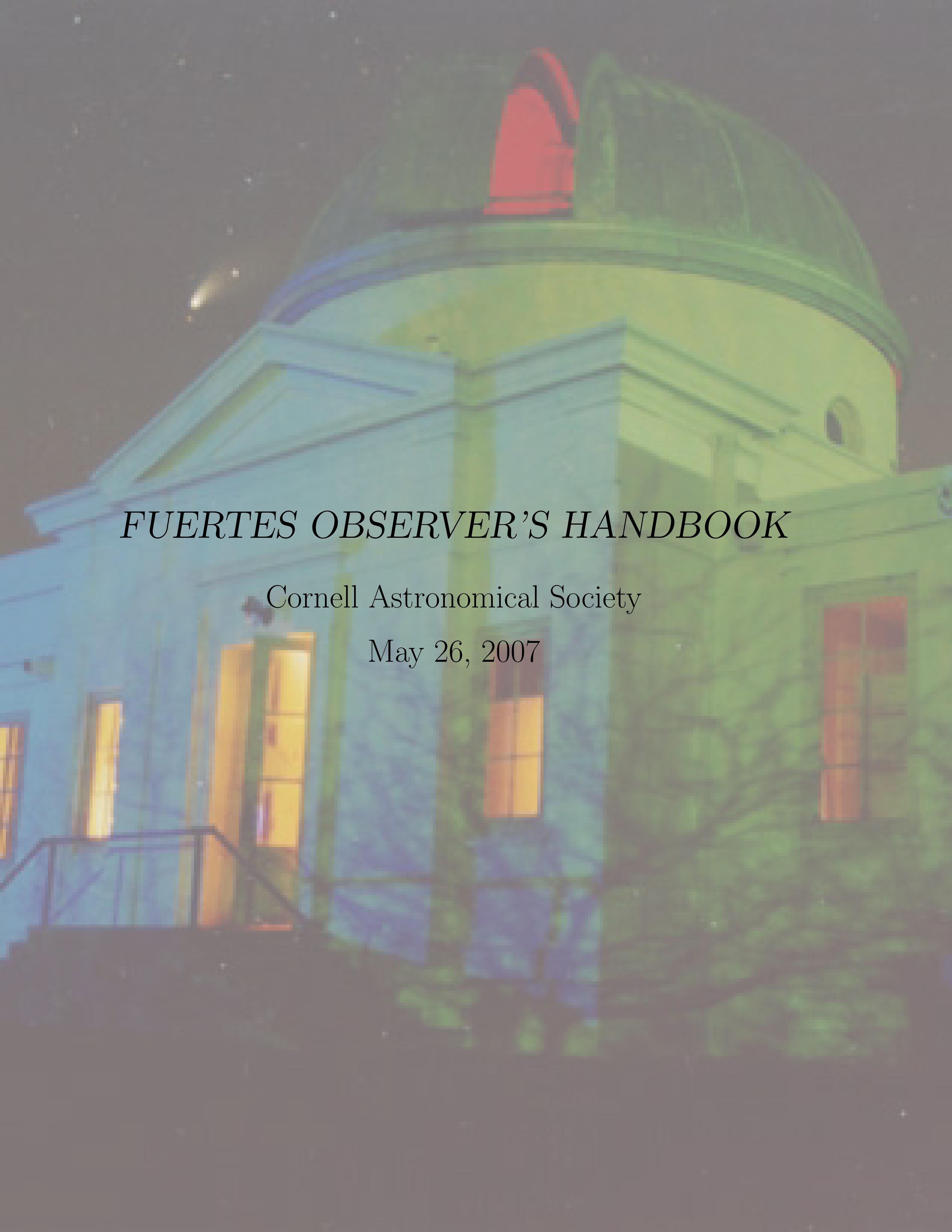

FUERTES OBSERVER'S HANDBOOK

Cornell Astronomical Society

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Foreword

If you're reading this, you're likely either a new member of the Cornell Astronomical Society (if so, welcome!) or a senior member trying to learn the more esoteric aspects of Fuertes observing. Either way, I hope this guide will serve you well. I've tried to write the sections as independently as possible, so that you can start at any point.

This guide starts with some general information about telescopes and astronomical objects – in my experience many new members aren't familiar with this material, and sadly we almost never bother to teach it during training sessions. Chapter 3 repeats most of the information you will hear at a night-time training session. Chapters 4 and 6 describe more advanced observing techniques, although new readers may be interested in Chapter 4 for its listing of equipment for use with the telescope. Chapter 5 describes anything not involving the main refractor, including binocular and naked-eye astronomy. The appendices describe reference material on observatory equipment or popular targets.

If you're reading this as a PDF, make use of the links! Each cross-reference is a clickable link that will take you to the section, appendix, table, or figure in question. This should make it easy to jump back and forth between segments. If you're reading a paper copy, I hope turning the pages won't be too much of a bother. Clear skies,

– Krzysztof Findeisen

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Chapter 1

General Observational Theory

To a large extent all telescopes are the same. If you've been part of an astronomy club elsewhere or have your own telescope, you can probably skip this chapter, although Section 1.4 has some notes specific to Ithaca observing. If you're familiar only with research-class telescopes I suggest you read Section 1.5 on eyepieces, but otherwise you have enough background to get to the interesting parts.

1.1 Navigating the Sky

1.1.1 A Model of the Sky

The universe extends, as far as we can tell, infinitely in all directions. Impressive, maybe, but infinity is a bit hard to measure. Fortunately, space is also so big that we have no real sense of its depth – all we can see is which direction some object is in. This is the basis for all *celestrial coordinate systems*. Imagine that the sky, and everything in it, is really part of a single, bowl-shaped surface floating over our heads, like in Figure 1.1. In a moment we'll extend this bowl into a sphere surrounding the observer, but for now this is a good enough picture of the sky.

Where is something on this bowl? Because we've never specified a size for our imaginary bowl (and we can't!), normal units of distance like feet or meters are meaningless. Instead, distances and positions are measured as angles. Angles are typically measured in degrees, but it turns out that even one degree is too large for most applications. Therefore astronomers divide each degree into 60 *minutes of arc*, or arcminutes ($'$) for short. Since arcminutes still turn out to be pretty big, they are divided into 60 *seconds of arc* (arcseconds or $''$). Arcseconds are good enough for most astronomical applications, including ours, because you usually can't see details smaller than about an arcsecond.

1.1.2 Altitude and Azimuth

Once you have the framework of describing positions as angles, there's a very natural way to describe on object's position. It's a certain height above the ground, clearly, and it's in a certain geographical direction (in the example in Figure 1.1, a bit south of east).

This gives us the *altitude-azimuth* (sometimes shortened to "altazimuth" or even "altaz") coordinate system. Any celestial object has an *altitude* (the angle between that object and the horizon) and an *azimuth* (the angle you would have to turn from due north to be facing it). An object with an altitude of zero degrees is just rising (or setting); one with an altitude of ninety degrees is directly overhead (a point called the *zenith*). An azimuth of zero degrees is due north; ninety is east; one hundred eighty is south, and two hundred seventy (or, rarely, minus ninety) is due west.

Should you care about the terminology? No; it doesn't matter. What does matter is that this gives you a great way of thinking about **what to look at and where to expect to see it.** Suppose you load up a planetarium or almanac program and find

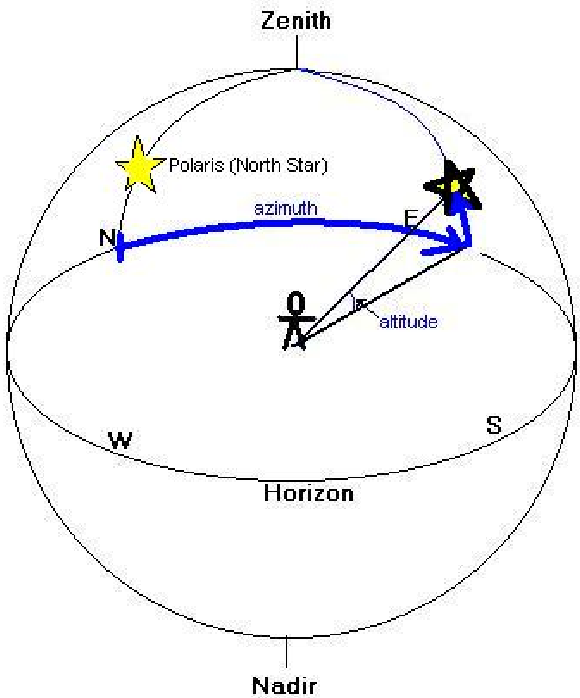

Figure 1.1: The sky as a bowl or sphere over the observer. Positions in the sky can be given by the height over the horizon (altitude) and the difference from due north (azimuth).

out that, at 10:00 PM tonight, Saturn will have an altitude of ten degrees. Should you go and look at it? Probably not: ten degrees is pretty low in the sky, and even if by some miracle you can catch Saturn through a hole in the trees Earth's atmosphere will make a mess of the image. Maybe you also find out that at the same time Jupiter will be fifty degrees above the horizon. That's a much better use of your time!

