives you a summary of the damage that will occur, along with other related statistics.

Meteorites

Earth is constantly being bombarded by debris left over from the formation of the solar system. While pieces of this debris are still in outer space – if they are small – they are called ***meteoroids.*** (Larger objects are ***asteroids*** or ***comets.***) Approximately one ton of material falls to Earth every day. Most of this material is comprised of small dust grains that burn up in the atmosphere producing streaks of light that called "shooting stars" or ***meteors***. Occasionally, larger objects survive their passage through Earth's atmosphere and reach the surface. They are called ***meteorites***.

Most of the material that falls to Earth is left over from when the solar system formed 4.56 billion years ago. Some of this material has gone unchanged from this time, while other material has undergone processing to change its structure. The most common process to cause a change is heating. We need to understand how objects in the solar system may undergo enough heating to produce a change.

The first geologic processes in the solar system occurred long before Earth existed. Before the solar system formed, it was a huge cloud of gas and dust. The cloud was so cold, only 10 K (-442°F), that complex molecules were able to condense from the gas. These regions are called ***molecular clouds*** and they still exist in other parts of our galaxy, as well as in other spiral galaxies. They appear as ***dark nebulae***, some of which are pictured below. If there is a nearby supernova, it can cause part of the molecular cloud to collapse and form stars and solar systems.

Figure 49 - The pictures above show two examples of dark molecular clouds. The picture on the left shows the clouds over a dense background of more distant stars. The picture on the right shows a bright star with a variety of nebulae around it. The dark molecular clouds are seen as dark silhouettes against the background of bright nebulae.

Some of the material from the molecular cloud core is drawn to the center of the cloud where it feeds a growing ***protostar***. The rotation of the cloud flattens the outer portions into a disk of gas and dust which surrounds the protostar like a ring. As more material is added to the protostar, the temperatures and pressures in its core became high enough to initiate nuclear fusion. The onset of nuclear fusion marks the transition from protostar to star. In the case of our solar system, the protostar became the Sun. The planets, moons, comets, and asteroids came from the disk surrounding the protosun (called the ***solar nebula***).

As the solar nebula cooled, the dust ***accreted*** (clumped together) to produce larger particles. Occasionally some of the larger dust particles were melted in brief, but intense, heating events producing molten droplets which have been described as fiery rain. Since the heating events were brief and the surface area of the droplets was small, the molten material was soon ***quenched*** (cooled rapidly) to produce spherically-shaped, millimeter-size rocky beads called ***chondrules*** (see figures below). Chondrules provide a record of what the solar system was like shortly after it formed. Within about 10 million years, the solid material in the solar nebula (*e.g.* dust grains, chondrules) accreted into small ***planetesimals*** with diameters of a few kilometers to perhaps a few hundred kilometers. The planetesimals, in turn, accreted together in a few regions of the solar system to form even larger planetary bodies. About 100 million years after the molecular cloud core collapsed, planets like Earth and Mars had grown to the approximate sizes that we see today.

Figure 50 - An example of how chondrules appear in a stony chondrite meteorite

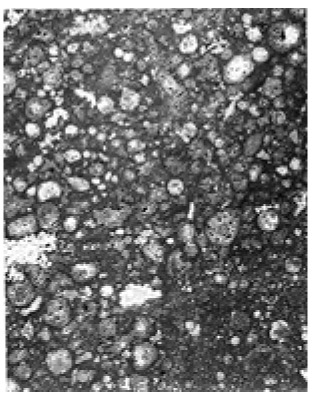


Figure 51 - Another example of the appearance of chondrules

In cases where a planetary body is hot enough to become partially or wholly molten, materials with different densities can separate. This process is called ***planetary differentiation***. Material with higher density will “sink” due to gravity, while lower density material will “float” to the top. On Earth, for example, dense metallic liquids fell towards the center of the planet to form an iron-nickel rich core, while lighter rocky material rose toward the surface to create the crust and mantle. The same differentiation processes that produced an iron-nickel-rich core in Earth also produced cores in other planetary bodies (Mars, Venus, and Mercury).

The Process of Differentiation

The spheres shown in the following images represent objects that are miles across. You need objects of at least that size to have enough heat to concentrate to melt the core.

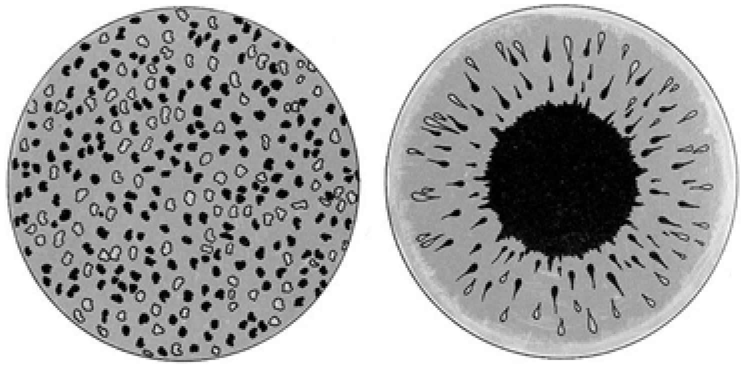


Figure 52 - The black material in this picture represents denser elements like iron and nickel. The lighter colored portion represents less dense rock. When enough heat is present, as it is in an asteroid in the early solar system, the interior melts and separates into denser material at the center and less dense material toward the surface.

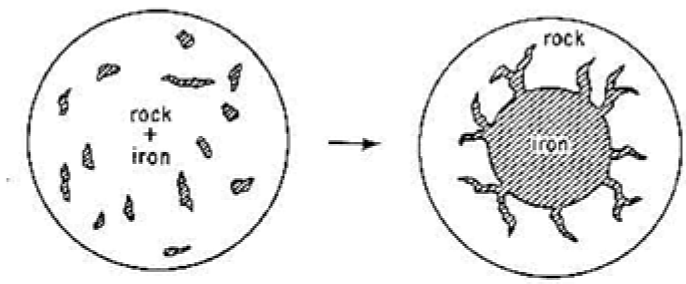


Figure 53 - Another diagram showing the process of differentiation. The material in an asteroid that has undergone differentiation has changed and can no longer be used to study pristine material from the solar nebula.

In the pictures above, dense iron and nickel deposits are represented as dark spots or regions, and less dense rocky materials are indicated with lighter spots or regions.

At first, the rock and iron are randomly distributed throughout the asteroid or planet. With enough heat, they liquefy. The iron then moves to the center due to gravity, and forces less dense material to the surface.

Some of the differentiated asteroids between Mars and Jupiter collided with each other, exposing their metal-rich cores. The collisions that disrupted the asteroids ejected both stony chunks from the asteroid crusts and iron chunks from their cores. Many of these chunks fall to Earth in the form of ***stony meteorites*** and ***iron meteorites***.

Types and Classes of Meteorites

There is a distinction between three ***types*** of meteorites *based upon their compositions*: iron, stony, and stony-iron. ***Iron*** meteorites come from the iron-nickel cores of differentiated planetary bodies. ***Stony*** meteorites come from the outer rocky layers of a planetary body. ***Stony-iron*** meteorites almost always come from differentiated planetary bodies, as they are made when iron-rich material becomes embedded into a rocky mass.

We will consider two classes of meteorites: *chondrites* and *achondrites*. For the purposes of this lab, ***chondrites*** are meteorites that have not been significantly processed since their ***parent body*** (the planetary body on which the meteorite originally formed) accreted. In fact, many chondrites contain primitive particles like chondrules. ***Achondrites*** are meteorites that have been significantly processed either through volcanic activity or planetary differentiation. All iron meteorites are achondrites. Stony meteorites that have chondrules or that otherwise show a "jumbled" interior are usually chondrites. Stony meteorites which have a uniformly smooth interior, and which contain no obvious inclusions are generally achondrites that come from the crust or mantle of a differentiated planetary body. Nearly all stony-iron meteorites are achondrites.

Since chondrites contain regions that have not been significantly processed since the formation of the solar system, they are said to retain a "memory" of the early solar system. This does not mean that they have a brain and a central nervous system. It means that we can get an idea of what the early solar system was like by examining their chemical properties. The heating that goes with planetary differentiation or volcanism alters these chemical properties and erases the direct link to the solar system shortly after it formed.

Some characteristics to help you tell the difference between iron and stony meteorites:

- Iron is much denser. It is about 8 times denser than water, while typical rocky material is only about 3 times as dense as water.
- Metals have a property known as "luster" – they reflect light much better than rocky materials.
- The texture of iron tends to be smoother than that of stone. Stone tends to have a rough texture, or feels like it might crumble.

Fusion Crusts

During its passage through Earth's atmosphere, the outer surface of a meteorite can be heated to temperatures as high as 30,000 K. This causes the outer surface of the meteorite to melt. After the meteorite lands, the outer surface cools very quickly to form a blackened crust called a ***fusion crust***. The meteorite has spent a great amount of time in the cold depths of space. We will examine how these temperature differences affect the appearance and thickness of the fusion crust in a few of our samples.

Widmanstätten Pattern

The iron-nickel core is the last part of a differentiated planetary body to cool because it is insulated by the outer layers of rock. The weight of the outer layers squeezes the iron core as it cools. The combination of slow cooling and constant compression produces a criss-cross pattern of crystals that is preserved when the iron core finally solidifies. This cooling is extremely slow and regular – the core of a differentiated body will take many thousands of years to cool by

1°C. This process cannot be replicated by humans. When the cut and polished face of an iron meteorite is etched with acid, the pattern becomes visible. This pattern observed in etched iron meteorites is called a ***Widmanstätten pattern***. At least one of the iron meteorites you will examine in this lab has been etched to expose the Widmanstätten pattern.

Figure 54 - A piece of an iron meteorite that has been polished and etched with acid to reveal the Widmanstätten pattern.

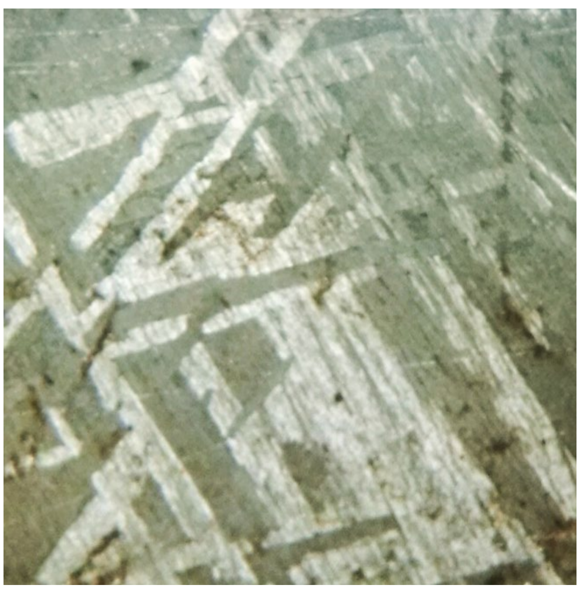


Figure 55 - A view through a microscope of another sample of an iron meteorite that displays a Widmanstätten pattern.

Meteorite Falls and Finds

Any meteorite that is seen falling to Earth and that is subsequently recovered is called a meteorite ***fall***. Meteorite falls are usually collected very soon after falling so the samples are nearly pristine. Meteorite samples that were not observed to fall are called meteorite ***finds***. Nearly all meteorites that are recovered are meteorite finds. Meteorites may sit unnoticed on the surface for decades, centuries, or even millennia

Because of the difficulty in telling the difference between a stony meteorite and a terrestrial rock, there is a disproportionately high number of finds for iron meteorites outside of Antarctica. In Antarctica, there are places that are covered with hundreds to thousands of meters of snow and ice. If you find a rock on top of this thick sheet, it is very likely a meteorite.

Geologists and meteorite hunters hope that looking for meteorites in Antarctica will give a better overall idea of how many of each type there are, as well as typical masses, sizes, etc. NASA has a site where you can see the statistics about meteorites that have been collected in Antarctica. Look closely at the number of chondrites vs. achondrites on the chart there.

Beyond Our Solar System

Stellar Classifications

In the section on absorption spectra, we mentioned the work of Cannon, Leavitt, and other astronomers who examined the spectra of stars. Cecilia Payne-Gaposchkin provided the theoretical framework for interpreting the spectra. Her Ph.D. thesis – *Stellar Atmospheres* – is one of the most important papers ever written in astronomy. Her work showed that stars are made primarily of hydrogen. The vast majority of stars consist of mostly hydrogen and helium. In stars like the Sun, many other elements are present. What Payne-Gaposchkin's thesis showed is how strong the absorption is from a particular element depends on the temperature of the star. At some temperatures, the absorption lines from a particular element can be very dark, but they may barely show up at another temperature. If you can correctly determine how strong the lines are from each element, you have a direct way of measuring the temperature of the star.

This thesis came after the other astronomers had recorded the details of *hundreds of thousands* of spectra of stars. They looked for patterns in the spectra and decided to classify them based on how strong the hydrogen lines are. The stars with the strongest hydrogen absorption lines were A-class stars, with B-class having the second strongest hydrogen lines, and so on. At one point, there were 22 letters in use. After further consideration and understanding of the patterns, only seven letters were left for classifying stellar spectra. Those letters are OBAFGKM, and they correspond to the following temperatures:

Table 1 - Spectral classifications with their corresponding temperature ranges

O	B	A	F	G	K	M
> 30,000 K	10,000 K to 30,000 K	7,300 K to 10,000 K	6,000 K to 7,300 K	5,300 K to 6,000 K	3,800 K to 5,300 K	2,500 K to 3,800 K

The surface temperature also affects the color of the star hotter stars are bluer, and cooler stars are redder. If you prefer to think of the spectral types that way, use this association of colors and spectral types:

OBAFGKM

There are a variety of mnemonics for memorizing the spectral classes. You may have heard "Oh Be A Fine Guy, Kiss Me" or "Oh Be A Fine Girl, Kiss Me". Another version is "Only Boys Accepting Feminism Get Kissed Meaningfully". There are also objects that are not hot enough to be stars called *brown dwarfs* that would come after M. Those would add extra letters. We are only going to consider objects that are powered by ongoing thermonuclear fusion as stars. Brown dwarfs do not meet that description.

In addition to the main spectral classes, there are subclasses for smaller temperature differences. These range from the number zero for the hottest star in a class, to nine for the coolest. The F class stars from hottest to coolest are then:

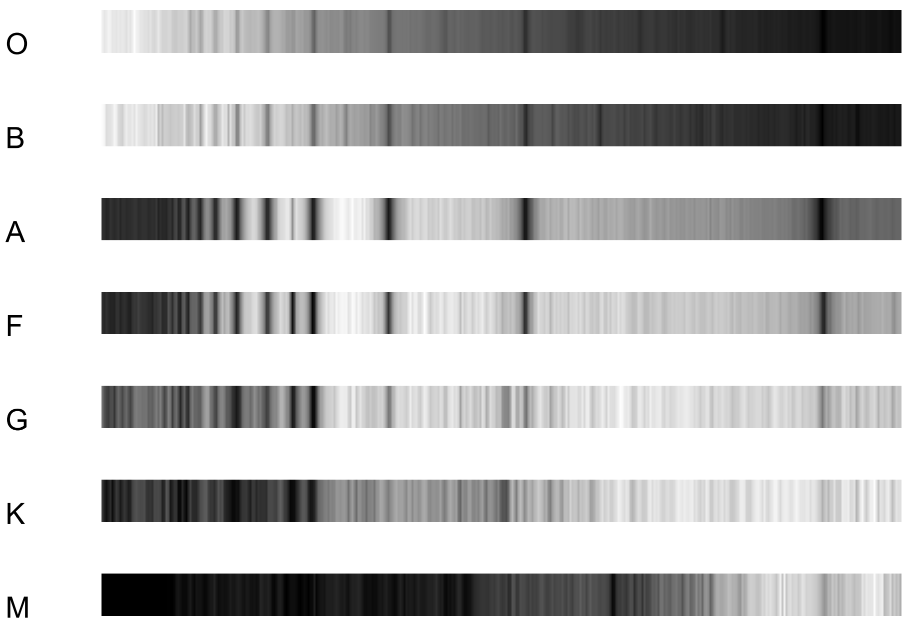
F0 F1 F2 F3 F4 F5 F6 F7 F8 F9

If a star is a bit hotter than an F0, it's the coolest A class star, which is an A9. If it's cooler than and F9, it's the hottest G class star a G0. If we extend the subclasses above, we get:

...A6 A7 A8 A9 F0 F1 F2 F3 F4 F5 F6 F7 F8 F9 G0 G1 G2 G3…

Our Sun, for example, has a surface temperature of 5800K, which makes it a G2 star.

In Figure 25 through Figure 27, we showed examples of spectra for three different stars. What do the spectra for stars of class O through M look like in general? The images below are used with permission from the Pisgah Astronomical Research Institute.



In the spectra shown above, the short wavelength (blue) end is at the left and the long wavelength (red) end is at the right.

What are some details you can see that will let you distinguish between the different spectra? You may notice that hotter stars have a brighter spectrum at the blue end, while cooler stars have a brighter spectrum at the red end. Can you think of why that is the case? If you're not sure, review the section on Wien's Law. More importantly, look at how the pattern of dark lines changes from one spectral type to another. These are the absorption lines caused by different elements. For the main spectral types (OBAFGKM), the differences are fairly distinct. Some lines stay relatively the same as you go from one type to another, but others become more prominent or fade away. These are the details you should be most aware of when trying to classify stars – how dark is a particular line relative to the other lines in the spectrum?

What about the differences within a spectral type? How different does a B3 spectrum look from a B6 spectrum?

B3 

B4 

B6 

B8 

The pattern of overall brightness is virtually the same, so much more attention needs to be given to the relative strength of the absorption lines.

Here's another example comparing some M-class stars.

M0 

M1 

M5 

Since these are all M-class stars, their spectra look very similar, even though they are an M0, an M1, and an M5. To do well with your classifications, note the small changes in the pattern of absorption lines when you look at different temperature stars.