Altitude-azimuth is easy to visualize and translates intuitively into directions on the sky. Unfortunately, these are its only advantages. The altitude and azimuth of an object depend on your exact location and on the exact date and time. In fact, the altitude and azimuth of an object change in a complex way over the course of the night. Before the advent of computers, it was impossible to track objects using telescopes based on altitude and azimuth (described in Section 1.2.1). Even now, it's still a lot of work.

1.1.3 A More Practical System

As it turns out, there are several coordinate systems that don't depend on the observer's location and time. The most important of these are *equatorial coordinates*. You're already familiar with longitude and latitude, the two angles that allow you to describe any position on the surface of the Earth. Now imagine that you take Earth's longitude-latitude grid and expand it away from the surface of the Earth until it hits the sky-sphere we invented at the end of Section 1.1.1. The result, shown in Figure 1.2, is the equatorial coordinate system.

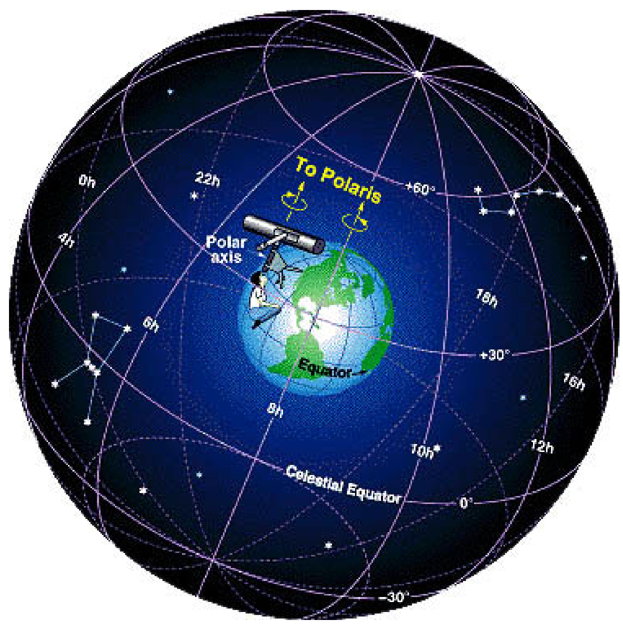

Figure 1.2: The definition of the equatorial coordinate system. Lines of declination are parallel to Earth's lines of latitude, while lines of right ascension are parallel to Earth's lines of longitude. © *Sky Publishing*

Equatorial coordinates have a *celestial equator* located (roughly) over our own, and two *celestial poles* located, again, over our own. Since Earth's axis points in (roughly) the same direction in space at all times, the poles are (roughly) fixed, and so **every object has fixed coordinates in this system**[1]. In fact, because the coordinate system is aligned with Earth's rotation, tracking objects across the sky doesn't require any computing power. Much more convenient!

The distance of an object from the celestial equator (the analogue of Earth's latitude) is called *declination*, and is measured in degrees. The distance of an object along the celestial equator (like Earth's longitude) is called *right ascension*, and is sometimes also measured in degrees. More often, however, it's measured in hours (24 hours is 360 degrees, so 1 hour is 15 degrees). Why use such a strange system? I'll get to that at the end.

Degrees, as explained in Section 1.1.1, can be subdivided into arcminutes and arcseconds, and these divisions provide a common way of describing an object's declination (although sometimes fractions of a degree are just given as decimals). Likewise an hour of right ascension can be divided into minutes and seconds[2]. For example, the bright star Vega has the coordinates 18h36m56.336s $+38°47'01.29''$. That's a right ascension of 18 hours, 36 minutes, and 56.336 seconds (or $18 + 36/60 + 56.356/3600 = 18.6157$ hours), and a declination of 38 degrees, 1 minute, and 1.29 seconds (or $38 + 1/60 + 1.29/3600 = 38.0170$ degrees) north of the celestial equator. **The star atlas we have at Fuertes uses this system, so learn it well.**

Now for the catch – unless you live at the North or South Pole, equatorial coordinates won't be aligned with altazimuth coordinates. Instead, you get the awkward system shown in Figure 1.3. The north celestial pole (close to the star Polaris) is still due north, but it's at an altitude equal to the observer's latitude (about 43 degrees for Ithaca). Not only does this mean that any telescopes based on equatorial coordinates are "tipped over", it makes navigation tricky.

Star atlases are normally written in terms of directions like "North" and "West". **But which way is "North" depends on where you are in the sky!** Near the zenith or the southern horizon, celestial North (toward the north celestial pole) will be close to geographical North. But between the pole and the northern horizon, going North means going up – or *away* from geographical North! Similarly, if you're in the northern sky, moving a telescope East or West means tracing a circle around the pole. This is one of the most confusing aspects of using the Fuertes main telescope. You will get the directions mixed up first time you try this, I assure you. I still have to think through it myself.

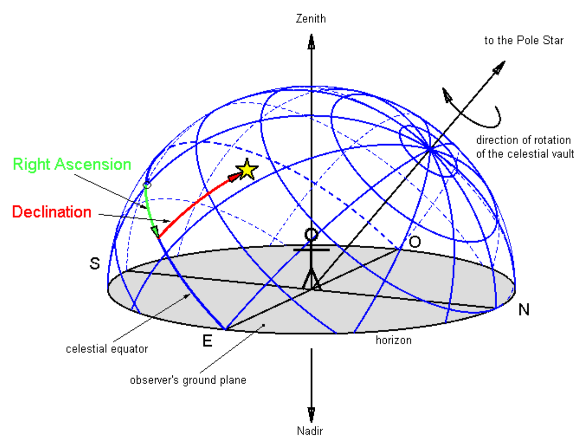

Figure 1.3: Equatorial coordinates from an Ithaca observer's point of view.

So, why measure right ascension in hours? Because if you look carefully at Figure 1.3, you'll notice that the line going from the northern horizon through the north celestial pole to the southern horizon (called the *meridian*) is always along a line of right ascension. As the Earth rotates, the sky will seem to rotate around the axis shown in the figure. There is always a line of right ascension going through the north-south line, but *which* line it is changes. How long will it take for the same line to match up with the meridian? The same time it takes for the stars to appear in

[1] Actually, Earth's axis *precesses* (wobbles) with a period of about 26,000 years. To keep up with the changes, astronomers update the equatorial coordinate system once every 50 years. All our software and atlases are in 2000 coordinates, but you may find a few sources that use the 1950 system. Those coordinates will be off by some fraction of a degree.

[2] Beware: a second of right ascension = 15 seconds of declination = 15 arcseconds!

the same places in the sky, or just under 24 hours[3].

This fact is the basis for *siderial time* – a measure of which stars are above the horizon at any given time. If right ascension is defined in hours, then you can simply define siderial time to be equal to whatever line of right ascension is on the meridian. The siderial time therefore tells you what's in the sky. More importantly, **it gives a very good way of calibrating our telescope's coordinates** – if the telescope is pointed due south (i.e., toward a point somewhere on the meridian), than the right ascension it sees is equal to the siderial time. The details of the calibration will be covered in Section 3.2.6.

1.1.4 Other Coordinates

Astronomers sometimes use *ecliptic coordinates* (measured relative to the plane of the solar system) or *galactic coordinates* (relative to the plane of the Galaxy). They work a lot like equatorial coordinates, except that there's no precession to worry about, and their relationship with the visible sky is even more complicated. However, they're not very useful for the kinds of observing we do from Fuertes.

1.2 Telescope Mounts

Before you can look through a telescope, you have support it and point it, and do both as stably and reliably as possible. This is what *mounts* are for. Mounts come in a variety of shapes and sizes, but they generally fall into two categories, altazimuth and equatorial. Readers of the previous section can probably guess at the difference; the mounts naturally correspond to the two most important celestial coordinate systems.

The most important characteristic in any mount is stability. A mount that wobbles every time somebody nudges the telescope, moves to a new position, or walks nearby will make for a very unpleasant view. Our main telescope solves this problem by being disconnected from the floor of the dome – the mount doesn't touch anything until it hits the foundations of the building. If you ever look through the Celestron we sometimes mount on the roof, you'll see what happens when a mount *does* touch the deck.

1.2.1 Altazimuth Mounts

Altazimuth mounts, like our binocular mount, often take the form of an upright tripod. The telescope can be turned around a vertical axis and a horizontal axis. Motion around the vertical axis changes the telescope's azimuth while keeping its altitude fixed; motion around the horizontal axis changes altitude only (for a review of the altazimuth coordinate system, see Section 1.1.2).

Figure 1.4: Two telescopes on altazimuth mounts. Though they look very different, they behave very similarly. *Left:* © *Telescope House, Inc.* *Right:* © *Sky Publishing*

Altazimuth mounts are easy to set up and respond exactly as you expect them to. Unfortunately, they share the biggest disadvantage of the altazimuth coordinate system: if you want to track the sky, you need a computer operating the mount.

1.2.2 Equatorial Mounts

Equatorial mounts, like the 12-inch in the dome, the 14-inch Celestron we sometimes mount on the deck, and the 12-inch Meades that the astronomy labs use,

[3] The reason for why it's "just under" is a lesson for another day, but basically it's because the Earth has moved along its orbit and so the Sun doesn't move across the sky at quite the same speed as the stars

have one axis of rotation aligned with the north celestial pole. Rotating the telescope around that axis (the *right ascension axis* or *polar axis*) will only change what right ascension the telescope is looking at without touching the declination; rotating the telescope around the the *declination axis* will have the opposite effect (for a review of the equatorial coordinate system, see Section 1.1.3).

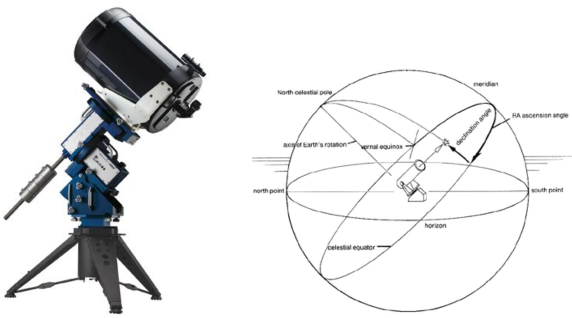

Figure 1.5: a) A typical equatorial mount. © *Meade* b) The orientation of an equatorial mount compared with the sky.

Although equatorial telescopes make it easy to use atlases and other resources written in equatorial coordinates, **the biggest advantage of this mount is tracking.** The telescope can follow the sky just by turning around the right ascension axis. All you need to track is some kind of motor, be it electric (as in the Celestrons and Meades) or mechanical (like in the dome telescope). The big disadvantage is that a portable equatorial telescope needs to be aligned with Earth's rotation axis every time it gets moved. This is a difficult and time-consuming process. Fortunately, the Fuertes telescope was aligned when it was first installed, and I don't think you're strong enough to move it.

Equatorial mounts have one more, fairly trivial disadvantage – because a mount is "tipped over", the telescope tube usually isn't located directly over the support structure. To keep the tube's weight from forcing it to look at the ground or, worse, from causing the entire assembly to fall over or break, equatorial telescopes generally need a *counterweight* located on the opposite side of the mount. Figure 1.5a has a good example of a counterweight; it's the four cylinders on the bar on the lower left. The counterweight needs be to adjusted whenever the load on the telescope changes, but at Fuertes this is not really an issue.

1.3 Telescope Optics

Contrary to popular belief and the insinuations of cheap telescope salesmen, the purpose of a telescope is *not* to magnify objects a thousandfold. Often, it's a bad idea. **What a telescope does do is gather and focus light.** Light enters through a large opening at the front (the *aperture*) and exits through a much smaller opening (the *pupil*) at the other end. Since, ideally, all the light that enters the aperture gets concentrated on the pupil, objects appear much *brighter* than they otherwise would.

1.3.1 Types of Optical Systems

Telescopes differ mainly in how the light gets from the aperture to the pupil. Which elements redirect the light and how they are arranged is what gives different kinds of telescopes their strengths and weaknesses.

Refractors

Refractors, like the 12-inch telescope in the Fuertes dome, use lenses to focus light from the aperture onto the pupil (which is usually an eyepiece with more lenses, but sometimes a photographic device of some sort). They are the oldest kind of telescope and are what most people imagine when they hear the word. Refractors differ mainly in the number and position of the lenses; I do not know the details for the 12-inch.

Assuming the lenses are well made, refractors offer much higher contrast than other kinds of telescopes – important for **good views of the Moon and planets,** especially under high magnification. They also don't require much maintenance because the lenses can't get misaligned (good for us – our telescope's *well* past its warranty).

The down-side is that the lenses of refractors act like weak prisms, focusing light of different colors at different points along the length of the tube. This causes *chromatic aberration* – if an image is focused in one color, **all other colors will appear slightly out of focus.** In practice, this is usually only a problem with bright targets like the Moon and the planets, where you may see a bluish (or sometimes reddish) halo around the object. Refractors also tend to be quite long (ours is 15 feet from end to end), mainly because weak lenses produce higher-quality images.

While this doesn't affect us, it's very hard to make large (research-class) refractors because a large lens needs to be made with extremely high quality and may sag under its own weight. This is one of the reasons why no modern observatory uses refracting telescopes.

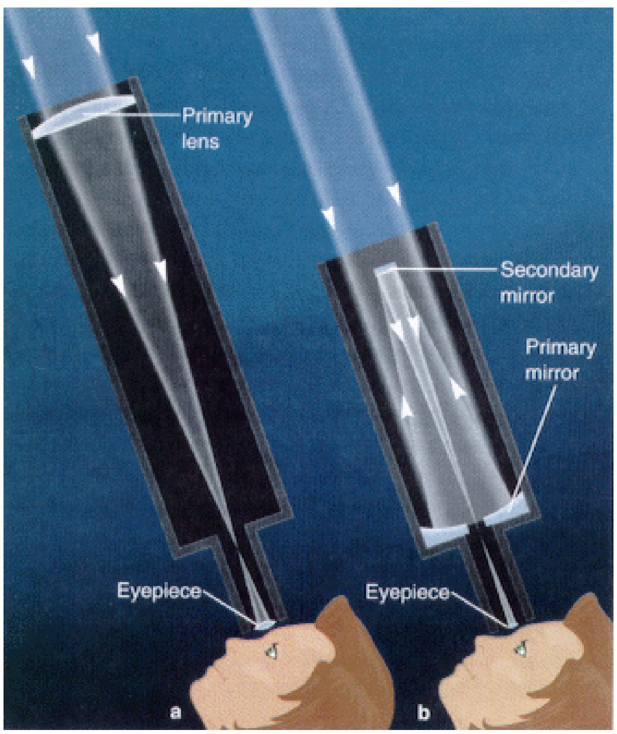

Figure 1.6: a) A generic refracting telescope. b) A generic reflecting telescope. *Image obtained from Matt Oltersdorf*

Reflectors

Reflectors use two or more mirrors to move their light around. They are the most common type of telescope, and the *only* kind you'll find in big observatories. A huge amount of work has gone into working out which arrangements of mirrors will maximize various measures of image quality, and there are half a dozen different reflector designs.

Reflectors tend to be much more compact than refractors, in part because nearly all mirror arrangements let the light bounce back and forth in a confined space. They're also easily make to very large sizes – only the surface of the mirror needs to be of high quality, and because a mirror can be supported over its entire back surface weight is less of an issue as well.

The down-side of a reflector is that it requires quite a bit more maintenance than a refractor – the optics get dirty faster, and the mirrors need to be realigned every so often. Some reflector designs also offer poor contrast, or distorted images at the edge of the field of view.

Hybrid Designs

In the last century, an increasing number of telescopes have included both lenses and mirrors. These compound telescopes (called *catadioptric* telescopes by fans of big words) typically feature a front-end lens and a back-end mirror, although other variants are possible. The 14-inch Celestron we mount on the deck and most of the telescopes you can buy from the "big-name" dealers are hybrids.

Catadioptrics are the most compact telescope designs in existence, and like reflectors are easy to make very large. They are also fairly versatile – while they have strengths and weaknesses, they aren't limited as far as the types of objects they can look at.