Another way to compare spectra would be to look at their intensity vs. wavelength profile.

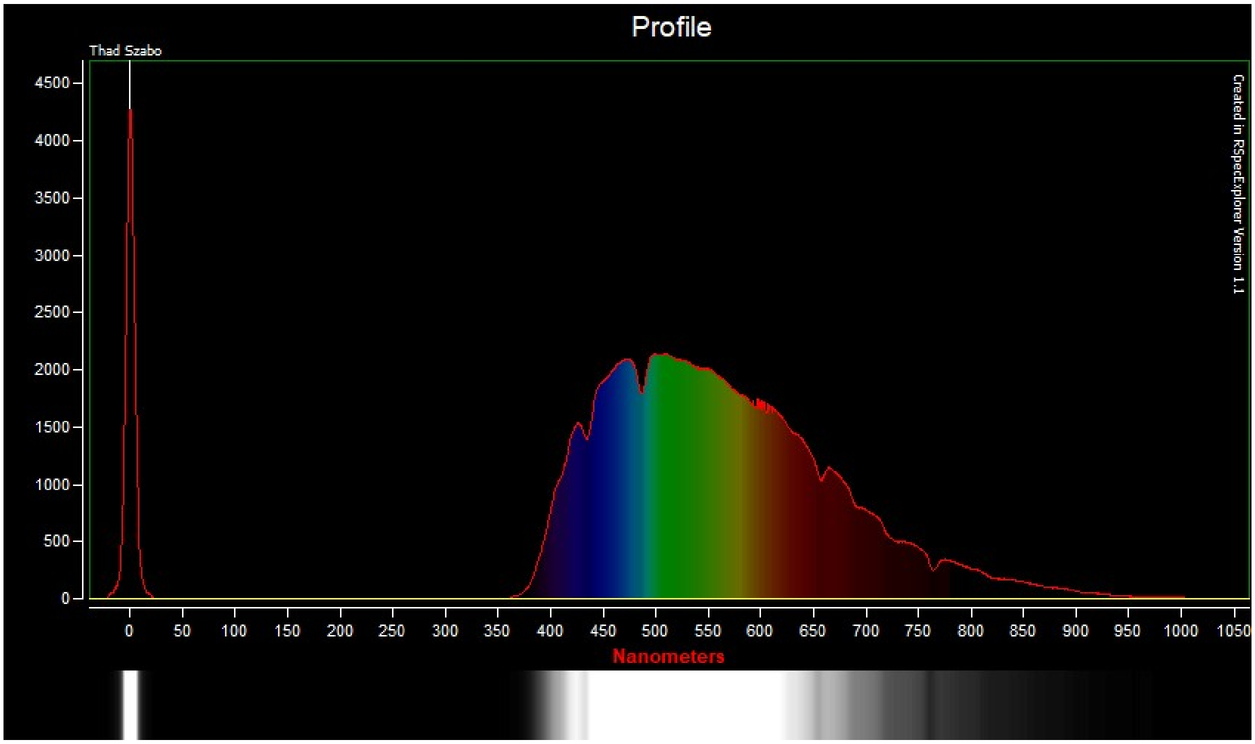


Figure 56 - Spectrum of the star Vega, a main sequence star with a surface temperature of 9600 K

Using this sort of plot has some advantages. For one, the wavelengths are included so that you can use more information than just the pattern of dark and light areas. You may also notice a problem with the representation of the spectrum below the plot – the region between about 440 nm and 600 nm is so bright that no absorptions lines appear. We say this part of the photo is overexposed. However, when you look at the intensity plot, you can see some significant drops that correspond to absorption lines. Also, if you can plot data, that means it can be represented numerically. It might be easier to use the raw data and compare numerical values at each wavelength.

Using numerical values, though, means that the spectra all need to be calibrated the same way. One spectrum might have numbers that are typically 4 times higher than another spectrum, so a direct numerical comparison won't work without adjusting by that factor of four. The problem is that you won't know what the factor is that you need to multiply by to get the correctly calibrated spectrum. If you have the option to use both the intensity plot and the picture of the spectrum, that is the best way to go.

Another way of representing what is happening with the absorption spectra at different temperatures is to see how strongly an element absorbs light at that temperature. The curves in Figure 50 show how much a particular element will contribute to the absorption spectrum at a given temperature. For example, for an A0 star at about 10,000 K, the curve for H (hydrogen) reaches its peak. We expect to find very strong hydrogen lines in these stars. There is also some contribution from Mg II (magnesium that is missing one electron) and from Si II (silicon that is missing one electron).

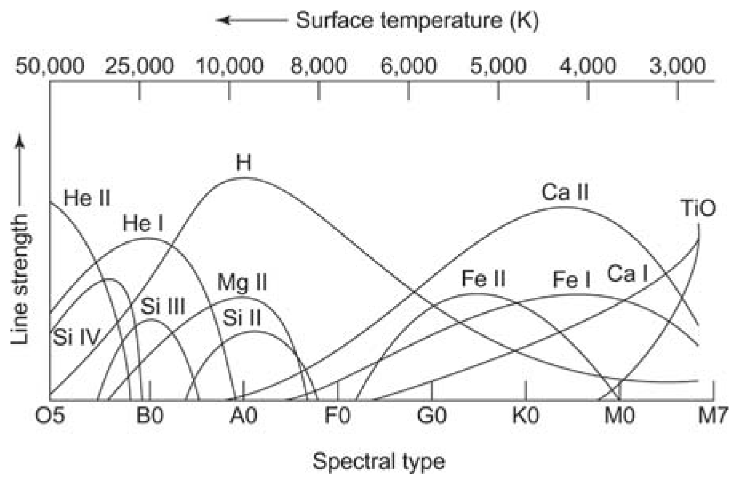


Figure 57 - Strength of the absorption lines for various elements depending on the surface temperature of the star. The taller the curve is at a given temperature, the more strongly light is absorbed by that element.

A G5 star would have a temperature between a G0 and a K0. Find where that would be in Figure 57. Note that the contribution from hydrogen (H) is much weaker. Ca II (calcium that is missing one electron) is strongest along with Fe II (iron that is missing one electron). There will also be a contribution to the spectrum from Fe I (neutral iron) and Ca I (neutral calcium).

Here are some general rules to keep in mind if you are trying to analyze absorption spectra by thinking about which elements contribute spectral lines.

- O-class stars are extremely hot. For atoms to interact with light, they need to have electrons attached. At such high temperatures, most atoms are ionized, meaning that they are missing electrons. Helium (He) contributes to O-class spectra, and overall, the lines are not very strong. O-class stars are also exceptionally rare; fewer than one in a million stars is massive enough to be an O.
- A-class stars will have exceptionally strong hydrogen (H) lines, but you will also find this to be a feature of cooler B-class stars. Look closely at what other elements appear in the spectrum. If you see ionized calcium (Ca II), it is a cooler A-class star. If there are no calcium lines, it is a B-class star.
- Cooler stars tend to have more absorption lines. G- and K-class stars will have strong Ca II lines. These are sometimes referred to as “H and K lines” because of how they were assigned when they were first found in the spectrum of the Sun. They occur at wavelengths of 397 nm and 393 nm; thus, they are at the violet end of the spectrum. The overall spectrum for these cooler stars tends to be fairly weak at the violet end, so it may be hard to see these lines.
- The spectra for M-class stars are particularly busy. There are many dark lines and dark areas present, and there is a molecule that contributes to the spectrum rather than only individual atoms. The molecule is titanium oxide (TiO). Other stars are too hot for atoms to join together to make molecules in their lower atmosphere, but M-class stars are cool enough for it to happen.

Deep Sky Objects

Aside from individual stars, there are other objects that maintain their position on the celestial sphere that have a diffuse appearance. Rather than appearing as individual points, these objects look like clouds of light or a sprinkling of many stars. One example that is visible from campus with the unaided eye is the Pleiades star cluster (M45). With the 8” telescopes, other star clusters are visible, as is the Orion Nebula (M42). The 14” telescope allows us to see even more of these sorts of objects. If we move away from visual observing to astrophotography, it is possible to get images of thousands of star clusters, nebulae, and galaxies from campus. Collectively, these are known as *deep sky objects*.

If you can get away from the lights of populated areas, there are deep sky objects that are visible to the unaided eye. We already mentioned the Pleiades star cluster and the Orion Nebula. Under dark skies, the Andromeda Galaxy (M31) is visible in autumn and winter in the evening from the Northern Hemisphere. From even darker skies, you can see the Beehive Cluster (M44) in winter or the Lagoon Nebula (M8) in summer. If you are in the Southern Hemisphere, you can look for the Large Magellanic Cloud (LMC) and the Small Magellanic Cloud (SMC).

At this point, you may wonder why you see “M” with a number appear after several of these objects. Astronomers like making lists of various types of objects that they see in the sky. The “M” stands for Charles Messier, a French astronomer who lived from 1730-1817. He observed the sky before the invention of photography, so his observations relied on sketches and descriptions. His primary focus when he started was discovering comets. Visually, comets and deep sky objects have very similar appearances. The big difference is that comets appear to move relative to the stars because they are located within our solar system. Deep sky objects lie far beyond the solar system, so they maintain their position on the sky. Messier was making a list of objects that he might confuse for comets. The largest catalog he published in his lifetime had 103 objects, but his notes allowed later astronomers to positively identify 7 more objects. The Messier catalog contains 108 deep sky objects along with 2 entries that are just a few stars. If you see an “M” with a number, that is a reference to one of the objects in his catalog.

Overlapping with the time that Messier made his observations, William and Caroline Herschel also started systematically scanning the skies for deep sky objects. Beginning in 1783, their observations led to the discovery of thousands of new deep sky objects that became part of the New General Catalogue (NGC). This is another common designation you will find. In most cases, a Messier object will also have an NGC number. For example, the Lagoon Nebula is known as both M8 and NGC 6523.

There are other catalogs of deep sky objects that you may encounter as you are learning what is available to view in the sky. The Caldwell Catalog is another set of brighter deep sky objects, like the Messier Catalog. It includes some conspicuous objects that Messier missed. If you are looking for nebulae, the Index Catalog (IC) or the Sharpless Catalog (Sh2) will provide additional targets. The Principal Galaxies Catalog (PGC) has about a million galaxies, most of which are too faint for anything other than photography.

Although all of these objects have a similar appearance visually, what can we learn about what these objects are like in space?

Within our solar system, there are changes that we can observe over minutes or hours, and some changes that take months or years to become obvious. The phase of the Moon changes noticeably from day to day, and the positions of the planets relative to the stars can be observed from week to week (or, day to day, if you look more closely). It is not possible to see changes of this sort in deep sky objects. They are so far away that for us to be able to see them, they need to be huge. Some nebulae are about a light year across; others are tens of light years in their extent. Open clusters tend to be a few light years in size, while globular clusters can be tens or hundreds of light years in diameter. Galaxies are tens of thousands or hundreds of thousands of light years across. Aside from a few special cases, it is impossible to see changes in any of these objects. We know they have to change over time, but it is not possible for a single observer to track these changes over their lifetime. Is there a way to understand how different deep sky objects are related to each other? Do they represent different phases of existence that an object or set of objects has during its time in the Universe?

Is there a way to use observations of different deep sky objects to put together the story of how structures form and evolve in our Universe? Do you think you could put together the story of how nebulae, star clusters, and galaxies are related?

Measuring Distances to Stars and Galaxies – The Distance Ladder

There is no easy way to judge the distances to objects in space. Even working out the distance to the Moon – the closest object to the Earth – took some careful thinking about geometry, lunar phases, eclipses, and the measurement of time. Measuring the distances to stars and galaxies is even more difficult. Some techniques that work for objects that are nearby no longer work when an object is more distant. It takes a set of techniques that overlap in order to measure distances of hundreds of millions of light years. Because of the different steps in this process, determining these distances is often called using the *distance ladder*.

Parallax

If you have vision in both eyes, try the following: hold an object (like your finger or a pencil) in place close to your face and switch which eye you view it with. As you change the view from your left eye to your right eye and back again, what does the object appear to do?

It should appear that your finger moved relative to the background. But you didn't actually move your finger, right? This apparent change in position is known as *parallax*. If you have two functioning eyes, the light entering each one at a slightly different angle generates a slightly different view. Our brains have evolved to compare these differing views in a way that gives us depth perception – we can make a rough estimate of how far away something is.

The key feature needed to make this judgement is that you have observations from two different locations. The observations do not even need to be at the same time. They both need a similar background for reference. The easiest object to do this with in the sky is the Moon. Your two observing locations still need to be fairly widely separated. Two people on opposite sides of a city won't be able to notice much of a difference. Two people on opposite sides of a continent will. Imagine that we have a night where the Moon appears fairly close to a bright star. You take a picture of them together, then you have someone you know who lives far to the north or south take a picture at the same time. When you compare the pictures, you see that the Moon isn't in the same place. If you measure the amount of angle that it shifts between the two pictures and you know the distance between you and your friend, you can figure out the distance to the Moon!

Aside from the Sun, stars are generally millions of times farther away than the Moon. You can't use two different points on Earth's surface as your baseline for measuring the distances to stars by using parallax. That's a few thousand kilometers at most. You can create a much wider baseline by having the Earth orbit the Sun. The Earth is 300 million kilometers away from where it was 6 months ago. This is a wide enough separation that we can use it to measure the distances to some nearby stars. The main thing to remember is that the apparent shift will be smaller for more distant objects and that the angle of the shift will be bigger for objects that are closer.

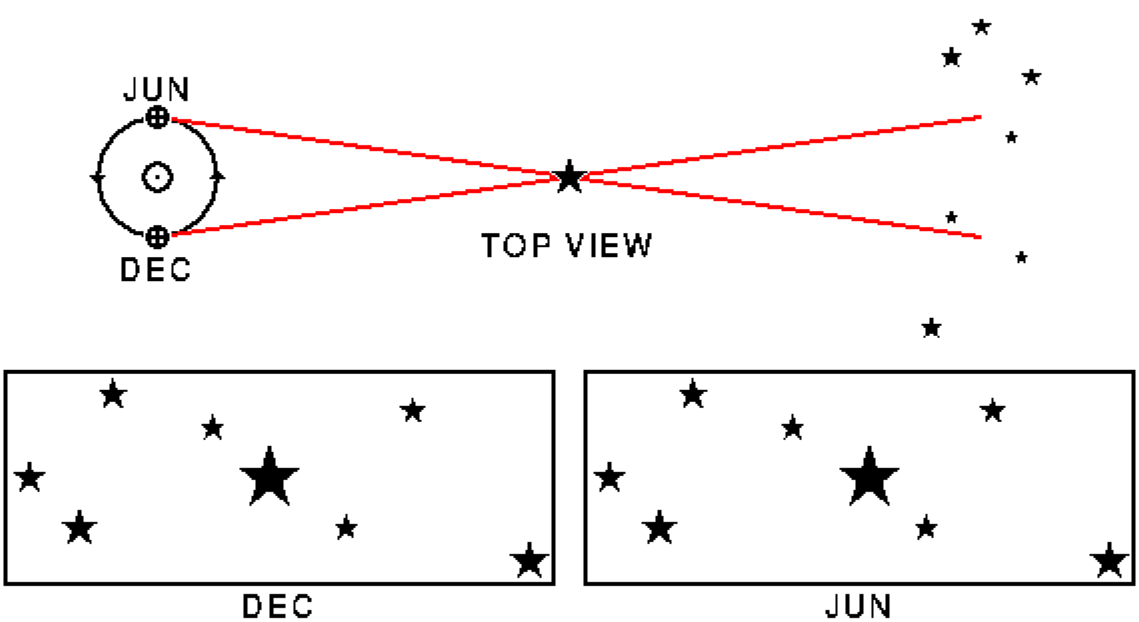


Figure 58 - The view of a nearby star relative to distant background stars changes as Earth orbits the Sun. The apparent change in position is very small.

Units of Distance in Astronomy

The distances that we need to think about in an astronomy course are enormous. There isn't anything in everyday life that gives us a useful comparison. If you feel like you can't picture or think about distances that are as big as we are about to discuss, you're not alone. It's beyond our intuition, but let's try.

If you move from the side of campus near Studebaker Road to the side near the stadium, you have moved about one kilometer (km). That's a distance that is pretty straightforward to comprehend. The distance from Cerritos College campus to downtown Los Angeles is about 30 km. That's also a distance that you could travel by walking (if you really had to). What about hundreds of kilometers? From Los Angeles to San Francisco is about 640 km. It's a long drive, but it can be done in a day. When we get to thousands of kilometers, our minds start to have trouble comprehending how far that is. On the ground, that's a journey that takes multiple days. If you fly, you don't get a sense of reference from an airplane that you need to judge distances.

What about the Moon? It's the closest thing to us in space. If you do the experiment I mentioned above where you compare the position of the Moon relative to the background stars from two different places on Earth, and you measure the distance between those places along by the size of the angle the Moon appears to move, you find that it is about 384,000 km away. That's 30 times farther than the diameter of the entire Earth.

When we talk about the distance to the Sun or to other planets, the distances get so big that it gets hard to keep track of all the zeroes if we measure in kilometers. We introduce a new unit for talking about distances in the solar system. We say that the Sun is one *astronomical unit* (au) from the Earth, on average. If you want that in kilometers, 1 au is 150,000,000 km. Our brains already don't deal very easily with distances of thousands of kilometers – how are we supposed to come to terms with hundreds of millions of kilometers?

We'll measure distances in the solar system generally with au. Giant stars can be an au or more in diameter, and supergiant stars like Betelgeuse and Antares have diameters of about 10 au. What about distances to other stars? An au is already really big, so it's probably good for measuring distances to stars, right?