The mirrors of hybrid telescopes need to be realigned, and dew is a danger for any model with a lens on the front. The biggest problem, however, is that hybrid telescopes tend to have narrower fields of view than other models and don't provide very good contrast.

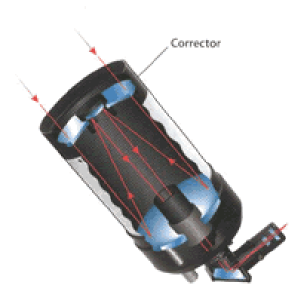

Figure 1.7: A hybrid telescope similar to our 14-inch. © *Sky Publishing*

1.3.2 Performance

All telescopes, regardless of size, can be characterized by some basic parameters. The most important, as mentioned at the beginning of this Section, is *aperture*: the size of the front end of the telescope. **The larger a telescope's aperture, the more light it collects and the fainter the objects it can see.** Our main telescope has an aperture 12 inches across, which is pretty typical for an amateur telescope (and very good for a refractor; most are half that size or smaller). Some amateur astronomers have assembled reflectors up to 30 inches across, and research-class telescopes are typically one to ten meters across (a meter is about 40 inches). 30-meter designs are on the drawing board. Aperture matters!

The second most important characteristic is the distance light travels from the optics to where it focuses, a region known as the *focal plane*. This *focal length* determines, among other things, the telescope magnification; the exact formula is slightly different for eyepieces (Section 1.5) and cameras (Section 1.6). Our 12-inch refractor has a very large focal length of 15 feet (4572mm, to be precise), and one of our standing goals is finding ways to reduce the magnification of the telescope.

The ratio of the focal length to the aperture is the *focal ratio*, in our case 15. This is sometimes represented by saying we have an f/15 telescope. The focal ratio describes, among other things, the image quality – optical aberrations, including chromatic aberration, are less significant at high focal ratios.[4] This is why, although we have a refractor, chromatic aberration is usually not a problem – our focal ratio is very high.

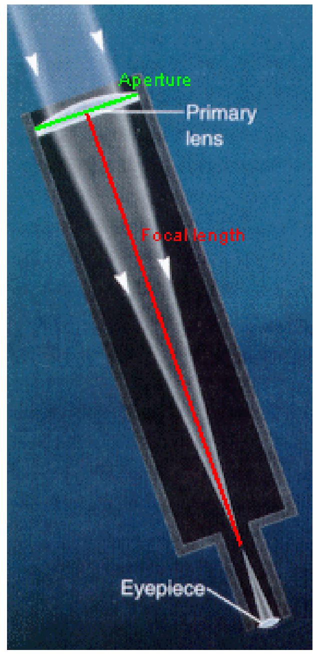

Figure 1.8: Aperture and focal length.

1.4 Telescope Limitations

1.4.1 Image Brightness

A 12-inch aperture is a very powerful tool. Clear Sky's limiting magnitude page (http://cleardarksky.com/others/BenSugerman/star.htm) predicts that an experienced CAS member might be able to see a 5.4th magnitude star on a dark night. Plugging this into Larry Bogan's telescope calculator (http://www.go.ednet.ns.ca/~larry/astro/maglimit.html) gives a limiting magnitude of 13.8. The magnitude scale is explained

[4] This applies to aberrations both in the telescope and in the eyepiece – keep this in mind if you take your eyepieces to a different telescope.

in more detail in Section 2.1, but this is roughly the brightness of tiny Pluto. Sounds good, right?

Although Ithaca is not a very large city, it does have a small amount of light pollution, and this reduces what we can see with the naked eye to about magnitude 4 (a factor of 4 reduction) . The faintest stars that we can detect through the 12-inch under such conditions are about 13th magnitude (a factor of 2 reduction). **For extended sources like galaxies and nebulae, light pollution is a bigger problem.** However, 13th magnitude is still faint enough to see plenty of objects. While certain CAS members will complain about light pollution given half a chance to do so, Ithaca's lights aren't about to shut us down.

1.4.2 Image Detail

All telescopes have limitations. One is set by the laws of physics. Electricity and magnetism courses call it diffraction, quantum mechanics courses call it uncertainty, but the final result is the same: squeeze light through an aperture of a certain size, and you limit how sharp an image you can make. For a 12-inch telescope, diffraction makes it impossible to see details finer than 0.4 arcseconds (an arcsecond is 1/3600 degrees, see Section 1.1.1).

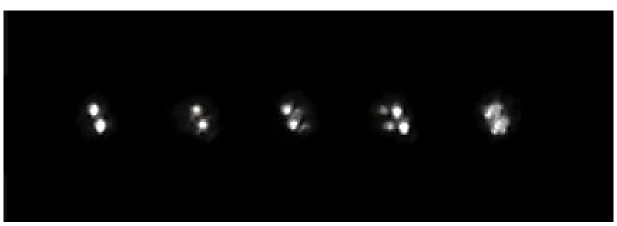

Figure 1.9: Seeing can distort, shift, or blur an image, and its intensity can very over a period of just a few minutes. © *Alan Adler*

Another limitation is *seeing*. The atmosphere is constantly in motion. Patches of air become warmer and colder, bending light differently. Turbulence mixes regions of air together. The overall effect is that light passing through the atmosphere gets bounced around. This is what causes stars to twinkle, but it also reduces telescope image quality. In Ithaca, we can get seeing forecasts by visiting Clear Sky Clocks (http://cleardarksky.com/c/IthacaNYkey.html), which gives its forecast on a 1-5 scale:

1. Seeing is 4 arcseconds or worse.
2. Seeing is 3-4 arcseconds.
3. Seeing is 1-2 arcseconds.
4. Seeing is 0.4-0.9 arcseconds.
5. Seeing is better than 0.4 arcseconds.

In Ithaca a rating of 3 is good; I can only remember a couple of 4's in my time here. This means that seeing overwhelms the effects of diffraction on our telescope. Only if we were to switch to a smaller scope (for example, on a road trip) would diffraction matter. Keep this in mind when reading materials that tell you how to get "diffraction-limited performance" from a camera or telescope – they're not relevant.

How much is one arcsecond? Not much: Saturn is 47 arcseconds across if you include the rings; the Ring Nebula is 60 arcseconds; a mid-sized crater on the Moon might be of a similar size. So under periods of good seeing you will need to crank up the magnification to see problems. Once seeing gets as bad as 6-8 arcseconds problems will become pretty obvious; for example, Saturn's rings will seem to change shape.

While seeing matters at Fuertes, **it's usually not the limiting factor**. The observatory dome (and the telescope itself) are typically warmer than the night air; turbulence between warm air near the telescope and the outside air will act like a very intense version of bad seeing. To reduce interference from *tube currents* and *dome currents*, open the dome slit and the door to the roof as soon as possible, and close the door leading downstairs. This will allow the dome to cool down to outside temperatures. Uncover the telescope (especially the front lens) early for the same reason.

Sadly, the downstairs door usually has to remain open during public viewing nights, and warm air from the observatory's main floor will prevent seeing from getting below a certain threshold. This threshold is marked in Appendix A as "Typical Dome Seeing".

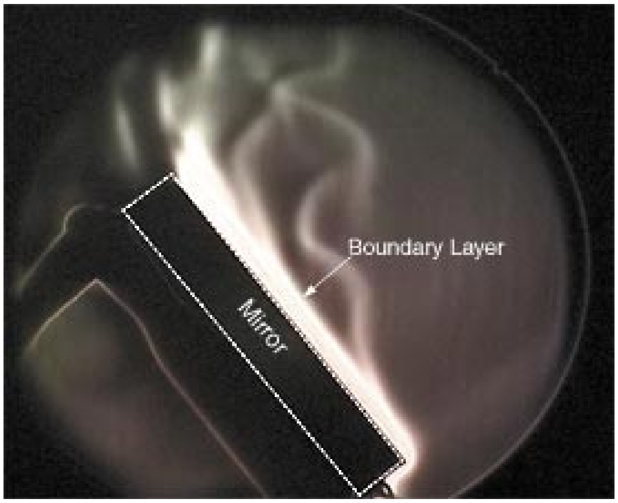

Figure 1.10: A lot of distortion comes from a thin layer of warm air sitting over a lens or, in this picture, a mirror. The recommended way of dispelling such a layer is with a fan, but since we don't have that we need to settle for a long cool-down. © *2000 Bryan Greer*

1.5 Eyepiece Observing

1.5.1 The Human Eye

Know thy instrument, and for most of us that means our eyes. Humans are primarily diurnal creatures, and so our eyes don't respond to faint light in quite the way we expect them to. Many of the practices of eyepiece observing are designed to get as much as possible out of these idiosyncratic detectors.

There are two types of light-detecting cells in the eye, *rods* and *cones*. Cone cells are the source of color vision, but require bright light levels to function. Rod cells are much more sensitive, but are colorblind. For most observations we need our rod cells.

During the day, rod cells have reduced sensitivity to keep them from getting overwhelmed by the plentiful light. When the light becomes too dim, rods undergo a complex series of chemical reactions that make them more sensitive; it takes about ten minutes for the fastest reactions to complete, and another half hour before everything is done. This *dark adaption* can be undone almost instantly by exposure to more light.

But we need to see what we're doing – how do we illuminate the observatory without destroying our night vision? It turns out that rods are relatively insensitive to red light. Dim red lighting, in principle, lets us see with our cone cells while leaving the rods relatively untouched. This is why nearly all our lights are red.

There are more rods near the sides of the retina than in the center, so we are more sensitive to light out of the corner of our eye.[5] This leads to the technique of *averted vision*, whereby an observer looking through a telescope can see a faint object only when he or she isn't looking directly at it. It takes a bit of practice to look at something without looking directly at it, but it is a very useful skill for any kind of observing.

1.5.2 Optics

Most observing at Fuertes is through eyepieces. CAS owns several dozen eyepieces (see Section 4.1 and Appendix B), and it is important to know which is most appropriate for which objects. Eyepieces can be characterized by three parameters in addition to generic factors like optical quality.

The *focal length* of an eyepiece determines the magnification. Specifically, the magnification is the focal length of the telescope (4572 mm for the main refractor at Fuertes) divided by the focal length of the eyepiece. A 40 mm eyepiece therefore has a magnification of 4572/40 =114x, while a 25 mm eyepiece has a magnification of 4572/25 =183x. For galaxies and nebulae a magnification of about 100x is usually good, while for planets you want a magnification of 200x or more if seeing allows it.

The *apparent field* of an eyepiece describes how big the image looks. Typical values are 45-50 degrees, although we have one "super wide-field" eyepiece that offers 68 degrees. If divided by the magnification, the apparent field gives you the true field of view. Our 40mm wide-field eyepiece, for example, has a true

[5]However, the center of the eye sees slightly sharper because of better optics and more densely packed retina cells.

Figure 1.11: Some common eyepieces.

field of 68/114 = 0.6 degrees, or 36 arcminutes (one arcminute = 1/60 degrees. The Moon is 30 arcminutes across).

The *barrel size* of an eyepiece determines what accessories (such as filters) can be used with that eyepiece. It also places some limits on how large an apparent field of view an eyepiece can be designed to have. All eyepieces and accessories are manufactured to be either 1.25 inches or 2 inches across. The 12-inch refractor can hold items of both sizes.

1.5.3 Results

So what do you see if you look through an eyepiece? The field of view is easy to calculate – it's given by the formulae above. On the other hand, there's no formula for how bright the object will appear because there are no units for subjective perception. However, there are some basic rules that come into play.

When you increase the magnification by, say, two, you spread the light you see over a four times larger area of your eye. So you would expect that objects would appear much fainter and less distinct at higher magnification, and in many cases this is exactly what happens. However, the mind's perception of brightness depends in a complicated (and not entirely understood) way on many factors other than the amount of light entering your eye, including the contrast of the image, the shape of the image, the fraction of your eye's field of view occupied by the image, and the amount of background light.

The final result, though, is that some objects will actually appear more distinct when some people increase the magnification (I, for example, have found that the Orion Nebula is easiest for me to see at a power of 200-250x). Experiment with different eyepieces for different objects under different conditions. When in doubt, however, **"higher power is fainter" is a very reliable rule of thumb**. We've gotten excellent results with galaxies by lowering the magnification as much as we could.

Magnification also affects how much the subjective image quality is reduced by seeing (see Section 1.4.2) and other atmospheric effects. If your field of view is one hundred times larger than the distortions caused by seeing, you will have a much easier time overlooking it than if your field of view is only ten times as large.

1.6 Photography

Recently CAS has acquired several cameras, detailed further in Section 4.4 (see also Appendix C). While valuable tools, **cameras behave differently from eyepieces,** and a user would do well to keep these differences in mind.

1.6.1 Optics

Strictly speaking there's no such thing as a "magnification" for a camera. When you look through a telescope with your eye, you see light entering from certain angles and you can relate those back to the corresponding angles without the telescope. For any kind of photography, be it digital or electronic, your final product is a fixed-size image – a nebula might be a certain number of centimeters across when you print the photo, but there's no obvious way of representing that as an angle.

What you instead talk about in photography is something called the *plate scale*. The plate scale is essentially how far something would need to move in the sky (an angle) to move it a certain amount in the telescope's focal plane (a distance) where the detector is mounted. It turns out that the plate scale is simply the inverse of the focal length. In the case of the main telescope at Fuertes, the plate scale is 1/4572 mm = 0.0002 radians/mm = 0.0125 degrees/mm = 45 arcseconds/mm. If you know how large a given camera's recording surface is in millimeters, you can calculate its field of view.[6]

Note that, unlike with eyepieces, there's nothing you can replace to change the plate scale. The only way you can change it is to use a *barlow lens* (described in Section 4.3) or a *focal reducer* to change the effective focal length of the telescope.

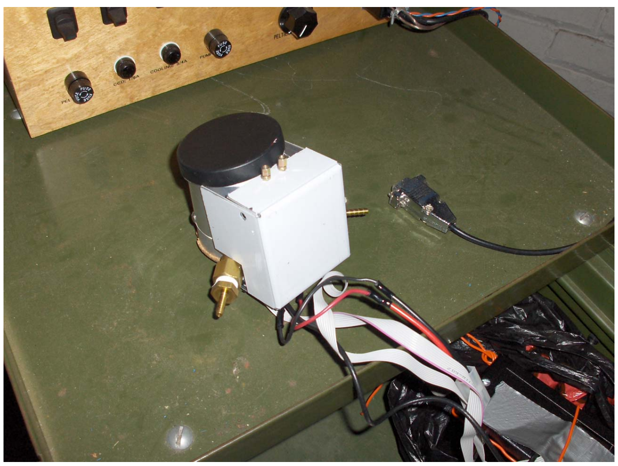

Figure 1.12: An astronomical camera.

1.6.2 Film Cameras at Night

1.6.3 Digital Cameras at Night

Charged Coupled Devices (CCDs, coloquially known as digital cameras) work by allowing incoming light (or, more precisely, the individual *photons* that make up the beam of light) to knock electrons off the chip. Those *photoelectrons* are then passed from pixel to pixel until they reach the edge of the chip. Then some kind of electronic system counts the electrons, uses the pattern of passing to work out which pixel each measurement came from, and passes the information to a computer where it can be displayed.

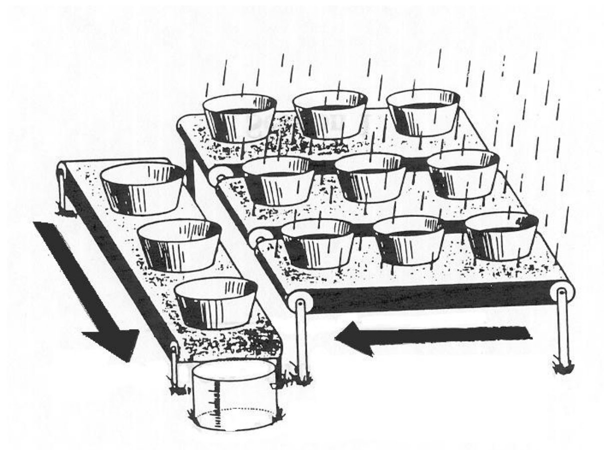

Figure 1.13: A popular analogy of how CCDs work. The buckets are pixels, while the rain is the incoming light. Note that you may be in trouble if there's no shutter to cut off the light while the chip gets read out.

Under bright-light conditions, this system works great and the human doesn't need to know anything about what's under the hood – err, chip. Under astronomical conditions, however, all sorts of quirks come up. Some are of interest only to researchers after precision measurements; others will affect the aesthetics of an artistic astrophoto.