The nearest star after the Sun is over 260,000 au away. Yes, that is the correct number. As large as the distances to planets are, the distances to the nearest stars are hundreds of thousands or millions of times bigger than that. In the interest of not having to write so many zeroes, we switch to a new unit again. One parsec (pc) is about 200,000 au. (To be exact, 1 pc equals 206,264 au.) If you want to measure the distances to stars in kilometers, you can, but I don't recommend it. The brightest star in our night sky is Sirius. It is 2.6 pc distant. That means it is 81,000,000,000,000 km away. Light takes eight and a half years to get to us from Sirius.

It seems like this number for the parsec is arbitrary. Why did astronomers decide that there are a bit more than 200,000 astronomical units in one parsec?

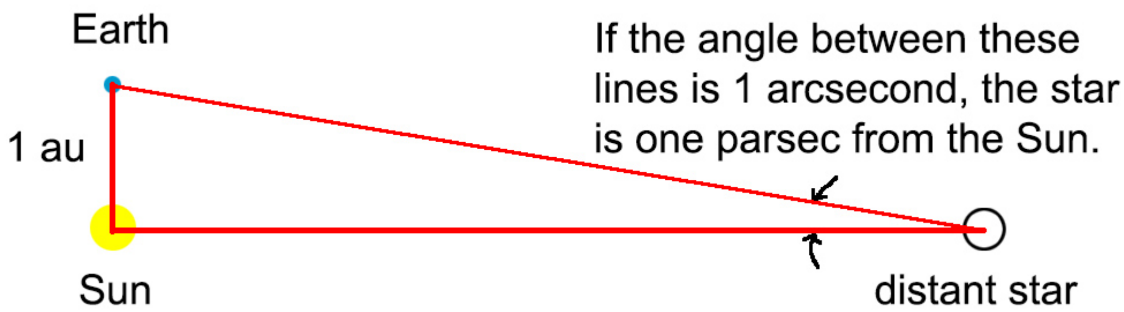


Figure 59 - How a parsec is defined; the drawing is not to scale, as an arcsecond is much smaller than this angle.

If you are one parsec away from the Sun, and you look back at our solar system, the Earth would appear one arcsecond away from the Sun. If you look at the angle in Figure 58 between the two lines of site to the star, that is defined as twice the parallax angle for that star. Figure 59 shows how the parallax angle is determined. If a star has a parallax angle of one arcsecond, it is one parsec from the Sun. A smaller parallax angle than that means the star is farther away than one parsec. There are no stars closer to the Sun than 1.3 pc. Parallax angles are very tiny and quite difficult to measure.

Relationship Between Distance, Brightness, and Luminosity

If we can't measure parallax, how can we find the distance to objects in space? If we know how much light a particular star produces, we can measure how much light reaches us and determine the distance from that. The amount of light that something produces is its *luminosity*. When we investigated continuous spectra, we saw that the Stefan-Boltzmann Law relates the temperature of an object to how much energy it produces per surface area. The luminosity of a star is related to its temperature and its size. Another way to talk about the luminosity of a star is to refer to its *absolute magnitude*. If we use the absolute magnitude in an equation, we assign it the variable of capital *M*.

How bright an object appears can be represented by its apparent magnitude, which uses the variable lowercase *m*. To get the distance in parsecs to a particular star, we use the following equation:

$$d = 10^{\frac{m-M+5}{5}}$$

You won't have to know how to solve that for this class, but let's do an example or two.

I mentioned the star Sirius previously. Sirius has an apparent magnitude of m = -1.4 and an absolute magnitude of +1.43. If we use those values in the equation, we get:

$$d = 10^{\frac{(-1.4)-(+1.43)+5}{5}}$$

$$d = 10^{\frac{2.17}{5}}$$

$$d = 10^{0.434}$$

This gives a distance of 2.7 pc for Sirius.

If you are looking at the sky in the autumn, you may notice the star Mirfak. Mirfak has an apparent magnitude of m = +1.8, but it is a supergiant star so it is incredibly luminous. It has an absolute magnitude of -5.1. (Like the relationship between apparent magnitudes and brightness, smaller or more negative absolute magnitudes mean higher luminosity.) If we use these values in our distance equation, we get:

$$d = 10^{\frac{(+1.8)-(-5.1)+5}{5}}$$

$$d = 10^{\frac{11.9}{5}}$$

$$d = 10^{2.38}$$

This puts Mirfak at a distance of 240 pc away. The light you see from that star left about 780 years ago just to land on your eyeball.

The main point to get from this is that if we have another way of determining the luminosity of an object, we can measure how bright it is and use that to determine the distance. Objects whose luminosity is well-known through another property they have are called *standard candles*. We will consider two types of standard candles for measuring greater distances in our Universe: Cepheid variable stars and Type Ia supernovae.

Pulsating Variable Stars (Cepheid Variables)

A casual look at the stars makes it seem like they all maintain their brightness. If you make careful comparisons between some stars and some of their neighbors in the sky, you will note that they change brightness over time. In some cases, this is because the star has used up enough of its fuel that it is now unstable. There are giant stars that pulse regularly – some with periods of hours and some with periods of months. These are known as *variable stars*.

One of the most important types of variable stars are δ Cepheid (pronounced *delta SEE-fee-id*) stars. The American Association of Variable Star Observers (AAVSO) has a very informative page about these stars and their importance. During the 1910s, Henrietta Leavitt found that Cepheid variables with longer periods had higher average luminosities. If you could measure the period of one of these stars, you had a direct way of knowing its average absolute magnitude. That makes Cepheid variable stars a type of standard candle. You can measure a separate property and that will tell you its overall power output.

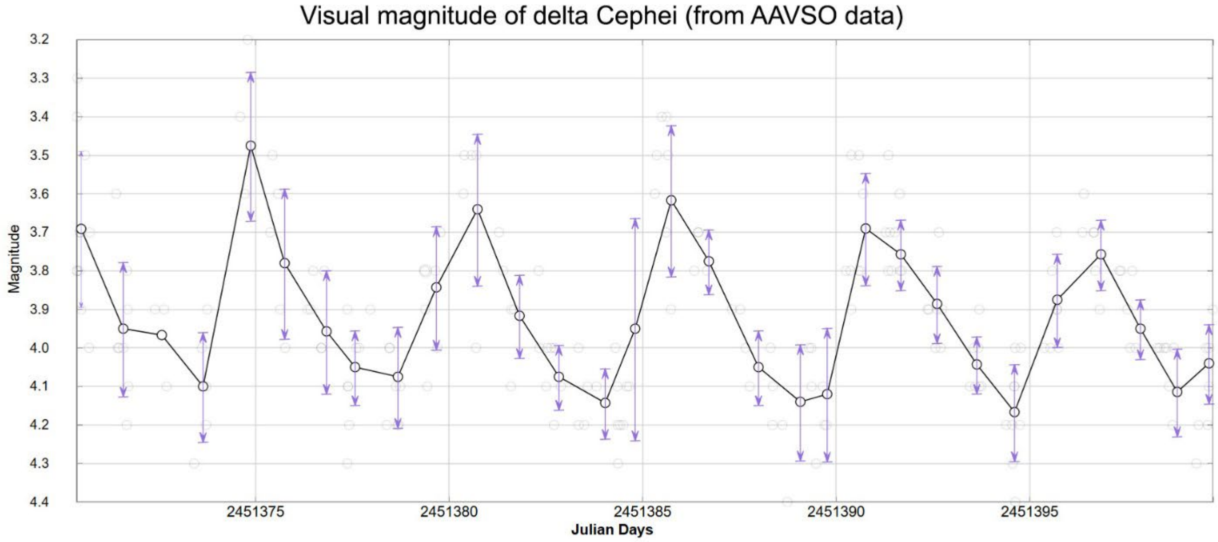


Figure 60 - A plot showing how the magnitude of delta Cephei changes over a span of 30 days. It has a period of 5.366 days.

Type Ia Supernovae

All detonate by runaway carbon fusion (not constrained at the core of a star by its outer layers). Because it is always the same mechanism, these supernovae should explode with the same luminosity. The typical luminosity corresponds to an absolute magnitude of M = -19.3. This is a bit of an oversimplification – some Type Ia supernovae are more luminous than others. It is necessary to measure the time for a Type Ia supernova to brighten and fade and to make measurements in different color bands in order to characterize differences between them. The time for the supernova to brighten and fade correlates with its overall luminosity. With this correction being known, it is possible to use Type Ia supernovae as a standard candle for measuring distances in space. The incredible luminosity of Type Ia supernovae makes them the single objects that allow us to measure the farthest distances fairly directly.

Hubble's Law

At the beginning of the 1920s, we did not know what galaxies were. Dim, fuzzy objects had been observed for over a century in large telescopes, but determining their nature was beyond the ability of astronomers until that decade. These fuzzy objects sometimes showed a spiral structure, and occasionally a star would brighten and fade away in one of them. There are a few that are visible to the unaided eye – the Large and Small Magellanic Clouds in the Southern Hemisphere and one in Andromeda that passes high overhead in the autumn in the Northern Hemisphere. No telescope built before 1917 could discern any individual stars in these structures.

In 1917, astronomers first used the 100-inch reflecting telescope at Mount Wilson Observatory. This was a large enough aperture that images taken of the fuzzy patch in Andromeda could resolve individual stars. In October 1923, Edwin Hubble was taking pictures of the "Andromeda Nebula" and discovered over the course of a few nights that one of the stars was changing brightness with a regular, recognizable pattern. This pattern indicated that it was a Cepheid variable, so Hubble could use the relationship between period and luminosity that Henrietta Leavitt determined to get the distance to the star. Hubble measured the periods of 12 Cepheid variables in his images and used their luminosities to determine the distance to the "nebula". The distance was much bigger than any estimate for the size of our own galaxy, which showed that the object in Andromeda was another galaxy. The 100-inch telescope had paved the way to discovering the true scale of the Universe.

One point that should be clear from the previous sections of this manual is that taking the spectra of astronomical objects is a potent way to learn more about them. Hubble and his associates began taking spectra of galaxies whose distance they were able to measure. A careful analysis showed that they could recognize the patterns of lines for different elements, but those absorption lines weren't exactly at the expected wavelengths. Galaxies at greater distances had spectral lines that were shifted farther to longer wavelengths. Since the longest wavelengths visible to human eyes appear red, this shift was called "redshift". The essence of Hubble's Law is that the farther away a galaxy is, the more redshifted its spectrum is.

It didn't matter which direction Hubble made measurements – all galaxies, regardless of where they were on the sky, showed this pattern. The explanation for the change in the position of the spectral lines is that the galaxies were moving away from us. This motion puts more distance between the crests of the electromagnetic waves as they arrive at our telescopes. The faster the galaxy moves away, the more stretched the light becomes. Why were all the galaxies moving away from our galaxy?

Imagine that you are standing or sitting on a large rubber sheet. It extends so far that you cannot see the edges of it. You look around at other people and objects that are on the sheet with you and see that some of them are nearby and others are farther away. The sheet then begins to stretch in all directions. You can't see what is pulling it, but you notice that every other object is getting farther away from you. The objects that are more distant appear to be moving away faster. You ask some of the people you can shout to whether they are moving. They all report that, as far as they can tell, they are standing still and everyone else is moving away from them. They also all see more distant objects moving away faster, even though no one is walking around on the sheet. This example is akin to how Hubble interpreted what was going on with the galaxies. To explain the motion he saw, he realized the Universe must be expanding. Space itself, in between the galaxies, was somehow stretching and growing.

The equation that represents Hubble's Law is:

$$v = H_0 d$$

The speed at which a galaxy appears to be moving away is represented by v, and d is the distance to the galaxy. H_0 (pronounced "h naught") is known as Hubble's constant. It tells you what the expansion rate is of the local Universe. The equations that describe the expansion and history of the Universe show that the expansion rate was different in the past, so the zero or “naught” is used to signify that this is the expansion rate we measure for the current time. (Remember that due to the finite speed of light, as you look farther out into the Universe, you are looking into the past.)

Telescope Observations

One of the factors that affects visual observations of the sky the most is the weather. We will examine two factors in particular:

- transparency
- seeing

There is a website designed specifically to allow you to check these: astrospheric.com

Transparency

To put this really simply, if the sky is cloudy, the transparency is poor.

Of course, there's more to it than this. The big factor here is water vapor. There can be other effects, like smog or smoke, but the one that affects transparency the most is water vapor. Water vapor will prevent the light from astronomical objects from reaching the ground, so poor transparency may make it impossible to view certain objects.

Planets and the Moon are relatively unaffected by less than average transparency. There are times I have had my telescope aimed at a planet or the Moon, and as I am looking through the telescope, the image goes a bit dark. As I look away to the sky, I notice that the sky has completely clouded over. On nights with poor transparency, we can still try to view the Moon or planets.

Other fainter objects, though, become impossible to view. These objects have so little light reaching Earth's surface anyway, that this kind of interference blends them into the background of the sky. These are *deep sky objects* - star clusters, nebulae, and galaxies - we will discuss them later.

Seeing

Put simply, seeing is a measure of how steady the air is.

Have you ever looked at the stars on a night when they are twinkling like crazy? On those nights, the atmosphere is very unstable above you. It swirls and sinks and rises, and all those little changes in temperature and density bend the light that passes through the air. If you aren't concerned about very fine detail, you can still observe. If you're trying to see the Red Spot on Jupiter or small craters on the Moon -- forget it. When you look through a telescope on a night with bad seeing, it looks like small objects are under water. They're not - but they are under a roiling ocean of air.

On the other hand, here in Southern California, you might get nights where the stars do not twinkle. If the stars are shining steadily, that is the night to go after small features on Mars' surface or all the peaks in a mountain range on the Moon. You'll pick up the best detail in anything you are trying to take pictures of. Good seeing is one of the reasons so many observatories were built in Southern California.

Light Pollution

I didn't mention this one earlier. As long as you are observing from the Los Angeles Basin, you are going to have to deal with interference from background lights. If the transparency is poor, these background lights get scattered into the sky, obscuring the view of deep sky objects. There are filters you can put in a telescope that can help. They have a much stronger effect on photographs than they do on visual observations, because our eyes are only so sensitive. Filters always cut out light, but in some cases, that might help increase contrast with the background. It definitely can cut interference from artificial light when taking images of faint objects with a camera.

Unfortunately, we won't get to a truly dark sky during the course of the lab. The Astronomy Club at Cerritos sometimes takes trips to darker sites, if you want to join us on those trips. We could have a blackout that would make it possible to see faint objects, but if we're conducting the class on-line, a lot of people would have trouble participating at that point. I guess, if that happens, go outside and see if you can see the Milky Way.

Where to look on the sky

Either transparency or seeing will generally be better when you are looking through less atmosphere. It is best to try to view objects when they pass close to the zenith. That is where you are looking through the least atmosphere out into space.

Of course, with a lot of objects, you don't have a choice. There are a lot of really amazing nebulae and star clusters in the constellation Sagittarius. From the Los Angeles area, though, they are never very high in the sky. Observers in the Southern Hemisphere have this part of the sky pass high overhead -- it is an amazing sight from somewhere dark. On the other hand, in the Northern Hemisphere, we get a lot of really nice-looking galaxies that pass near the zenith. These are hard to observe from the Southern Hemisphere.

For planets, a good rule is "don't try to take pictures if the planet is less than 30° off the horizon."

Telescope Observation Basics

All telescopes used for visual observations have two main elements - an *objective* and an *eyepiece*. The objective is the part of a telescope that captures the light and first brings it to a focus. It can be either a lens or a mirror. The eyepiece takes the concentrated light from the objective and converts it into an image you can view with your eye. The objective is a fixed element that is built into the telescope. Eyepieces can be changed to give different *magnifications*. Magnification is defined as how many times bigger something appears through the telescope than it appears to the unaided eye.

Telescopes are measured by the *diameter* of the objective. A 4-inch telescope is not four inches long; it has a primary lens or mirror with a diameter of 4 inches. The *area* of the objective determines how much light a telescope can collect. *This is a far more important feature than the* *magnification of a telescope.* Enough light has to reach your eye for you to be able to see an image. If the magnification is too high, it takes that light and spreads it out to a degree where nothing is visible. The diameter of the telescope is the first characteristic you should focus on. Another name for the diameter is the *aperture*.

A telescope needs to be long enough for the light that comes from the objective to come to a focus before it reaches the eyepiece. The next bit of information that defines a telescope is the *focal length*. Sometimes, instead of the focal length, you are given the *focal ratio* of a telescope. What do these terms mean?

Let's use the example of our 4-inch telescope again. Although telescopes may be marketed by their aperture in inches, it will be best to convert that to millimeters to compute other important quantities. There are 25.4 mm in one inch. So, our 4-inch telescope has an aperture of

4 (25.4) = 102 mm

A quick search shows that there are models of these telescopes with focal lengths of 500 mm, 660 mm, 714 mm, 900 mm, and 1350 mm. Why are there so many choices? There is a general tradeoff between the focal length of a telescope and the field of view that it provides. *A longer focal length usually means a narrower field of view.* This means that some telescopes are better suited for some objects and applications than others.

To get the focal ratio, divide the focal length by the aperture. This means the 500 mm telescope has a focal ratio of

500/102 = 4.9

You will find this telescope listed as a 4-inch, f/4.9 telescope. Similarly, the one with a 714 mm focal length is a

714/102 = 7

4-inch, f/7 telescope. This scope will usually have a narrower field of view than the f/4.9 telescope of the same aperture.

Finally, the one with a focal length of 1350 mm would have an f/ number (focal ratio) of

1350/102 = 13.2

f/13.2. This likely provides the narrowest field of view of these examples.

Each eyepiece has its own focal length and its own field of view. You need the focal length of the telescope and the focal length of the eyepiece to compute the magnification. If you have a telescope with a 1000 mm focal length, you may be given a choice of a 25 mm eyepiece and a

10 mm eyepiece. To determine the magnification, *divide the focal length of the telescope by the focal length of the eyepiece.* For our example, this means the 25 mm eyepiece gives a magnification of

1000 mm/25 mm = 40.