The first and most important is *well capacity*. A CCD only gets read at the end of an exposure (the output would be swamped by noise otherwise), so photoelectrons have to stay in their home pixel as light keeps shining on the chip. If the source is too bright or the shutter is kept open for too long, the growing number of electrons will eventually "overflow" the pixel and start leaking into adjacent ones. Very sensitive CCDs, the kind suitable for deep sky objects, have too small a capacity to handle bright planets[7].

[6] The plate scale does actually have one application for eyepieces: if you multiply the scale by the diameter of the largest eyepiece you can mount, you get the maximum possible field of view for that telescope.

[7] You can't make an exposure arbitrarily short – either the

Light isn't the only source of electrons. Thermal fluctuations in the chip itself will also knock electrons loose to cause *dark current* ("dark" because you see it even if the chip isn't exposed). Dark current will add noise to the image and make faint structures harder to see; fortunately, since dark current is a thermal effect it can be reduced by cooling the chip[8]. All astronomical CCDs have some kind of cooling system, although we amateurs usually have to make do without liquid nitrogen.

Finally, every chip has its share of *bad pixels*. These are pixels that are too sensitive, or too insensitive, or produce large numbers of dark electrons. Bad pixels will appear as bright or dark specks on an image and should be removed with a calibration image.

A summary of how to use an actual CCD, and how to get around these problems, is given in Section 4.4.

1.7 Finderscopes and Binoculars

In principle, finderscopes are just small refracting telescopes, and binoculars are just small refracting telescopes with some extra mirrors to "fold" the light into a portable package. Therefore, most of the points made in Sections 1.3 and 1.5 continue to apply. The main difference is that you can't change eyepieces, so the magnification and field-of-view are fixed. Finders and binoculars are usually rated by magnification and aperture; for example, 7x50 binoculars magnify seven times and have two apertures of 50 mm each.

Most binoculars, of course, have a very wobbly altazimuth mount that feels neck pain near the zenith.

speed of the software or of the mechanical shutter will set a minimum time the chip sees the outside world

[8] And it can be removed from the image with appropriate calibration data.

Chapter 2

What's Up?

Your telescope is only as good as your ability to point it at something interesting. This chapter serves as a primer for the kinds of objects we can observe, some of the terminology used to describe them, and some essential facts about them. A listing of specific objects can be found in Appendix E.

2.1 Magnitude Scale

In the 2nd century BC, the Hellenistic astronomer Hipparchus of Rhodes created a catalog of about 850 stars, including their positions and brightnesses. How did he measure brightness without modern instruments? He took the brightest stars he could see and defined them as stars of the "first magnitude" (which roughly translates in modern colloquial english as "most important" or "most prominent" or "first priority"). He then took all the stars that seemed to be about half as bright and called them second magnitude. Third magnitude stars were those about half as bright as second magnitude stars, and so on.

Hipparchus ran out of stars after he got to sixth magnitude, but the invention of telescopes allowed the system to be extended to seventh magnitude, eighth magnitude, and so on. After the invention of the photometer in the mid-nineteenth century things got messy. For one thing, astronomers wanted something more precise than the magnitude system as it was then defined. For another, it turned out that sixth magnitude stars tended to be about 100 times fainter than first magnitude stars, not the 32 times one would expect if all the magnitude levels were really separated by a factor of 2.

Astronomers got around the problem by brute force: the magnitude of the star was made a **logarithmic function of its brightness** as measured by a photometer, and the distance between magnitude levels was tweaked so that a difference of 5 magnitudes was still a factor of 100 (a difference of one magnitude is then a bit over 2.5)[1]. So, if you have two stars, and one is r_f times brighter than the other, the magnitude difference Δm between them is

$$\Delta m = -2.5 \times \log r_f$$

and the reverse is:

$$r_f = 10^{-0.4 \times \Delta m}$$

Note that even after the magnitude lost its original meaning and became a precise measure, astronomers kept the convention of **lower-numbered magnitudes for bright objects**. This has been a source of confusion for astronomy students ever since.

It seemed like a good idea at the time.

The system underwent a few more changes after the invention of photography (and color filters) and after the introduction of infrared astronomy. The biggest change, however, had to be made to describe the brightness of galaxies and other *extended objects*. The problem is that the "brightness" of an object

[1] The scale was also defined so that the star Vega has a magnitude of zero. This convention has since been dropped so that new measurements of Vega no longer throw off every other measurement in astronomy, so Vega has a modern magnitude of about 0.02.

depends not on how much light you see from it, but how much light you see per a given area of the sky (the *surface brightness*). A very large object looks fainter, all other things being equal, because the light is more spread out.

The "size" of a star, however, depends on atmospheric distortion and the properties of the telescope (see Section 1.4.2 for more details). Since an ideal telescope would see the star as a point of light (and the eye can't tell the difference anyway), the original magnitude scale was defined in terms of total light. However, galaxies, nebulae, and other extended objects have an apparent size because they're really big – any telescope under any conditions will see that size, and surface brightness rather than absolute brightness is the important measure.

In the end, astronomers decided to be consistent and defined the magnitude of a galaxy as the magnitude of a star that would put the same amount of light in a telescope.[2] Magnitude, in other words, tells you nothing about how much an object's light is spread out. Therefore, **a tenth-magnitude galaxy or nebula will appear fainter than a tenth magnitude star.** That is, unless your telescope is so terrible that it spreads the light of a star into a blob the size of a galaxy.

We can see roughly 12th- or 13th-magnitude stars through the main telescope at Fuertes (see Section 1.4.1 for more on the capabilities of our telescope).

So, what sorts of things can we look at in the sky?

2.2 Sun

Astronomers like to look at stars, and for some that includes the Sun. Unfortunately, at magnitude -27 the Sun is overwhelmingly bright, and the fact that it's one of the larger objects in the sky doesn't change that significantly. The biggest challenge in solar observing is cutting down the amount of light that enters the telescope – not only will the concentrated beam permanently blind the viewer and possibly burn something, it can also damage the telescope optics. The bigger the telescope aperture (see Section 1.3.2), the bigger the problem, because more light gets in.

Most astronomy suppliers make filters made of mylar or specially processed glass that reflect or block about 99.999% of the incoming light. There are also similar filters for naked-eye observing. **Observing the Sun without a proper filter can be devastating to your health.** If you want to do solar observing at Fuertes, be sure to read Chapter 6 *even if you've done solar observing elsewhere.* We have some extra safety precautions that address concerns specific to Fuertes.

The Sun is a ball of plasma with fusion reactions (hydrogen to helium) producing energy in the center[3]. The plasma cools and thins as you travel outward from the core, and suddenly – over a distance of only a few hundred kilometers in the million kilometers of the Sun's diameter – the plasma goes from being almost completely opaque to almost completely transparent. This transition layer, the *photosphere*, is the "surface" of the Sun you see if you look at it through a filter because that's where light first has a decent chance of running into space without bumping into an electron first.

Most of the photosphere is smooth except on scales much finer than those we can see without photographic aid. However, there are places where the Sun's magnetic field causes the plasma to cool. Because slightly cooler matter emits much less light, we see these regions as dark *sunspots*[4]. Because of how twisted the magnetic fields around them can get, sunspots are generally associated with solar flares and other violent events. The Sun's magnetic activity

[2] Naturally, they also defined a version of magnitudes for surface brightness. The unit of magnitudes per square arcsecond is defined so that a source one square arcsecond across has a surface brightness equal to its magnitude. Remember that the magnitude scale is logarithmic – spreading the light over twice the area does *not* halve the surface brightness in these units.

[3] Despite what a lot of non-astronomers seem to think, the proton-proton chain that dominates solar fusion is not a very intense reaction at all. In fact, it proceeds excruciatingly slowly, and the Sun manages the power output it does only because the reaction is taking place over a volume many times that of the Earth. This is why engineers trying to build fusion power plants don't try to reproduce solar fusion.

[4] Another popular misconception – sunspots are not completely dark. They do emit plenty of light, and a properly equipped telescope can measure and analyze it.