Thus, this combination makes an object appear 40 times bigger, or that it has a magnification of 40x. If we use the 10 mm eyepiece with this telescope, you get a magnification of

1000 mm/10 mm = 100.

This combination makes objects appear 100 times bigger (100x). It sounds like it may give a better view. You need to also take the field of view into consideration. Let’s say that both eyepieces have a 60° field of view (or 60° FOV). To get the field of view when these eyepieces are used with our 1000 mm focal length telescope, *divide the field of view of the eyepiece by the magnification*.

For the 25 mm eyepiece, this gives a

60°/40 = 1.5° field of view.

This is about 3 times the diameter of the full moon. For the 10 mm eyepiece, we would get 60°/100 = 0.60° FOV.

The full moon would just barely fit in the field of view with this combination.

When you are first aiming a telescope at the sky, a bigger field of view makes it easier to find the object you are looking for. It gives you a wider window onto the sky. *Always start with the longest focal length eyepiece when you are trying to find an object*. This will make it easier to get it in view. Once you have the object you are looking for in view, then you can decide to switch to a shorter focal length eyepiece with a higher magnification.

Note how if you use these eyepieces with telescopes of different focal lengths, you get different magnifications and different fields of view. These are values you need to compute with any combination that you use. In the sky journal examples that were provided earlier, note how the magnification of the telescope and eyepiece combination are provided. You will need to include the magnification with every telescope observation that you make, so make sure to note the aperture and focal length of the telescope along with the focal length of the eyepiece.

Telescope Designs

Since the objective of a telescope can be either a lens or a mirror, the main classifications of the design of a telescope are *refractors* (which use a lens) and *reflectors* (which use a mirror). In the section on optics, we discussed that different types of glass can have different indices of refraction. Since the lens of a refracting telescope bends or refracts light, they are called refractors. Similarly, a mirror reflects light, which is why telescopes that use a mirror as the objective are called reflectors.

Refracting Telescopes

The first telescopes ever constructed were refracting telescopes. The objective is a large convex lens in the simplest refracting telescopes. In more expensive telescopes, multiple lenses work together to reduce the effects of different wavelengths of light having slightly different indices of refraction in glass. These differences cause color fringes to show up when you look at objects or take pictures of them through the telescope – an issue known as *chromatic aberration*. You may see these telescopes referred to as *achromatic refractors* or *apochromatic refractors*. An achromatic refractor can get two different colors to focus in the same plane, while an apochromatic refractor can get three different colors (or wavelengths) to focus in the same plane. Apochromatic refractors can produce very high-quality images, but they tend to be quite pricy for apertures larger than 4 inches.

If you use the Coronado H-alpha telescopes to observe the Sun during the semester, those are refracting telescopes. The finderscope on the back of the telescopes you use for nighttime labs is also a small refractor. Binoculars are designed like refractors, but they have additional prisms inside to bend the path of the light more than it is redirected in a telescope.

You can change the eyepiece in a refractor the same way you would in most telescopes. Because the light path in a refractor is straight, the length of the telescope is usually about the same as its focal length. This means that, in general, you get more magnification from longer refractors since the number in the numerator for computing magnification is bigger.

Newtonian Reflecting Telescopes

There are a variety of possible setups for reflecting telescopes. We will go over the two types that you will use in lab.

The primary type of telescope you will use in the lab is an 8” Newtonian reflector.

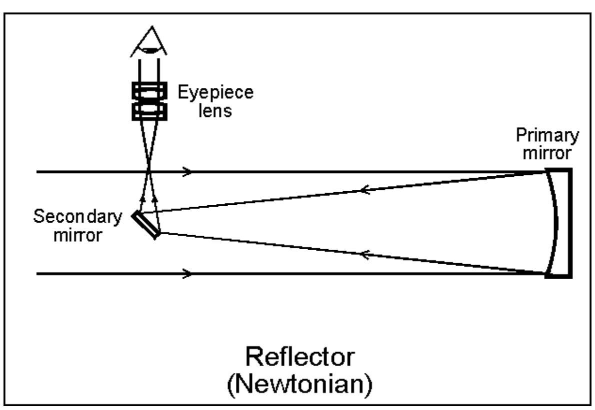


Figure 61-- Light path for a Newtonian reflecting telescope

(image from www.morehead.unc.edu)

In this case, the objective is a *parabolic mirror*. As mentioned in the discussion about mirrors in the optics section of the manual, parabolic mirrors do not have distortions from light rays that reflect off them. All of the light rays come to a focus at the same distance – the focal length of the telescope.

Cassegrain Reflecting Telescopes

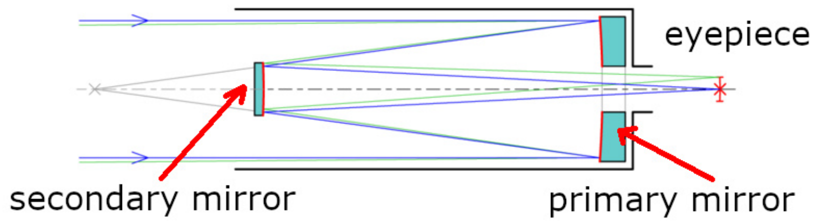


Figure 62 - Light path for a Cassegrain reflecting telescope -- the primary mirror is the objective. Sometimes the secondary mirror has a convex shape to achieve a longer effective focal length.(Adapted from an image from Wikipedia)

Cassegrain reflectors are not as long as Newtonian reflectors since the light path bends back on itself. This design choice allows the length of the telescope tube to be used twice. The diagram in Figure 52 shows the light reflecting off the primary mirror to travel back up toward the opening, then traveling back down the tube toward the eyepiece. This can be accomplished with a parabolic primary mirror. It is less expensive to produce a spherical mirror than a parabolic one, so Cassegrain reflectors often have a shaped piece of glass that holds the secondary mirror in place. This glass allows light rays that strike a spherically curved mirror to reflect the incoming rays to the same point. If this corrector plate is present, the design is a *Schmidt-Cassegrain reflector.* The 14-inch telescope in the observatory is a Schmidt-Cassegrain design.

Using the 8” Dobsonian Reflectors

Most often, these telescopes will be given to you with the tube of the telescope attached to the base. This is done with bolts that have a knob on opposite sides of the base. You want to make sure that the bolts are not too loose or too tight. If they are too loose, when you tilt the telescope to a certain position, it will continue to move. You want the telescope to point steadily at a point on the sky, so you should tighten the bolts in this case. However, you want to be able to change the position of the telescope without too much force. It should move smoothly as you push it. If you find that it is hard to move or it feels like it gets stuck, loosen the bolts. With practice, you will find the amount that makes it most comfortable for you to use.

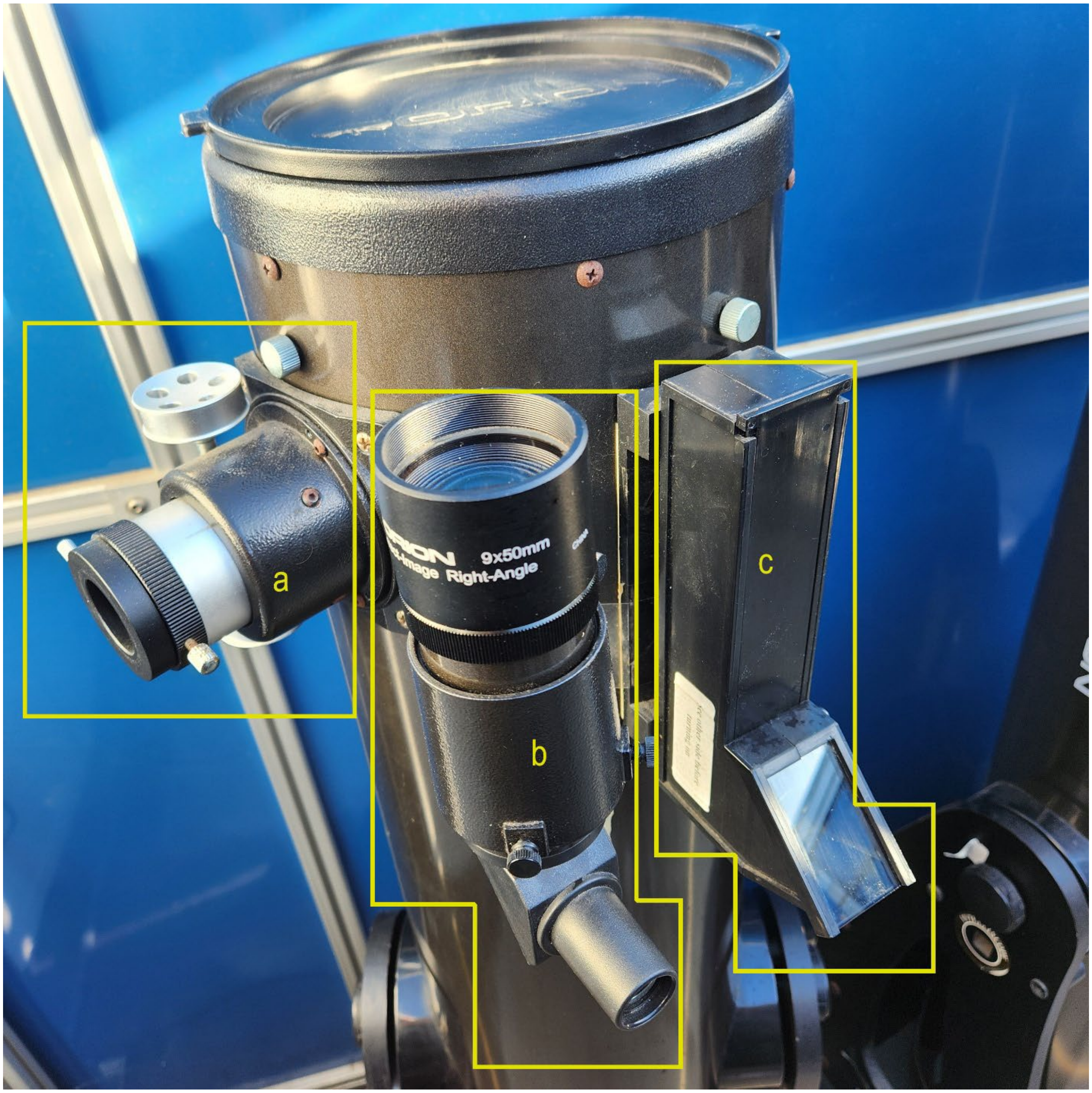
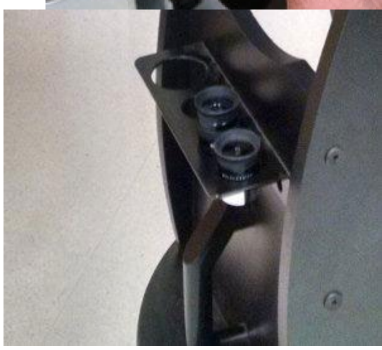


Figure 63 - look for the following three items on the back of your 8" Dobsonian telescope: a) is the focuser where the eyepiece is placed; you focus the telescope by turning the metal wheel; b) is the 9x 50mm finderscope; and c) is the Telrad.

The eyepiece holder can accept eyepieces with either a 1.25” diameter or a 2” diameter. The set of eyepieces you are given with lab all have 1.25” diameters.

To put an eyepiece in the telescope, loosen the screw on the eyepiece holder -- do not remove the screw. Slide the eyepiece into place until it is seated in the holder, then tighten the screw.

Be gentle when you do this - the eyepiece and focuser are sensitive mechanisms. Do not attempt to jam, force, or twist the eyepiece into the holder. Please ask if you need assistance.



Store the eyepieces you are not using in the rack that is on the base of the telescope. This will make it easy to get to them when you need to switch eyepieces to change magnification. *Do not attempt to move or lift the telescope with this rack*, as it will break off from the base.

Aiming a telescope requires that you have a device with a wider field of view that you can point at the sky. This is why there is a *Telrad finder* and a *finderscope* mounted on the back of each Dobsonian telescope. (See Figure 63 for how to identify each of these pieces of equipment.)

Do not use the Telrad as a handle, or to move the scope around. Doing so can damage the Telrad or its holder, or cause it to become misaligned. Only move the telescope by holding onto the tube, or the handle under the opening at the top of the tube.

You are now ready to align the Telrad to the telescope. Remove the cap from the top of the tube, and aim at a bright streetlight. A streetlight is best at first, since it will not move. Get the light centered in the view in the eyepiece.

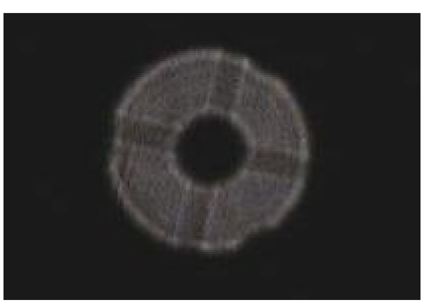
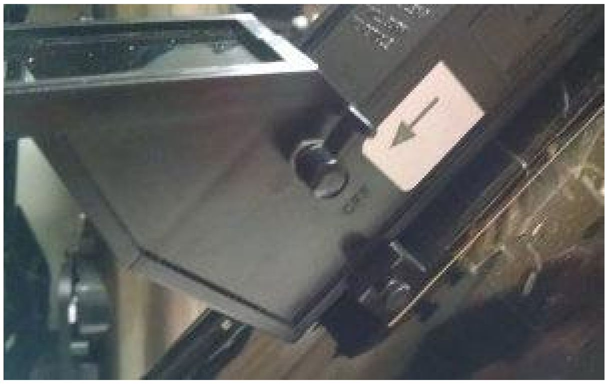


Figure 64 - an out-of-focus star viewed through the telescope

The eyepiece is set inside a focusing mechanism. Each person has a slightly different structure to their eye, so you should not expect an image that is in focus for someone else to be in focus for you. If an image is badly out of focus, it will appear like it does in the picture in Figure 64 - like a fuzzy circle with a dark spot in the middle. If you turn the focus knob and the fuzzy circle keeps getting bigger, turn the focus knob the other way. Continue turning it while watching the fuzzy circle get smaller and smaller. Eventually, the dark circle in the middle will disappear, and the object will come into focus. If the focus knob stops turning, it has reached its limit. Stop, and turn it back the other way.



Once the streetlight is centered in the view in the eyepiece, turn on the Telrad with the switch on its right side. The image to the right shows the switch on the Telrad in the “ON” position.

If you look into the Telrad, you should now see a red bullseye. If the Telrad is properly aligned with the telescope, a reflection of the streetlight you are aiming at will be in the center of the bullseye. If the bullseye is not centered on the streetlight, but the streetlight is still in view in the eyepiece, there are three screws on the back of the Telrad that can be adjusted to change the position of the bullseye. You can try adjusting them to get the bullseye centered on the streetlight, or you can ask for help.

You can also try this procedure with the Moon or a bright planet or star. If you do, keep in mind that diurnal motion will move the object on the sky as you are trying to make adjustments. It is trickier to use this method to align the Telrad, but you will likely be successful doing it this way as you get more experience with the telescope.

The finderscope is a small refractor that has a low magnification and a crosshair in the view through its eyepiece. You may need to make adjustments to where the finderscope is aimed using the two screws on the sides of the circular bracket that holds it. It should be aligned on the same target as the Telrad and the main telescope. Some objects are hard to locate with how much light pollution there is on campus. The finderscope will make it easier to see fainter stars, which will make it easier to move the telescope to a precise location on the sky. This technique is called *starhopping*. When used in combination with an app like Stellarium, it makes it possible to locate many more objects with the scope. This can be particularly useful for fainter objects like star clusters and nebulae.

You will likely start with observing the Moon. Look at how the Moon is oriented in the sky and compare that with the view through the eyepiece. You may notice that the Moon appears rotated 180° in the eyepiece view. This is because of the way the rays of light move through the telescope and eyepiece after they bounce off the parabolic mirror. When you make sketches in your sky journal of your view through this telescope, draw objects as you see them. Do not try to correct for the rotated appearance.

Using the 14” Schmidt-Cassegrain Telescope

In general, your instructor will set up and aim the 14-inch Celestron Schmidt-Cassegrain telescope (SCT) for you. You may need to make small adjustments to the focus for images to look as sharp as possible for you. The focus controller is electronic. While looking through the eyepiece, hold down one of the buttons on the focus controller. If the image is getting blurrier, switch which button you hold down until it becomes sharper.

Figure 65 - The controller for the focuser for the 14-inch SCT

NEVER ADJUST THE FOCUSER BY HAND – only use the controller. It looks like there is a shiny brass knob on the back of the telescope for you to turn; do not touch it. Sometimes the telescope is used with automated software that requires the focuser position to be read from the position of the motor. If you turn the knob by hand, the position of the motor and the position of the focuser will be out of sync. Using the controller makes sure that they stay in sync. The response is slow, but that is by design. We can achieve a very sharp focus when we need it with this motorized focuser.

You should also be aware of what sort of *visual back* is attached to the 14-inch SCT when you are using it. Usually, it will have a diagonal in place between the telescope and the eyepiece.

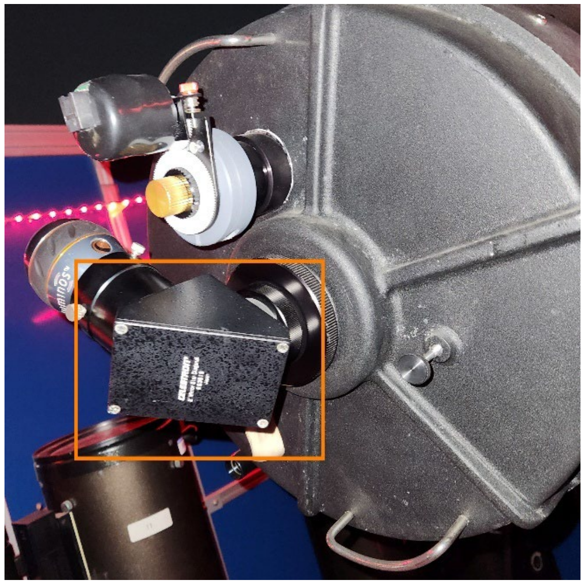


Figure 66 - The back end of the 14-inch SCT showing the diagonal outlined in orange. The mechanical focuser is shown here above the diagonal and eyepiece.