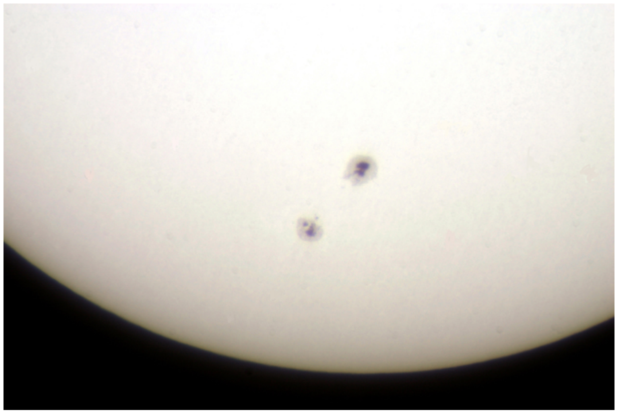

Figure 2.1: The Sun as seen from Fuertes. © *2006 Mike Roman*

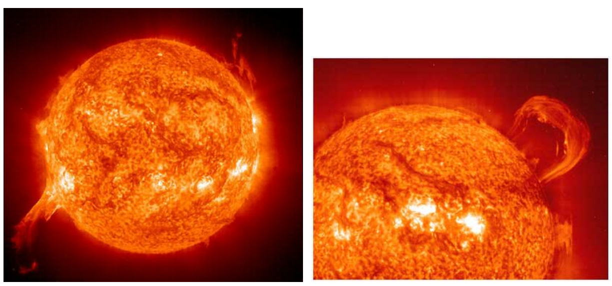

Figure 2.2: a) A solar flare. b) A prominence. *Images courtesy SOHO*

varies over a roughly 11-year cycle, and at the peaks in this cycle you can see quite a few sunspots. The Sun also rotates about once a month, and how many spots you see will also depend on which side is facing Earth at any given time.

In addition to the protective filter on the aperture of the telescope, you can place a *hydrogen alpha filter* near the eyepiece. This restricts the light entering the telescope to a very narrow set of wavelengths associated with emission from atomic hydrogen. Most of this emission comes not from the photosphere, but from a layer just higher up called the *chromosphere*. The chromosphere is a violent place, and through the filter you can see *solar flares* and *prominences* along the apparent edge of the Sun.

Prominences are places where the Sun's magnetic field loops high over the photosphere, and what you see is plasma streaming along the magnetic field lines. Inside the loop is a cloud of rising hot gas that pushes the field outward like an inflating balloon or a soap bubble. Solar flares occur when the magnetic field "snaps", releasing the plasma to travel outward freely.

Figure 2.3: An aurora seen from the roof of Fuertes. © *2005 Matipon Tangmatitham, Carlos Nieto*

2.3 Aurorae

Solar flares and prominences tend to merge into the *solar wind*, a stream of charged particles constantly flowing out from the Sun. Sometimes these particles get trapped in Earth's magnetic field, where they are sent down into the atmosphere. Reactions between these particles and air molecules cause the latter to glow, producing an *aurora*: the northern (and southern) lights. Normally, they can only be seen from near Earth's poles.

Sometimes, however, the Sun has a *coronal mass ejection*, where a very large number of particles gets released. If the ejection happens to be facing the Earth, it can produce a much larger aurora that can be seen from Ithaca or even further south. There are several places where you can sign up for aurora alerts, particularly http://www.spaceweather.com/

or http://skytonight.com/.

2.4 Moon

The Moon, to quote a certain former CAS member, is really bright. While not as dangerous as the Sun, the brightness of a full Moon as amplified through a 12-inch telescope will still cause pain and make it impossible to see surface features. We have a set of moon filters (see Section 4.2.3 and Appendix D) that we put in front of the eyepiece to bring down the light level.

The most obvious features on the Moon are the dark *maria* ("seas"). They are seas not of water, though, but of hardened magma from the Moon's only burst of volcanic activity. In the maria and in especially in the surrounding brighter highlands you can see many craters ranging in size from hundreds to a few kilometers across[5]. Craters and mountains are much easier to see during the Moon's quarter phases, when the Sun shines at an angle onto them and casts shadows. The full moon looks oddly flat, with only regions of brighter and darker rock providing contrast.

Normally we try to avoid the Moon because its light scatters through the atmosphere and makes the sky around it brighter (in much the same way as the Sun makes the whole sky brighter). Near the Full Moon we can only look at the Moon (obviously), the planets (Section 2.5), and open star clusters (Section 2.8.1). The "faint fuzzies" of the sky get washed out.

The rising and setting times of the moon are easy to estimate if you know the Moon's phase.

- A crescent moon has its nighttime side turned toward us, so it's roughly in the direction of the Sun. It's therefore in the sky at sunset and itself sets within a few hours.

- A first quarter moon has advanced somewhat in its orbit (west to east), so it rises and sets a bit after the Sun. At sunset, the quarter moon is high in the sky and easy to observe.

[5]There are also craters smaller than a few kilometers, mind you – they're just too small to see.

Figure 2.4: a) The full moon as seen from Fuertes. b) The same region at first quarter. Notice that you can see a lot more detail because of the lighting. For those who are curious, both images are centered on the Sea of Nectar (the people who named lunar features were very imaginative). © *2006 Mike Roman*

- A full or *gibbous* (more than half-full) moon has its daytime side turned toward us, so it's in the opposite direction to the sun. It therefore rises at around the same time as the Sun sets and remains in the sky all night. Depending on the exact phase, though, you may get an hour or two of relative darkness.

- A last quarter moon is like the first quarter, except its rising and setting times lead the Sun. It's therefore well below the horizon at sunset and doesn't appear until a bit before sunrise.

2.5 Planets

The planets are always a popular target with visitors, although their small size and sharp features makes them very vulnerable to the effects of seeing (Section 1.4.2). Still, a moderate-magnification view of any of the planets can be quite impressive.

Because planets move around, some times to observe them are better than others. The *synodic period* of a planet is how long it takes for that planet to repeat its position with respect to the Earth and Sun – in other words, when it's equally easy to observe. If you're looking up a reference on planetary motions, you will want to know some more terminology; otherwise, the only other vocabulary word you need from this section is *opposition* (when a planet is on the opposite side of the Earth from the Sun).

Inferior planets orbit closer to the Sun than the Earth does (although the term describes their aesthetics too!). An inferior planet lines up with the Earth and Sun at *conjunction*. Whether or not a planet is at *inferior conjunction* (on the same side of the Sun as Earth) or at *superior conjunction* (opposite side), it's hard to observe because it's in the same direction as the Sun. You want to look at inferior planets when they are at *maximum (eastern/western) elongation*, i.e. they appear to be far away from the Sun.

A *superior planet*, one that orbits farther away than the Earth, has only one conjunction (when it's on the opposite side of the Sun). Again, that's not a very good time to observe. **The best time is during or just after *opposition***, when the planet is on the same side of the Sun as the Earth and therefore (because it orbits farther out) in the opposite direction from the Sun in our sky.

2.5.1 Venus

Venus is the only inferior planet that we can regularly see, and there's not much to look at. Venus's carbon dioxide atmosphere, with a surface pressure ninety times that of Earth, is topped by an unbroken layer of clouds. Thus, Venus appears to be a featureless disk except through filters.

Venus isn't completely boring, however, beacause it shows phases like the Moon. At maximum elongation, when Venus is easiest to observe, this phase will be the equivalent of the moon's gibbous phase. As Venus approaches the Sun in our sky it will either become entirely dark (if on our side of the Sun) or entirely bright (if on the other).

2.5.2 Mars

Mars is a small planet, and most of the time is little more than an orange ball. At opposition, however, Mars is near enough that you can usually see some features. Darker and brighter plains[6] are easy to spot, and most experienced Fuertes observers can pick out the white polar caps as well. Can't make heads or tails of the blotches? Sky Publishing has a free utility called Mars Previewer (http://skytonight.com/resources/software/3304921.html?page=2&c=y) which may come in handy.

Figure 2.5: A contrast-enhanced image of Mars taken at Fuertes. *© 2005 Rob West*

Again, most of the surface features are areas of darker or brighter rock (although sometimes the bright areas are more dust than solid rock). While Mars has many nifty features like volcanos, topography is not something that you can see easily from millions of kilometers away.

The biggest problem with Mars observing is that the planet is a bit too bright for our telescope – in fact, many visitors at first see a featureless disk because they are almost blinded by the light. We sometimes use a blue or grey filter to cut down on the brightness, but sometimes the best policy is to just

[6] Mars is essentially a giant desert, so almost everything you see is some kind of rock.

wait five minutes.

2.5.3 Jupiter

Jupiter is the largest planet in the Solar System, and is appropriately easy to observe. The most obvious features are the planet's four largest moons (we usually copy a chart from *Sky and Telescope* magazine, but if we don't there's a utility at http://skytonight.com/observing/objects/javascript/3307071.html to identify them). Each of those moons is interesting in itself – Io, for example, is volcanically hyperactive, while Europa might have a subsurface ocean – but from Fuertes they'll never appear as more than points of light.