If the diagonal is present, objects viewed through the eyepiece will be flipped north-to-south, but not east-to-west. In other words, they will appear upside down, but without a change in view left-to-right.

In some cases, there may not be a diagonal present. This arrangement is often used if we are going to do some astrophotography of the Moon or planets that evening. Like the view through the Dobsonian scopes, this arrangement will rotate the view of the object by 180°.

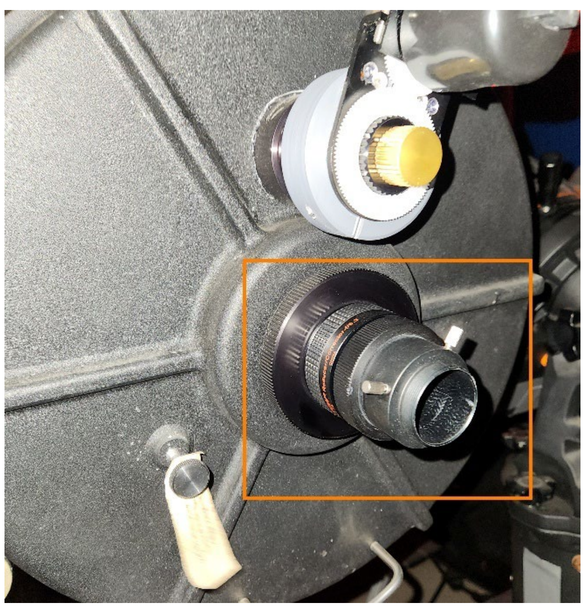


Figure 67 - The back of the 14-inch SCT when no diagonal is present. There is no eyepiece inserted in the telescope in this image. An eyepiece would be placed in the round opening inside the orange rectangle.

Advanced Observation Activities

The following activities are listed in order of difficulty. Some of them can be set up and working in about 15 minutes, while the more advanced ones can take hours of planning to execute. For any of these activities, you need a mount that will move with the sky. The C14 telescope in the observatory is permanently on an *equatorial mount*. One axis of the mount points at the North Celestial Pole. Once the telescope is aimed at an object while this mount is running, it will rotate with the Earth so the object stays fixed in the field of view. The controller for the mount has one pair of buttons that controls the right ascension (RA, east-west) and another pair that controls the declination (DEC, north-south). There is a separate CGEM DX equatorial mount that can be rolled out from the boiler room for use with other telescopes. If you want to take images of the Sun, you can use this portable mount with one of the Coronado 60 mm H-alpha solar telescopes.

An important step in using an equatorial mount is making sure it is properly balanced. A telescope plus an attached camera will make the mount top heavy. Properly positioned counterweights are used to prevent strain on the motors for the mount. The system needs to be balanced both in declination and right ascension. You should have the instructor check this for you, but if you need to rebalance anything:

- Start with where the telescope sits in its bracket. Rotate the mount so that the counterweight bar is pointing toward the ground. Unlock the clutch for the DEC axis while keeping a hand nearby to keep the telescope from swinging uncontrollably. If the scope turns freely so that the back of the scope is nearer to the ground, you need to move the scope forward in the bracket so more of its weight is toward the front. If the scope turns freely so the front of the scope points toward the ground, you need to move the scope backwards in its bracket so more of the weight is toward the back. Continue making adjustments until there is no preferred way for the scope to turn, or it only turns very slowly if tapped. This means the scope is balanced along the DEC axis.
- After the DEC axis is balanced, rotate the scope so the counterweight bar is parallel to the ground. The scope will be on the opposite side of the mount. With a hand in place to stop the scope if it moves quickly, unlock the clutch for the RA axis. Adjust the position of the counterweights so that there is no rotation one way or the other when you release the RA clutch. There are some knobs on the counterweights that can be loosened to allow you to move them up and down the counterweight bar as needed.
- One issue to be aware of with an equatorial mount is that the telescope will be on the east side of the mount when the object is in the west part of the sky, and the scope will be on the west side of the mount when the object is in the east. As an object moves from east to west throughout the night, it will cross the meridian. You will then need to switch the side of the mount that the telescope is on. This is called a *meridian flip*. It will interrupt any imaging you are doing, so plan accordingly. If an object is near the meridian, see if it is possible to aim at it with the scope on the east side of the mount. That way you can continue taking images continually as it crosses the meridian.

- Most telescope mounts of this sort rely on a gear that has teeth to drive the scope from east to west as the Earth rotates. To work best, these gears need to be engaged properly, and not loose. When using the scope for imaging, there should always be slightly more weight on the east side of the mount. That way the teeth in the gear on the mount are pressed into the teeth on the gear of the wheel that is driving the motion. It leads to a smoother and more efficient session. There should not be a large weight imbalance, but just enough to keep the gears engaged. This also means you will likely have to shift the counterweights a small amount after a meridian flip.

Planetary, Lunar, and Solar Photography

Your success in taking detailed images of the planets or the surface of the Moon or the Sun depends on the seeing. If the atmosphere is unsteady, when you look at your target visually, it will appear to “swim”. It will look like you are looking over a hot grill, and the waves of heat are distorting the image. Small features will appear and disappear, or they will never come into focus regardless of how much you try adjusting it. If this is how your target appears, that is not the time to try imaging it.

At night, you can check how the stars near the planet or the Moon appear. If they are twinkling considerably, it is a night of bad seeing. Pick another night for photography. However, if the stars are shining steadily or only twinkling a little bit, you will likely have success in getting detailed images of your target. Also, if you can, take images when your target is at a higher altitude. Seeing is always worse closer to the horizon.

This type of astrophotography is not strongly affected by moisture in the air. It is even possible with some high clouds – you will just need to adjust the settings for longer exposures.

During the day, there are no stars for judging the seeing. You just have to inspect the Sun visually **WITH PROPER FILTERS AND EYE PROTECTION** to see if it will be worthwhile to take images.

For the Moon and planets, you will need:

- the adapter to go from the 2” diameter back of the scope to a 1.25” eyepiece
- the ZWO atmospheric dispersion corrector (ADC)
- a small planetary camera (list of possibilities below)
- if the seeing is exceptionally good, you can use a 2x or 3x Barlow lens.

The planetary cameras that we have available are:

- a color ZWO ASI224MC
- a monochrome Skyris 618M
- a color Skyris 445C
- a Point Grey Flea3 GigE color camera

I would generally recommend the ZWO ASI224MC camera unless you have a good reason for using one of the others. I would avoid the Flea3 unless you need to take images at an exceptionally high frame rate.

Unless you are taking images where you need as much light as possible, you should use the UV/IR cut filter with the ZWO ASI camera. It is sensitive to wavelengths from about 300 nm through nearly 1000 nm. This means that, when you think you are taking an image with visible light, there will be some ultraviolet and a considerable amount of near infrared light. To give a natural appearance to your object, you want only visible light (between 400 nm and 700 nm). This UV/IR cut filter will limit the incoming light to these wavelengths.

The software to use is called FireCapture. You will be taking videos that are later processed by using software to pick out the best frames from each video and average those frames together. If you don't need high resolution images, you can tell FireCapture to record 8-bit AVI videos. To bring out the most subtle detail, you will want to record 16-bit SER files. Note that you will need copious free drive space to store the output. It is common for each SER file to be 1 to 2 GB in size. For best results, you want to keep shooting them, one after another, while weather and seeing are favorable.

The workflow that I recommend for taking data is as follows:

- You will need the laptop for taking images. Since these objects are always in the south part of the sky, I recommend setting up the laptop in the north part of the observatory. Do not position yourself under the telescope as you are taking images. The heat rising from you and the laptop will worsen the seeing.
- Turn on the dew heater to warm the top of the tube of the C14 telescope. We are close enough to the Pacific Ocean that dew often forms on the corrector plate of the C14. Warming the corrector plate can delay its formation.

Figure 68 - Dew heater controller for the C14. Only one heating band is on the scope, so that is the only power source that is on.

- If the object is at a very high altitude, you can leave the dew heater on. The warm air rises rather than swirling. It will not affect seeing if the object is at an altitude of 60° or greater.
- Make sure the dew shield is on the front of the C14. This will also help to reduce stray light getting into the telescope.
- As you are attaching optics to the back of the telescope, have the air bulb blower ready to blow a few puffs of air over each surface that light passes through. This will help remove dust particles that you don't want affecting your final images.
- Attach the 2" to 1.25" adapter to the telescope first. If you are using a Barlow lens, that comes next. If your target is at lower than 45° altitude, you will want the ADC in place next in your stack.
- Plug in the USB cable to the camera and the laptop and get FireCapture running. Make sure that the software is communicating with the camera properly.
- If you need to limit the incoming light to visible wavelengths, gently screw the UR/IR cut filter into the nosepiece of the camera.
- The size of the imaging chip in the planetary cameras is rather small. It is best to make sure the planet is centered visually before putting the camera in place. This is especially true if you are going to use one of the Barlow lenses for higher magnifications.
- Use the reticle eyepiece for centering the object. It has a crosshair in the field of view to help with this task.
- Gently slide the camera into the assembly at the back of the telescope. You want to make sure the scope does not move as you do so.
- You should at least see a light in the view through the camera in FireCapture at this point. If you're very lucky, it will be a focused image of the object.

Figure 69 - This is the setup for wider field planetary imaging. The 0.63x reducer attaches to the back of the telescope first, followed by the 2" to 1.25" adapter, the ADC, and the ZWO ASI224MC camera.

When you first launch FireCapture, it may bring up a dialog window about the particular camera being used. You should be able to click “OK” and start your session. If there are any issues, you will need to ask the instructor about installing the appropriate updates that will allow the software to talk to the camera. Here is what the interface will look like:

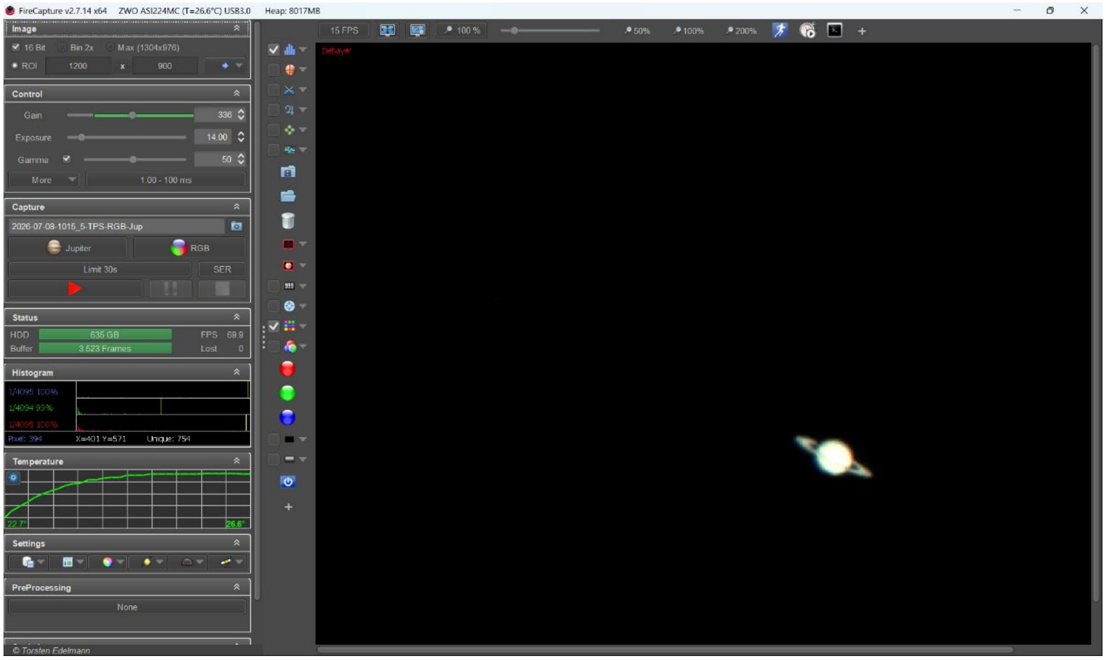


Figure 70 - How FireCapture appears when the program starts. Saturn is in focus in this view.

The view through the camera appears to the right. If you see a bright donut shape, it means the image is out of focus. You may not see anything, or only a faint flicker of light. That usually means the image is out of focus and the light from the object is too spread out. You should increase the gain, the length of the exposure, or both in order to see enough light to bring the object into focus.

There are tutorials on the [FireCapture website] that can walk you through examples of the settings to use. For reference, here are descriptions of the various controls on the left side of the screen.

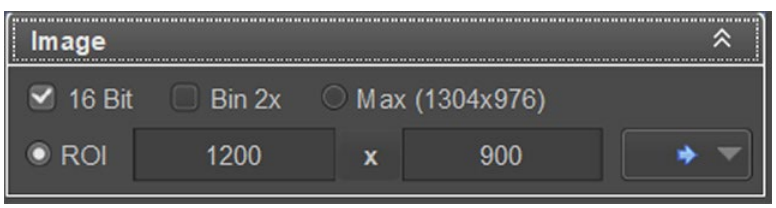


Figure 71 - Image dialog area in FireCapture

The "Image" box controls the size of the area (in pixels) of the camera detector used for imaging as well as the bit depth of the files produced. When you are first trying to locate or focus on an object, make sure that "16 Bit" is unchecked and "Max" resolution is checked. You can take more frames if you reduce the area of the chip being recorded. You can do that by setting the region of interest (ROI). In the example above, the ROI is set to 1200 x 900 pixels. Select "16 Bit" when you are taking SER movies of the planets for the richest detail. The blue arrow presents a drop-down menu with some preprogrammed choices for ROI.

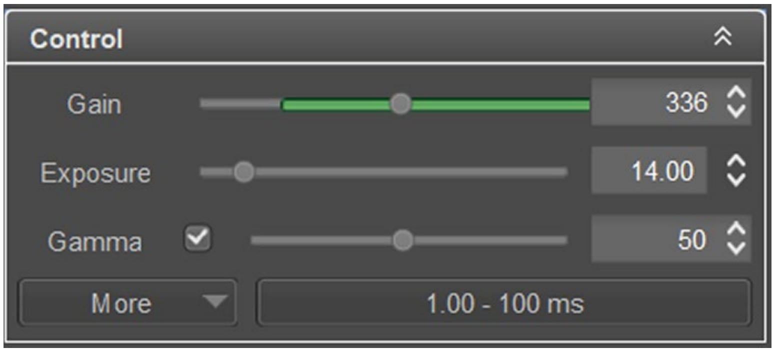


Figure 72 - Control dialog area in FireCapture

The "Control" box lets you set the parameters of the exposure. Note that if you set the "Gain" too high, it will introduce a lot of noise into your images. The exposure is typically listed in milliseconds (ms). Shorter exposures mean more frames per second can be recorded, and longer exposures give you fewer frames per second. The "Gamma" slider affects how the object is displayed within the program.

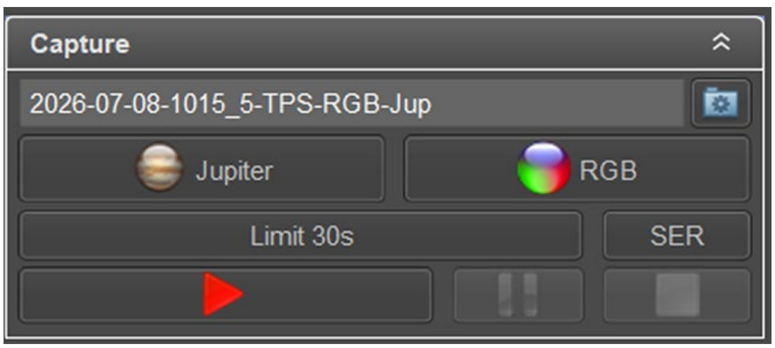


Figure 73 - Capture dialog area in FireCapture

The "Capture" section shows the name of the video file that will be created. You can click on the folder icon to see where files will be stored. You can click on the name of the planet to get settings that you used last time for that particular planet. If you are recording with a color camera, you want the filter section to show "RGB" like above. If you are using a monochrome camera and a set of filters mounted in a filter wheel, you can click on the filter button to select a particular color filter. The "Limit" can be set to either an amount of time or a number of frames when you click on that button. Record 16-bit SER files for the highest sensitivity to different light levels. Clicking the "Play" button starts a recording that you can then either pause or stop.

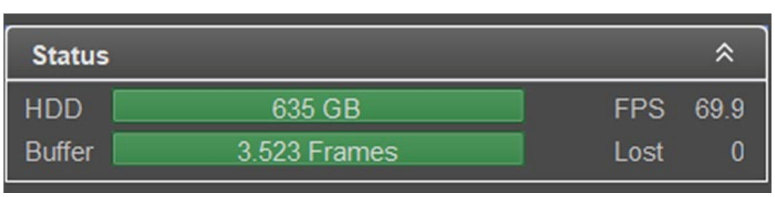


Figure 74 - Status dialog area in FireCapture

Through preferences elsewhere in the settings, you can choose where files will be stored. FireCapture will check and report on how much free space is left on that drive. At startup, FireCapture will set aside a memory buffer for recording videos. The “Status” panel will show how many frames are currently available. If you are recording a video of a specified number of frames or amount of time, the status panel will also show the progress of the recording as it runs. You can see the frame rate (69.9 frames per second or FPS in the example above). If you are running into issues with memory or hardware, frames might get dropped. This panel also reports those as “Lost” frames.

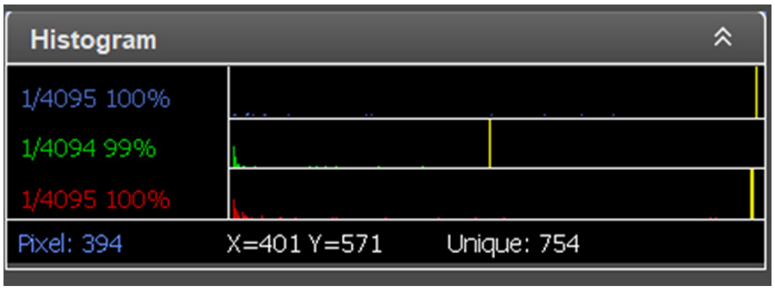


Figure 75 - Histogram monitoring area in FireCapture

The most important panel to pay attention to as you take images is the “Histogram” panel. If you see the bars shown here stretch to 100%, either your exposure is too long or your gain is too high (possibly both). Having pixels that are overexposed means that you are losing signal. The percentage value you get in each color depends on the object you are targeting, The main idea is to balance the gain and the noise it introduces with the exposure and the frame rate. Higher frame rates means that you will capture more data per second, but if you set the frame rate too high, you might not be getting much light in any single frame. You will use the information in the histogram panel to determine the best setting for gain, exposure, and frame rate.

Figure 76 - Setting control section in FireCapture

The “Settings” panel lets you launch various dialogs for controlling features of FireCapture. One of the options you will find allows you FireCapture to connect to the telescope mount via ASCOM. ASCOM stands for Astronomy Common Object Model. It is a platform for software that can communicate with astronomy hardware like mounts, cameras, and focusers. This will create a window on the screen that allows you to control the position and motion of the telescope. This is often considerably more convenient that trying to use the hand controller while taking SER movies.

One aspect of astrophotography that must always be considered for good results are calibration frames. (See the lab on Astronomical Data and the section on Data Calibration.) Flat frames are more important for deep sky imaging, but you can use the setup like the one in Figure 15 if you want to take flat frames for lunar and planetary photography. Set the panel brightness and the exposure so that the histogram is between 30% and 70% for all colors. Run a movie that is 100 frames in length. Name the resulting file something that you can identify as the flat frame. Later, you will take the median of all the frames to create an image to use for your flat calibration. FireCapture has an option for recording a dark frame that is automatically subtracted from each frame as a movie file is captured. Look for the setting for “dark subtraction” or “hot pixel map” in the settings. Put the cover on the front of the telescope and follow the prompts given by the program after you select the option to “map hot pixels”. Make sure this option stays active while you are observing. It will reduce the overall noise in each of your frames, allowing you to capture finer detail more clearly.

After you acquire your target, use the telescope mount controls to move it into the upper left corner of the view, as shown in Figure 77. If you are focusing on the details on a planet, you want the ROI to be only a bit bigger than the planet. There will be some drift in the mount, so leave room for making adjustments to keep the planet close to center as you image it. To get an idea of a typical ROI, look at Figure 78. There is a way to get FireCapture to interface with the mount via ASCOM and take care of these position adjustments automatically, but I have not been able to implement this feature successfully. Once you change the size of the ROI, you can zoom in to get a better look at the planet.

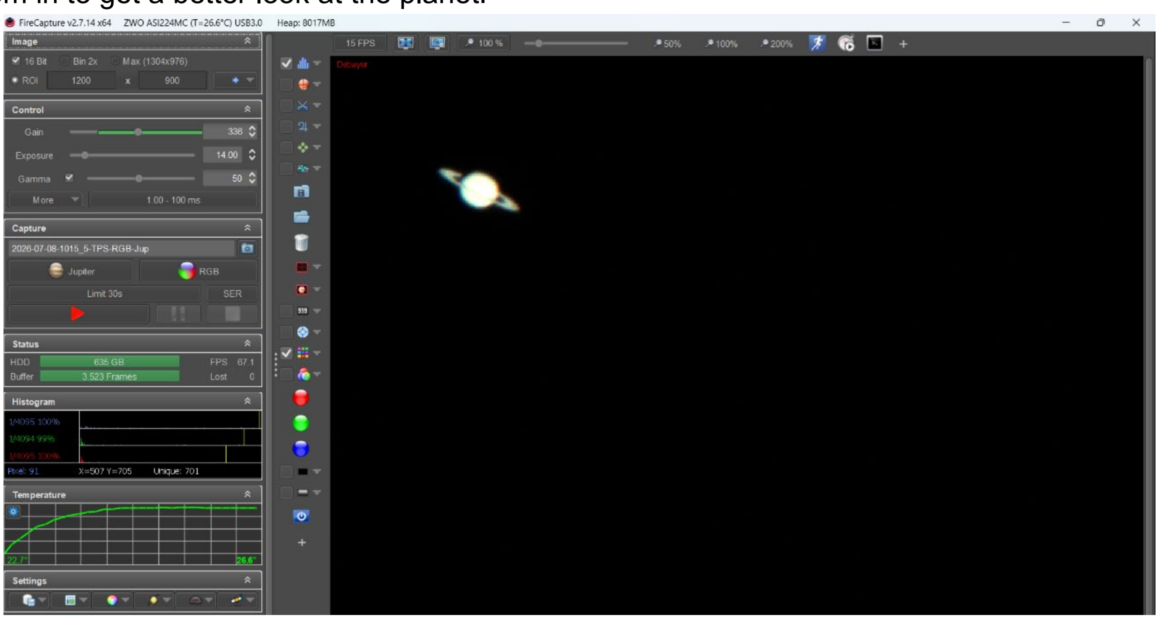


Figure 77 - After your planet is in focus, use the telescope controls to move it to the upper left corner of the view.

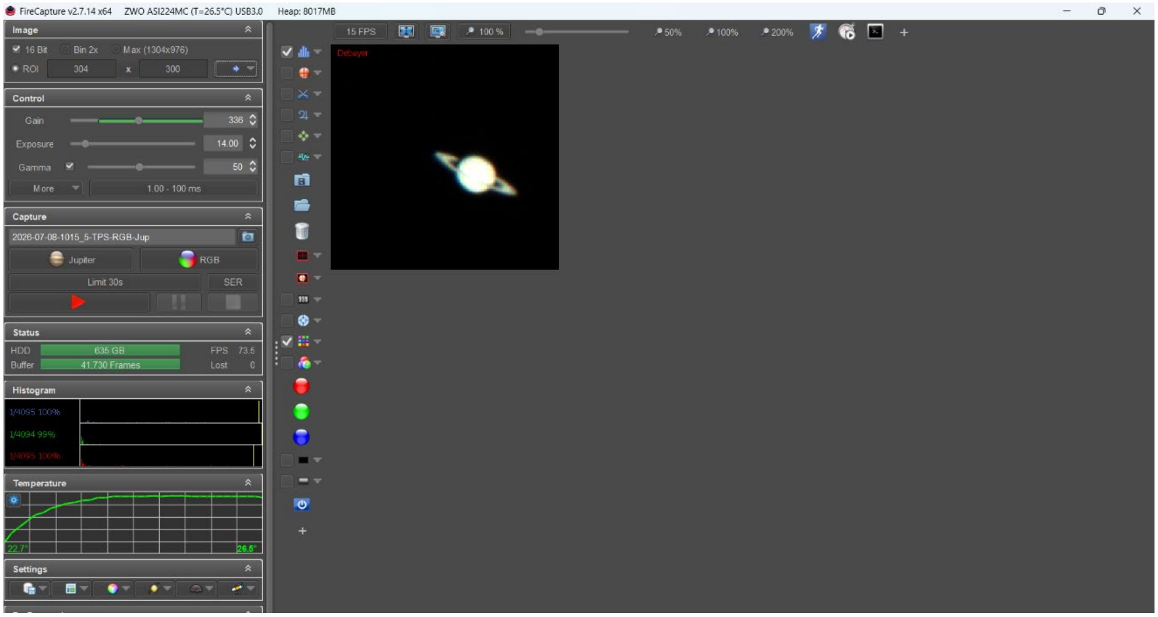


Figure 78 - Use the resolution settings in the "Image" part of the controls to fit the ROI tighter to the target.

If your target will be near the zenith for the entire imaging session, you won't need the ADC. If your target has an altitude less than 45° for part of your session, use the ADC. You will likely need to make adjustments to make sure the red image is aligned with the blue image. You may need to loosen how the ADC is seated in the Barlow or the adapter and rotate it. There are two levers on the side of the ADC. Click the button highlighted in green in Figure 79 to have FireCapture split the view of the red image and the blue image. Look at the pixel offset values in the x- and y-directions in the small square window that appears. Adjust the ADC until those offset values are as close to zero as possible. Figure 80 shows a relatively good alignment.

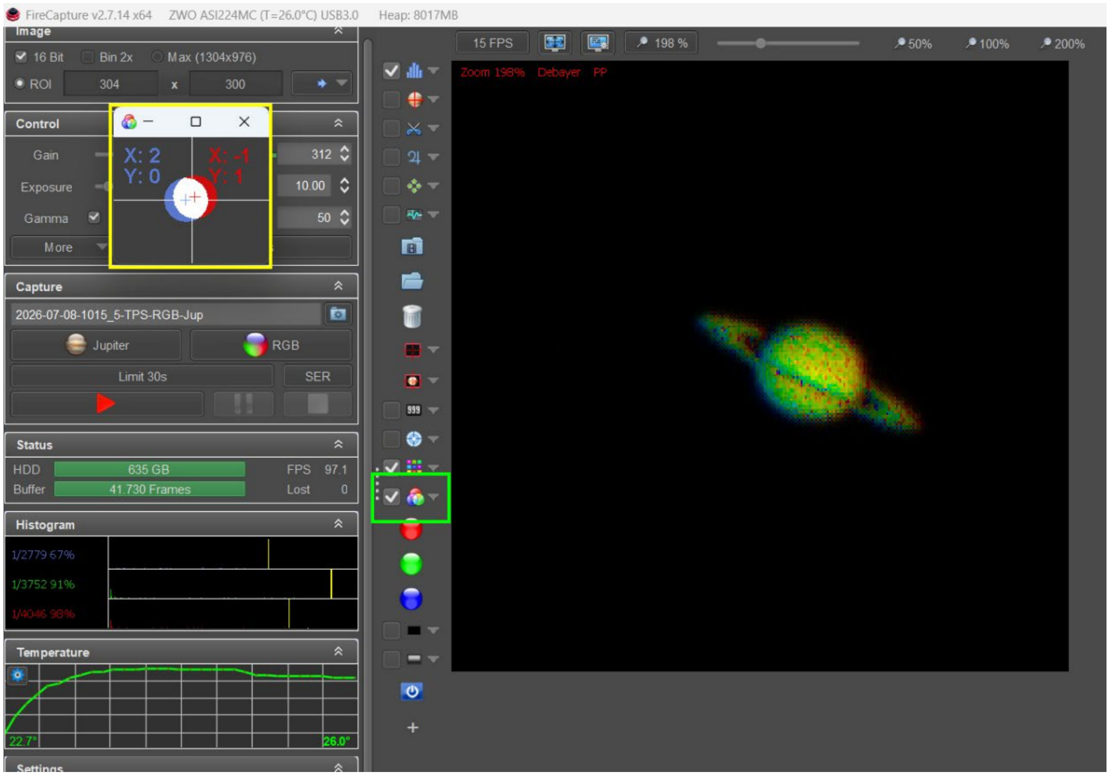


Figure 79 - Click the item with the three separated color circles to get the tool used for aligning different color channels (only needed for color cameras).

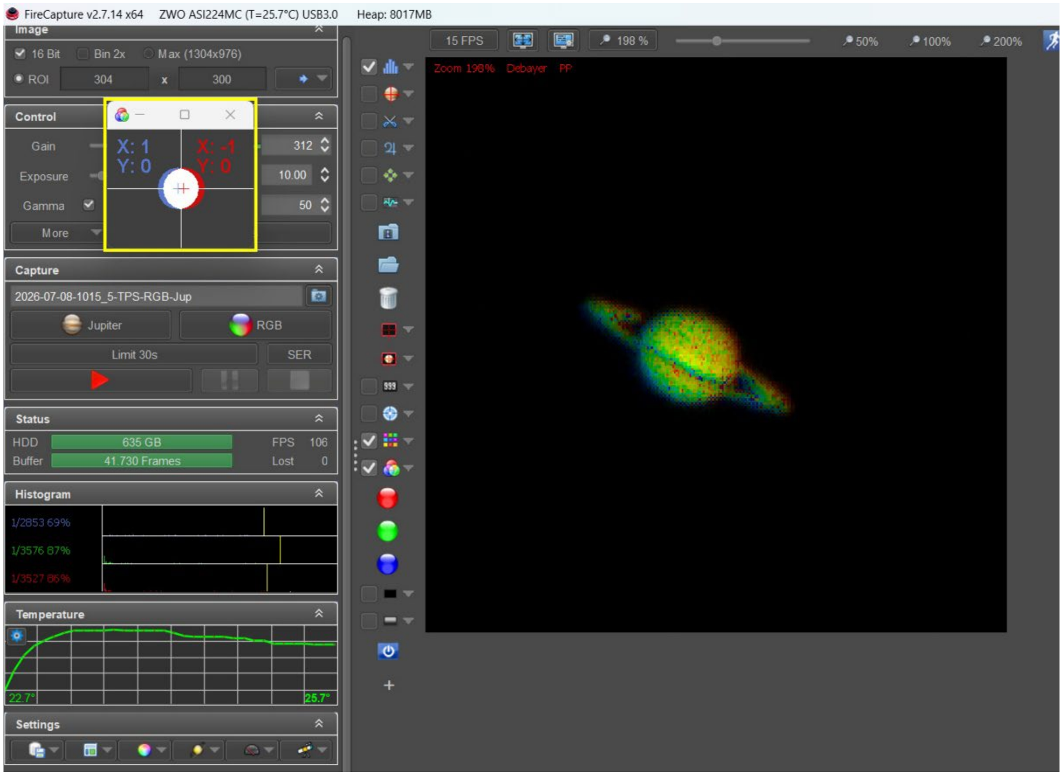


Figure 80 - Adjust the position of the levers on the ADC to reduce the offsets between red and blue images as much as possible. You may also need to rotate the ADC.

Once the color channels are aligned and the object is in focus, you're ready to begin recording SER files. After you select the object from the list in the "Capture" section, adjust the gain and exposure so that none of the pixels are saturated. When you look at the histogram for the video input, it should never reach 100%. A shorter exposure results in a higher frame rate, and that gives you a better chance of "freezing" the effects of seeing in Earth's atmosphere. However, if you set the gain too high, the image becomes noisy. It will take some experimenting to figure out the best settings depending on the planet, how high it is in the sky, and whether there are any clouds that night.

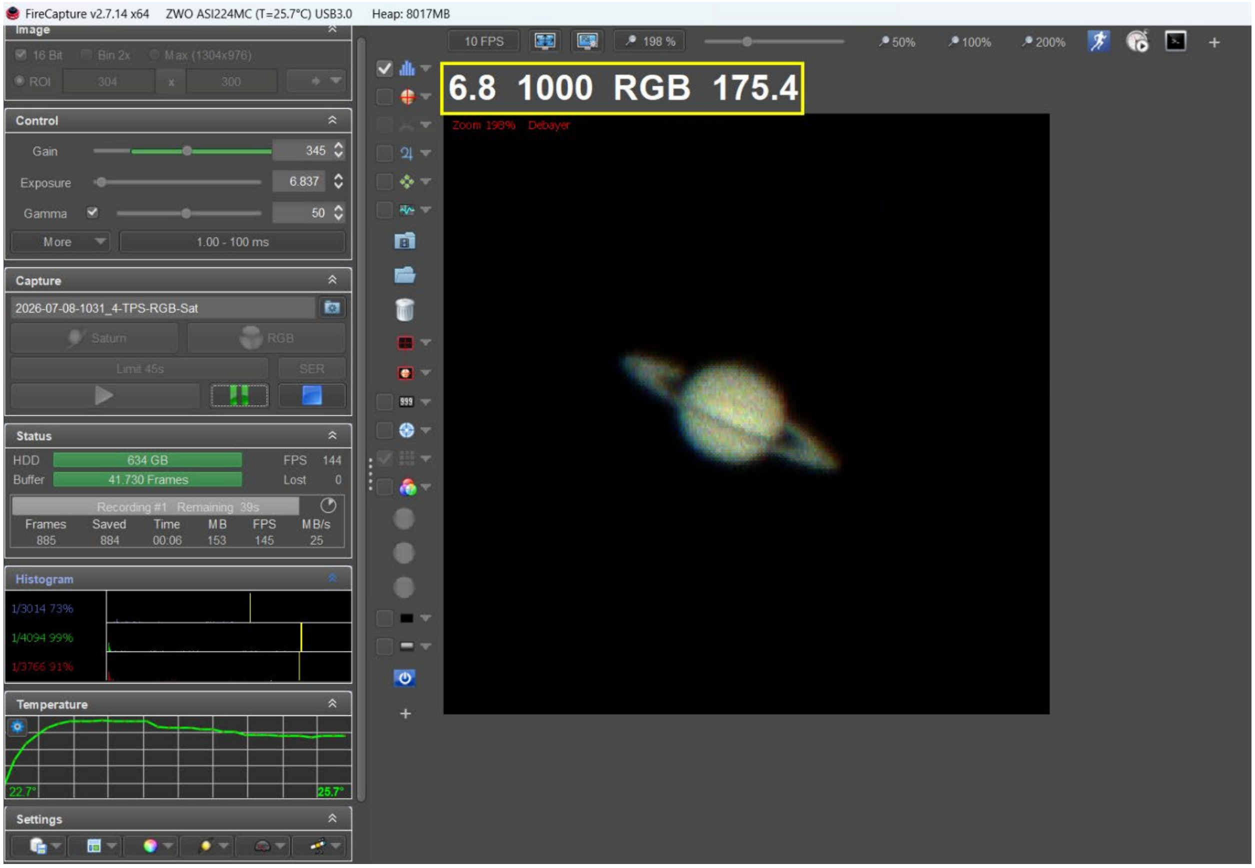


Figure 81 - When you record video, the area above the camera view will show the total time elapsed, the number of frames taken, the filter that you selected, and the number of frames per second being recorded.

Jupiter's Galilean moons are visible with the same settings as the planet. For Saturn, you'll be able to see Titan with same settings as for the planet, but the other moons are too small and faint. To see those moons, you'll need to set the gain higher and the exposure longer. This will make Saturn too bright, but it reveals the locations of the other moons.

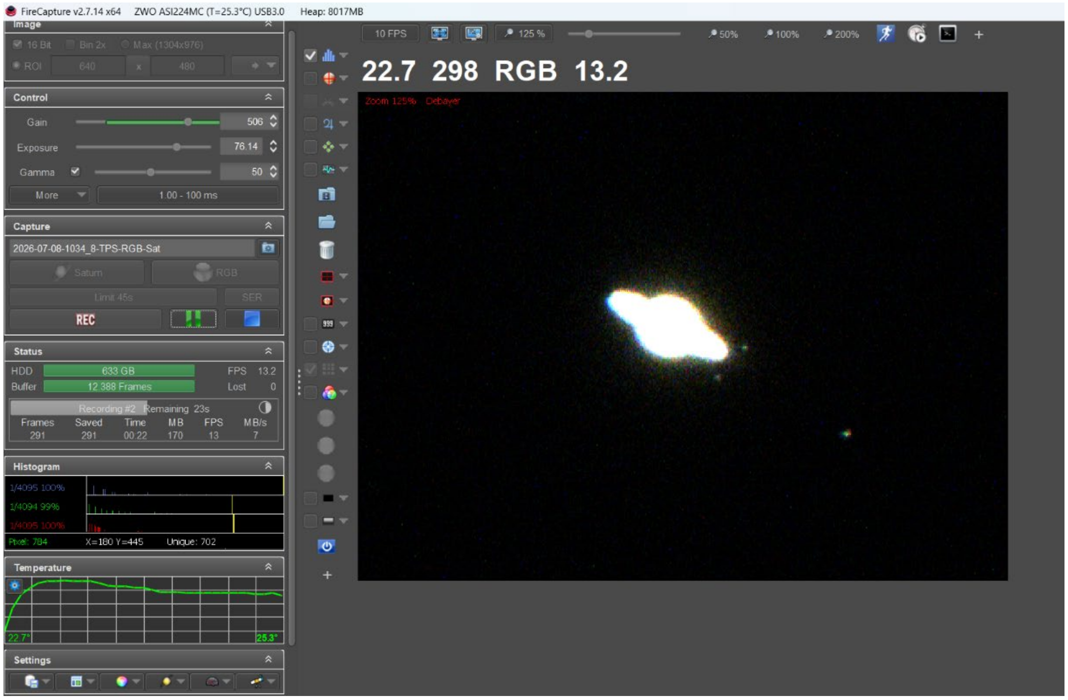


Figure 82 - To record the moons of Saturn, Uranus, or Neptune, you will need to overexpose the planet by increasing the gain and/or the exposure time.

An issue you will encounter when gathering data on planets is that they rotate. This means that the features that are visible change throughout the night. This limits the length of the SER recordings you should make since you don't want the features to move across the planet in any one video. Limit recordings of Jupiter to 30 seconds. You can use 60 second recordings for Mars and Saturn, but I usually do 45 seconds. Consider limiting videos for Uranus and Neptune to 120 seconds. They are so far away and appear so small that they won't show changes over that much time. You don't have to worry about rotation for Venus and Mercury since their rotation is so slow.

If the Moon is your target for the night, consider setting the tracking rate of the mount to "Lunar". The default is the sidereal rate, but because the Moon moves east relative to the stars, it will keep moving out of view if you stay with the sidereal rate. There's no concern about the Moon rotating as you image it, but unless you are focusing on just one particular feature, you will want to use the full frame as the ROI. Go to the "Image" dialog and click "Max" to achieve this.

Rather than taking movie frames for a specified amount of time, it is better to select a set number of frames per movie for the Moon. In the "Capture" dialog, click on the button that says "Limit". It will launch an interface for choosing whether you limit your movie by time or by number of frames, as shown in Figure 83. For most lunar imaging, 100 frames is fine. If you are trying to capture smaller details, try more frames. Because you are using the maximum size of the chip, the SER file that is produced can be mammoth in size if you let it run for too long.

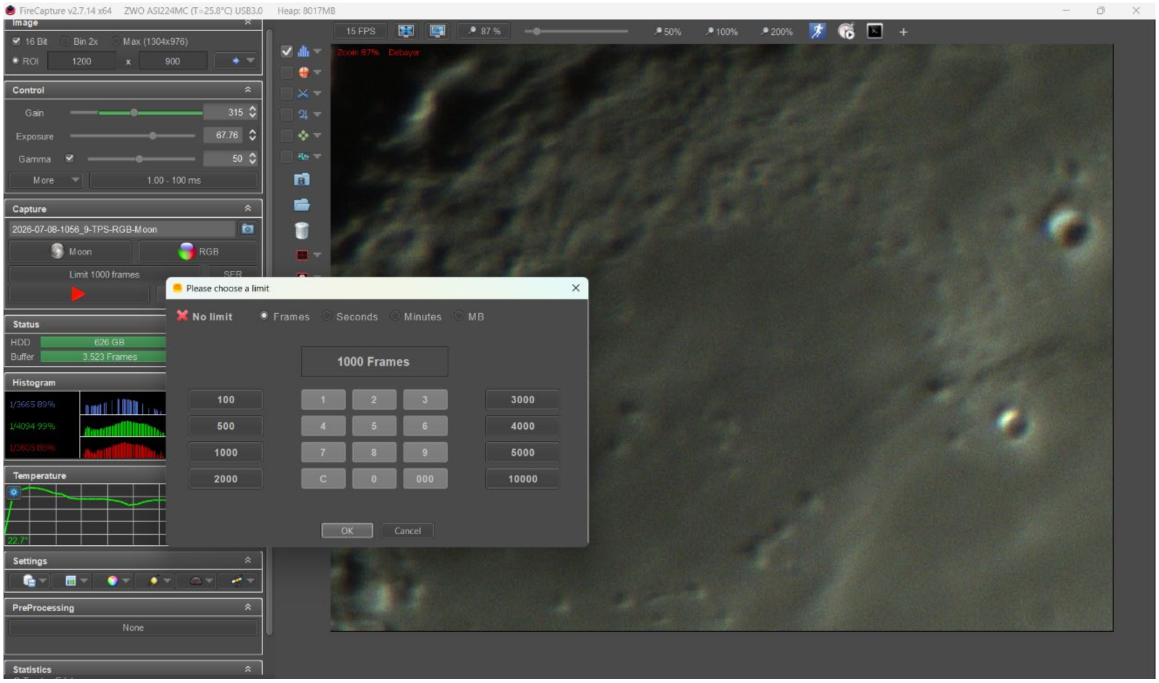


Figure 83 - Clicking "Limit" in the Capture dialog lets you select the option to stop recording afer a specified amount of time or a specified amount of frames.

I have the laptop setup to save files in the C:\observatory\fc folder. Under that folder, you will find folders with the names of the targets you select in the “Capture” dialog. Under each of these folders are folders with a date in YYYYMMDD format. The dates use Universal Time, so if you are taking images in the evening, the date will look like it is for the next day (i.e., taking images of Jupiter on the evening of 2024-04-15 will create a 20240416 subfolder in the “Jup” folder). Recording with FireCapture also creates a text file along with the SER file that has information about the settings used.

After you are finished taking data, you need to process it to make the highest resolution image possible. There are a variety of free software packages that will take you SER movies and average together the best frames to give you the clearest possible image. An older package that still works well is RegiStax. The last supported version is RegiStax6. You can find guides for using it elsewhere. The software we will use is AutoStakkert. It is also available as a free download. Search online for videos from Christopher Go and Damian Peach for examples of a workflow with these tools.

Deep Sky Imaging

While imaging solar system objects relies on having good seeing, imaging deep sky objects requires very clear skies. You need a night with good transparency. Water vapor scatters light, and these objects tend to be faint. With greater amounts of moisture in the air or high clouds, the light pollution in the Los Angeles area competes even more than usual with photons coming from deep space. If you're only able to see the brightest stars, conditions are likely not good for imaging deep sky objects.

Taking images of deep sky objects requires long exposures. Although a motorized mount is capable of keeping an object nearly centered for visual observations, the requirements to get the same features to always fall on the same part of the imaging sensor of a camera are more stringent. For successful deep sky imaging, you need to have guided exposures. This means there is a feedback system which tells the mount to make small adjustments if software detects stars moving within the image. If the image moves even by a few pixels while the exposure is being taken, the quality degrades dramatically.

Our camera for deep sky images is an SBIG STXL-6303E with an FW8G-STXL filter wheel. Unlike the planetary cameras where this a choice of monochrome or one-shot color, the SBIG camera is only monochrome. You position filters that allow different wavelength ranges to reach the camera. You can later build a color image by combining the images you took with different filters. There are also specialty filters called *narrowband* filters. These only allow through a very narrow set of wavelengths that are related to the emission of light from specific elements.
The camera and filter wheel mount to the back of the C14 telescope with a cylindrical adapter. One end of the adapter is 2" inside diameter to attach to the telescope, and the other end is 3" outside diameter to attach to the filter wheel on the front of the camera. The adapter should have the camera attached snugly to the back of the telescope when it is in place.

Before mounting the camera on the back of the telescope, connect the HDMI cable that goes between the body of the camera and the filter wheel. Make sure that the gray plug with the screws at each end to hold it in place is completely seated on the bottom of the camera and secure. Once the camera is in place, attach the power cable and the USB cable. These cables have a tendency to fall out during an imaging run, so I loop them around the handles of the camera as shown in the image below to help hold them in place.

Figure 84 - The SBIG STXL-6303 camera and filter wheel attached to the back of the C14 telescope. Note how the cables are plugged in and arranged.

Maxim DL software

The software for controlling the SBIG camera and filter wheel is Maxim DL. This software package can be set up to control an entire observatory and all its peripherals, but here we will go over the basics that you need. It can also act as image processing software, but we will not cover those capabilities. A full set of documentation and tutorials is available on the Diffraction Limited website.

Maxim DL needs to be run as an Administrator on Windows to have access to everything it needs. Right click on the icon for Maxim DL and choose the “Run as Administrator” option. Have the faculty member that you are working with enter the password.

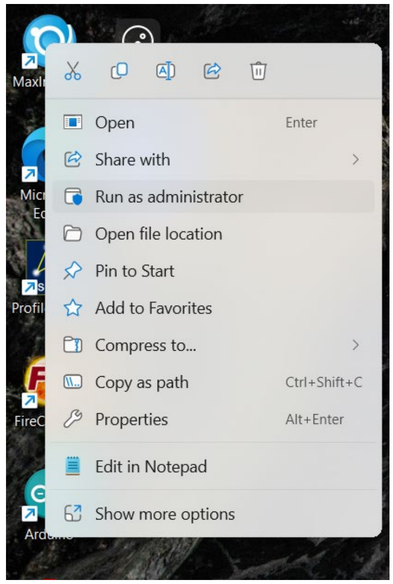


Figure 85 - Make sure you run Maxim DL as an administrator on the laptop.

The icon circled in green in Figure 86 launches the camera control dialog. There is a huge array of possible actions and information you can get from the camera controls. Here we will only go over some basics. Using the “Help” function in Maxim DL can guide you through a lot of other details. When it is first launched, the camera controls appear as they do in Figure 87. Make sure that “SBIG Universal” is listed under the “Setup Camera” button. “Dual Chip Mode” needs to be checked to use the guide camera in the filter wheel. When you click on “Options”, you get the window that appears in Figure 88. Even though the guide chip is built into the filter wheel, you still need to select “External Remote” to have it work properly.

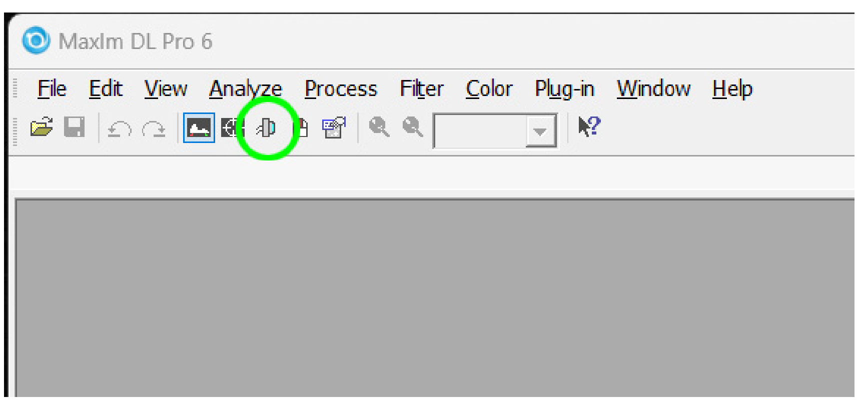


Figure 86 - This icon on the toolbar in Maxim DL launches the camera control dialog for connecting the camera, starting and stopping the camera cooler, setting and taking exposures, and setting up the guiding to keep the telescope on target.

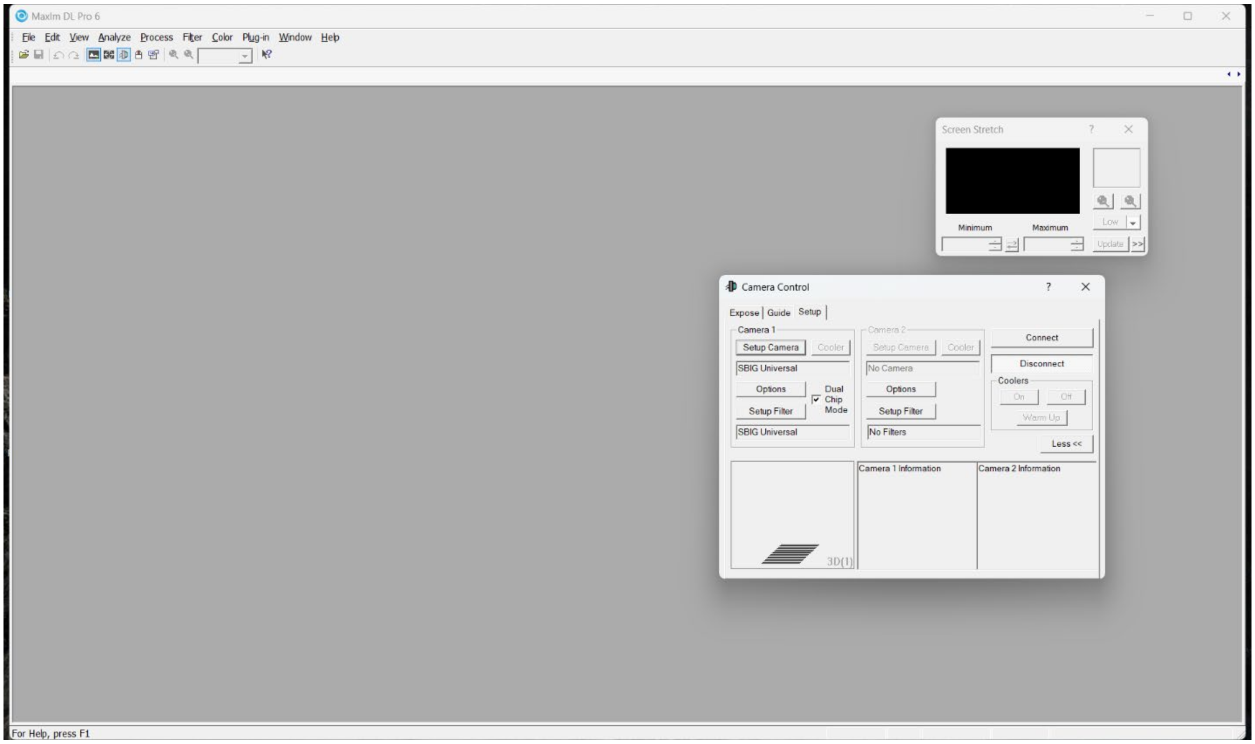


Figure 87 - This is what the camera control dialog window looks like when you first initiate it.

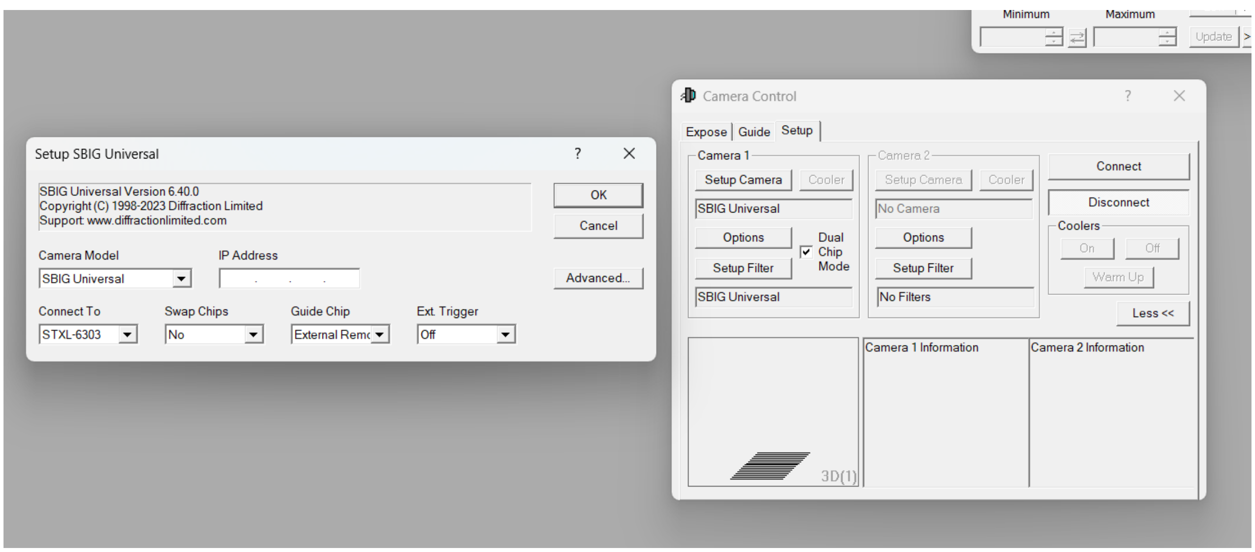


Figure 88 - When you click "Setup Camera", the dialog that appears should show that "External Remote" is selected for the Guide Chip. This is necessary for the guide camera in the filter wheel to work.

When you connect the camera, you should hear the filter wheel move the filter in slot 1 (the red filter) into place (unless it is already on the red filter). The information in the bottom sections of the “Setup” window will include the temperature of the CCD chip. Click “Cooler” and set the temperature to 30°C to 35°C *below the current temperature*. The colder that you make the sensor chip, the less noise will be present in your images. However, it is designed to cool only to 40°C below ambient temperatures. If you try to push it colder than that, it affects the power going to the sensor. This can degrade the quality of the images or make them unusable.

Click the tab that says “Expose” and try selecting different color filters. You will do this from the drop-down menu under “Filter Wheel” (see Figure 89). You should hear the filter wheel move each time you select a new filter. Set the exposure time to between 2 and 5 seconds and click the “Continuous” radio button. You also want to make sure the radio button for “Camera 1” is selected. Click “Start” to start taking exposures and adjust the focus to be as sharp as you can get it. We will do a final check on the focus once we enable guiding.

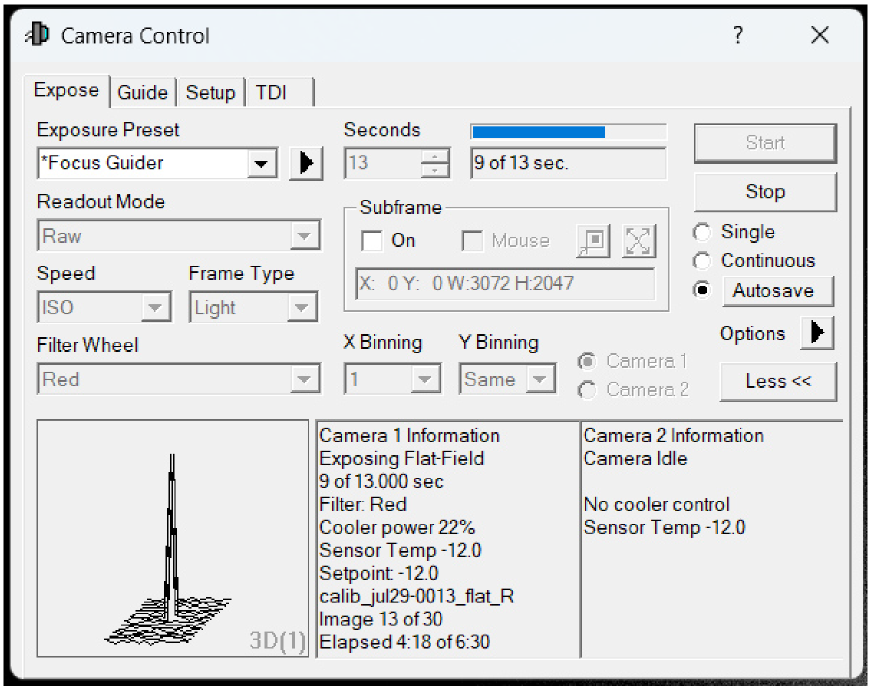


Figure 89 - Camera control showing "Expose" tab settings

To start guiding, click the “Guide” tab. Make sure the radio button for “Camera 2” is selected here. If you take an exposure, it will appear in a smaller window since the guide chip is smaller. If you got stars in focus with the main camera chip, they should also be in focus here. If not, the manual for the FW8G-STXL filter wheel has instructions for how to adjust the focus for the guide camera. If you are using the SBIG camera, you should have been added to the “Astronomy with the Cerritos College Observatory” Canvas course. The filter wheel manual is in the “Files” section of that course.

There needs to be at least one star that appears in the view for the guide camera. Maxim DL should indicate the X and Y pixel location of that star in the information on the “Guide” window. If it doesn’t find it, clicking on the star will put its location in that tool.

Before going further, you need to connect Maxim DL to the telescope mount. Click the icon in the top next to the camera that looks like an observatory dome. It is the icon immediately to the left of the one to start the camera control. The screen that comes up gives options for connecting Maxim DL to the telescope mount, the focuser, and other related equipment. For now, we just need to make sure the correct mount interface is selected and tell Maxim DL to connect. Maxim DL should call the ASCOM platform and allow you to control the mount from the laptop at this point.

Now, go back to the “Guide” window. Make sure the star is still visible in the guide camera exposure and the position of the star matches what is shown. Click the radio button marked “Calibrate”. When you click to start, you should see the camera take an exposure of the star, then the mount will move a little bit (probably too small to notice). On the next exposure, the star has moved somewhere else in the image. You should see a red line connecting its old position to its new one. For the next exposure, the star moves back closer to its starting point. Then, you should see the star move at a right angle relative to the first moves. Another red line will be drawn, and then the star should move back near the pixels where it started. This trains the program to know how much to turn the motors to get the guide star to move in response. Unless you choose to reset the calibration, Maxim DL will use the computed values for the rest of the session.

When you start guiding, you should see a small window appears that has an image of the guide star. In the information/status areas at the bottom of the camera control window, you should see the motions that the guide chip is detecting for the guide star. If these values are not appearing and changing very slightly every time the guide camera takes a new image, you are not successfully guiding. Try the calibration again.

Once you know the guiding works, you can stop it and then move the telescope to the target of your choice. Check with the “Expose” tab to make sure the object you want appears when you do a 10 to 30 s exposure. Adjust the position of the mount so your object appears how you want within the frame of the image. Then, switch to the “Guide” tab and take an exposure. If a star appears in the guide camera view and its position is listed in the areas for its X and Y position, you are ready to start guiding. If no guide star is present, you will have to make small adjustment in the mount position to find a star to guide by.

You can now do a final adjustment with the focus to make it as sharp as possible. There are tools within Maxim DL for this. When you click the arrow next to “Options” from the “Expose” view of the camera controls, one of the options it shows is “Big Statistics”. This will launch a window with large print information about a star in your image. Adjust the focuser so that FWHM is as small as possible in that statistic window. This means you are making the image of the star as sharp and as small as possible. You can then close the statistics window and start your imaging run.

Select the radio button for “Autosave”, then click the “Autosave” button. The controls shown in Figure 89 appear. Click in the area under “Autosave Filename” and type in an identifier for the object you are imaging. This will then appear in the names of all files created by this imaging run. Clicking on a Slot button activates the settings on that row. Set the “Type” to “Light”, then select the filter you want. For the suffix, type in something that will help you identify the filter. For example, if you are using the red filter, you could set the suffix to “_R” so that appears with all the filenames for images created with that filter. The exposure is listed in seconds. Binning should be 1 if you want to use the highest resolution. Setting a higher value for the binning concentrates more light but gives you a smaller final image. Leave the “Readout Mode” as “Raw”, then change “Repeat” to the number of exposures you want to take with that setting. Activate the slot and complete the row for every filter that you want to shoot with. When you are done, click “Apply” and “OK”. You will come back to the camera control window. At that point, make sure guiding is still working and click “Start”. That will begin your imaging run.

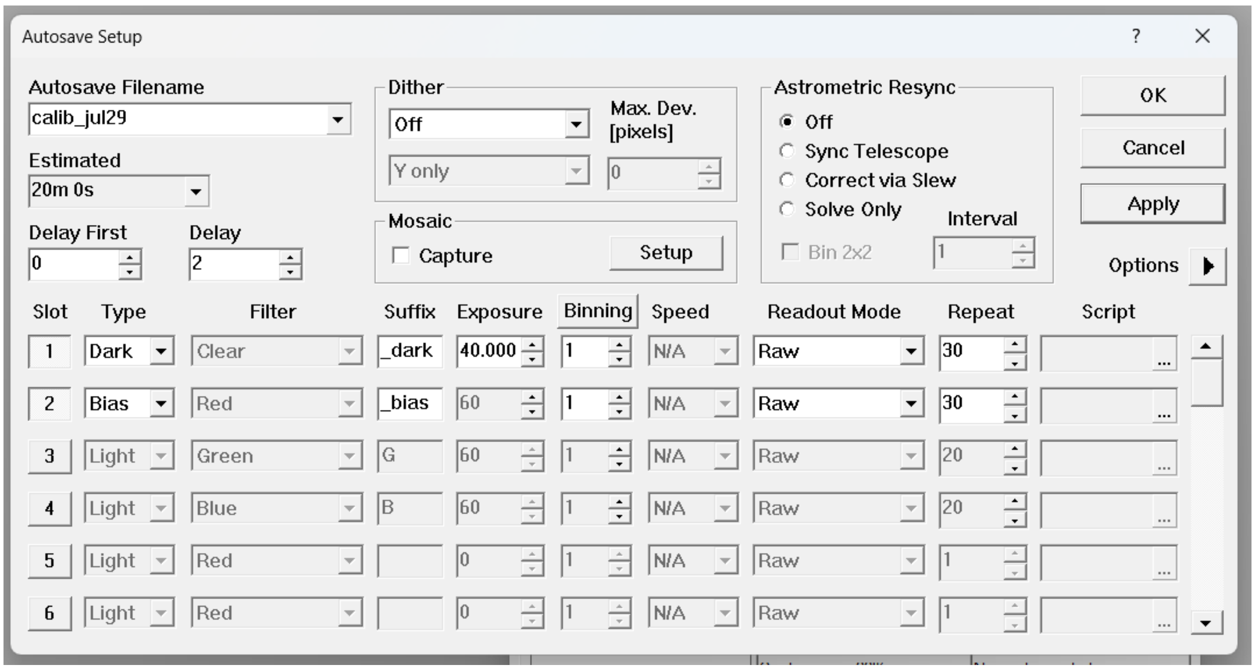


Figure 90 - This is the window that is launched by clicking "Autosave". You will set up your imaging run here.

Refer back to the Astronomical Data lab and Data Calibration. You can take dark and bias frames while it is still light out. The STXL 6303 camera has a built in shutter that will close while you take these calibration frames. Go into the controls with “Autosave” to setup taking your calibration frames. Name them something you will be able to identify easily later. I usually go with “calib_apr03” if I am taking these calibration frames for a session on April 3, for example. Change the “Type” to “Dark” for your dark frames and “Bias” for your bias frames. Set the exposure time equal to the exposure time for your light frames for your dark frames. I recommend taking at least 20 of each, but if you are taking long exposures for your light frames, you can get away with fewer dark frames. Always try to get at least 10 dark frames.

For flat frames, you need the scope to be focused the same way that it was for your light frames. Point the scope straight up and turn off the mount so that it doesn’t rotate as you are taking flats. Place the light panel from the bottom of the equipment cabinet on top of the telescope as shown in Figure 15 and adjust its brightness. You will need to take flat frames for every filter that you used. Before using the “Autosave” settings, you want to test the exposure settings for your flat frames. Go back to the “Expose” tab and set the mode to “Continuous”. Set the filter to the one whose exposure you want to check. Look at the “Screen Stretch” window (as shown in Figure 91. The camera reads out values between 0 and 65536 for each pixel. You want the counts for your flat frames to fall in the middle of this range, as is shown. The pixel values for your flat frames do not need to be exactly at 32,700, but they should be within a few thousand of that. Once you know what exposure to use for each filter, go back to “Autosave” and setup your run for flat frames. Make the suffix something along the lines of “_flat_G” as an example if you are taking flats with the green filter.

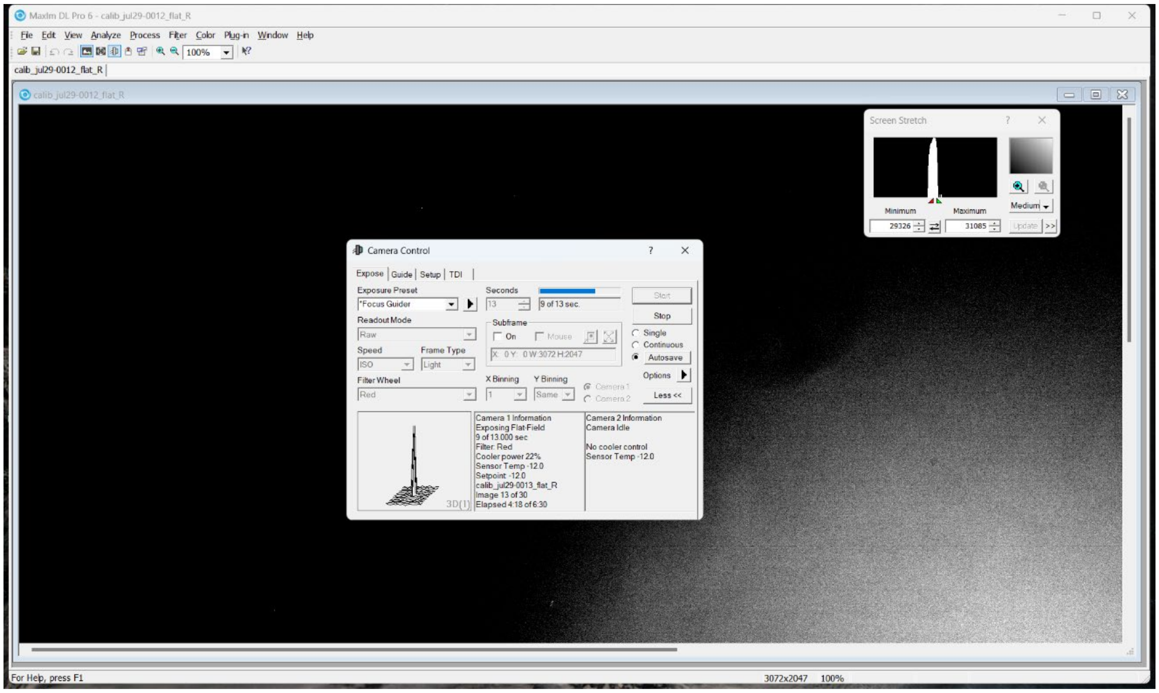


Figure 91 - Using the "Expose" tab to check the settings for taking flat frames

Once you have all your light frames and calibration frames, you’ll need a software package to turn this data into an astrophoto. [Siril](#) is freeware that is a common choice for this work. [Deep Sky Stacker](#) is another common choice for freeware for this task. There are lots of good online tutorials about how to use both of these programs. The package that I got excellent results from while processing data for this project was AIP4Win. This is written for Windows, but should run on a Mac or in Linux with an emulator. This is also freeware, and you can get it from the “Files/software” section of the “Astronomy with the Cerritos College Observatory” Canvas course. There is some questionable choice of wording in how images are related to each other in AIP4Win. I wish the programmer had gone with “primary” and “secondary” for referring to images instead of the terms he chose to use.

Taking Stellar Spectra

On the first shelf above the bottom of the cabinet, there should be a case that says “Star Analyser 100” – this is the diffraction grating you will use for taking spectra of stars. The star acts as a point source, and its spectrum will appear to the side of it. Note that there will be a spectrum produced to both sides of the star. One of them will be brighter than the other when you are examining them in FireCapture. Record the spectrum that is brighter.

The Star Analyser 100 threads into the nosepiece of one of the planetary cameras. Although you can use a color camera, you will lose some of the signal in the spectrum by doing so. If you want to examine what a spectrum looks like in color or share the view live, a color camera is OK. If you are recording scientific data, use the monochrome camera. There is a set of red, green, and blue filters over the pixels of the chip in the color cameras. This reduces the amount of light that gets to the detector chip. Using a monochrome camera removes this extra filter.

Also, don't stack the diffraction grating with another filter unless you are testing the wavelength response of that filter. You want as much light as possible to get to the camera, and that can include near infrared light. A more complete spectrum will be easier to process later. The camera may be sensitive to wavelengths beyond 700 nm, so you should record that light if possible.

The software that you will use for analyzing your spectra is RSpec Explorer software. It is best to follow some examples to learn how to use it, such as the ones in the Video guides for using RSpec Explorer.

Photometry – Measuring Light Curves

Images for photometry should be properly calibrated with dark frames, bias frames, and flat frames for whichever filter you used. This is especially necessary when you are comparing the brightness of two different stars in the same image (which is usually the case). Without calibrating the image, irregularities that vary across the image remain present. The background value could differ from one part of the image to another, and that would introduce inaccuracies in your magnitude measurements.

Two examples of free software that can be used for photometry are ASTAP and JS9.

A list of current supernovae that you could measure with our setup is kept at rochesterastronomy.org.

Asteroid Occultations

This type of measurement will require more careful planning and preparation than any of the other observations listed. A brief overview is as follows:

- Use Occult software from the International Occultation Timing Association (IOTA) to look for events that will likely be visible from campus;
- Review the position of the star and asteroid along with the timing of the occultation, the position of the Moon, and the weather for that night;
- Use Stellarium and other available tools to plot star charts and map out how you will get the telescope pointed at the correct location at the correct time;
- Set up as if you were going to do planetary photography, but do not use any filters;
- Set up the Arduino based GPS flash timer,
- including securing the LED flasher on the front of the telescope;

- Take a test movie, process it, and plate solve it to make sure the telescope is pointed at the correct target;
- Enter the event in Termite on the laptop so the flash timer starts the countdown to the event;
- Start the recording before the flash timer counts down to zero and let it continue to run through the time of the event;
- Analyze your movie data and the flash timer data in PyMovie and PYOTE from IOTA to generate a report you can submit.