Jupiter itself makes for great viewing, too. The gas giant's uppermost cloud layers have a characteristic striped pattern that should be visible on all but the worst nights. Unfortunately, Jupiter's famous Great Red Spot is trickier. Some CAS members have reported seeing the storm system from Fuertes, but it's quite hard. If you want to try, first check that it's even facing Earth. http://skytonight.com/observing/objects/javascript/Transit_Times_of_Jupiters_Red_Spot.html will tell you when the Spot seems to cross the middle of Jupiter's disk; you need to observe within one or two hours of the listed time to get a good view.

Jupiter, like all the gas giants, is mostly composed of hydrogen and helium gas – the clouds we see are the top of an atmosphere thousands of kilometers deep. Farther down, the high temperatures and pressures lead to such bizarre states of matter as *liquid metallic hydrogen* – hydrogen, as the name implies, that acts a bit like a metal. Some astronomers believe that Jupiter has a rocky core the size of several Earths; others believe that there is little or no core at all.

Some older textbooks refer to Jupiter as a "failed star", claiming that if Jupiter had been "just a bit more massive" our solar system would have a second Sun. This is a gross exaggeration. While it is true that stars, like Jupiter, are composed mostly of hydrogen and helium, Jupiter is roughly 80 times less massive than the lightest possible stars. It is thirteen times less massive than the lightest possible *brown dwarfs*, starlike objects that can't sustain long-term fusion. In short, Jupiter is nowhere near massive enough to be anything more than a planet.

Figure 2.6: Saturn and its largest moon, Titan, as seen from Fuertes. The rings will look like this on a night of moderate seeing (Section 1.4.2 for more on seeing). © *2007 Mike Roman*

2.5.4 Saturn

Saturn's rings make it by far the most popular of our planetary targets; while all the gas giants have some kind of ring system, only Saturn's is directly visible from Earth. Under good seeing you can see that the rings are divided into two sections of slightly different color with the thin, black *Cassini division* between them. The rings are far more extensive, with many faint sections that can only be seen from nearby probes.

The rings look solid, but they are really swarms of "rocks" (mostly ice, not rock, but you get the idea) in orbit around the planet. The Cassini division and other, less prominent gaps are areas where gravitational interactions with Saturn's smaller moons have pushed most of the debris away. Some particles, though, still orbit in the gaps.

Speaking of moons, Saturn has plenty, but they are harder to see than Jupiter's. Saturn's largest moon, Titan, is an orange dot that gets easy to recognize with practice[7]. There are also some more moons you can see close to the rings; check http://skytonight.com/observing/objects/javascript/3308506.html for a finder chart.

Saturn itself is quite boring. Although it is a gas giant like Jupiter, the cloud patterns are much less prominent. Saturn therefore looks like a yellowish ball; only skilled observers (or contrast-enhanced images) get to see stripes.

2.5.5 Uranus and Neptune

Uranus and Neptune are both "ice giants" – planets that, while lacking a solid surface, don't have the sheer amount of gas that Jupiter and Saturn do. As they are small and far away, we only see either planet as a bluish ball (the blue is from the methane that makes up roughly 3% of either planet's atmosphere). Sometimes amateurs observe the moons of these planets, but I don't think they can be spotted from Fuertes.

2.6 Stars

In principle, the stars in the night sky are just like the Sun, and astronomers have found evidence that they also have sunspots, flares, and cycles. Unfortunately, the evidence consists of precision measurements of the stars' brightness over a period of many years – not something accessible to a Fuertes observer. From light years away, a star is just a point of light.

Many (but, despite what all but the most recent textbooks say, not most) stars come in groups of two or three. These *binary* or *triple* star systems are often detectable only indirectly, but sometimes the individual stars are far enough apart that you can see them. The "best" binaries are those where the two stars have very different colors. For example, Albireo (β Cygni) is a very nice double with a bluish and a golden component. The exact color of a star depends a lot on who is looking at it, especially when it comes to red or orange stars, so you might want to describe the colors for yourself. A table of binary stars is included in Appendix E.

Figure 2.7: Albireo, one of several double stars we observe at Fuertes. © *2006 Michael Fulbright*

Some double stars are fake – rather than being in orbit around each other, as in a true binary, the stars just happen to be located in roughly the same direction. A good example of such an *optical double* is 24 Coma Berenices, whose stars appear to be even closer together than those of Albireo. The brighter one, though, is 600 light years away while the fainter one is 2400 light years away.

Where do the contrasting colors of binaries come from, you ask? Different temperatures. Like a piece

[7] The orange color is from a layer of haze high in Titan's nitrogen atmosphere. Titan is the only moon in the solar system with a significant atmosphere.

of heated iron, a red star is barely hot enough (about 3000 degrees Celsius) to shine at all. A yellow star (like the Sun) is considerably hotter (6000 degrees). Whitish stars tend to be 10000 degrees or more, and the very hottest stars have been known to have surface temperatures of 50000 degrees.

The temperature of a star depends (mostly) on how quickly it is fusing hydrogen in its core (which is much hotter, by the way – tens of millions of degrees, usually), and the reaction rate depends basically on the mass of the star. So red stars are the least massive[8] – a tenth to half the mass of the Sun – while white stars can be several times more massive. The most massive stars can have 50 or more solar masses of material, but only a few are known.

Incidentally, massive stars live shorter – although they have more fuel, they are hotter and so go through it much faster.

2.7 Our Galaxy

Look up on a dark summer night (or a *really* dark winter night) and you might see a band of haze stretching across the sky. That's our Galaxy, the Milky Way. Why the band? The Milky Way is shaped like a disk (see Section 2.10.1), but because we're inside it we see directions with lots of stars (along the disk) and directions with fewer stars (away from the disk). As a result, only the relatively nearby stars are scattered all over the sky, while the countless more distant stars blend into a hazy band.

While the Milky Way is full of clusters, nebulae, and other telescopic targets, the Milky Way itself is best seen with binoculars. Their wider field of view will give you a better idea of just how many stars are out there. If it's summer time be sure to look around the constellation Saggitarius. The center of the Galaxy is in that direction, and the sky is packed with star clusters and dark nebulae.

[8] As with every rule, there are exceptions. As explained in Section 2.9.2, stars tend to grow and cool as they grow old, and so they also appear red. In fact, most of the brighter red stars we see are old rather than small.

2.8 Star Clusters

Stars tend to be separated by many light years, with the exception of members of multiple star systems (Section 2.6). However, sometimes stars can be found in tight groups called *star clusters*. Star clusters are a popular target at Fuertes because they are large, minimally affected by light pollution, and can be found year-round. There are two types of star clusters that differ greatly in appearance and history.

2.8.1 Open Clusters

Open clusters are, for the most part, groups of newly formed stars. Most are tens of millions of years old, although a few hundred-million-year stragglers can be found (and I think I recall hearing of a billion-year-old open cluster). Open clusters are short-lived because the newly formed stars' gravity is too weak to hold the stars together. The stars slowly drift apart and eventually become the isolated stars we see in the rest of the sky[9].

Open clusters typically number a few hundred to a few thousand stars, but most are too faint to see even with the Fuertes telescope. To see more stars, you need to take a long-exposure photograph. Open clusters are typically a few thousand light years away, although there are some nearer ones. They are usually found near the plane of the Galaxy.

2.8.2 Globular Clusters

Globular clusters are, in many ways, the opposite of open clusters. Where open clusters are young, globulars are old – ten billion years or more. Where open clusters hug the plane of the Galaxy, globular clusters are scattered all over the sky. Where open clusters have at most a thousand stars, globulars have at least a hundred times that. Where open clusters are loosely bound and on the verge of breaking up, globular clusters are compact balls that can only be disturbed by external tides.

[9] In the meantime they become *associations*, a stage in which the stars are no longer gravitationally bound but are still relatively close to each other. Associations are usually identified by the fact that their members all travel through

Figure 2.8: M 38, one of many open clusters we look at. Through the eyepiece you will only see the brightest stars in this photo. © *NOAO/AURA/NSF.*

Globular clusters look like spheres of haze with invididual stars visible only on the outskirts. As with open clusters, you're seeing only the brightest stars – most globular clusters are tens of thousands of light years away. There are so many stars in a globular cluster that, if you could stand on a planet around one of these stars, the sky would never grow darker than our twilights. Many of the nearer stars would be visible during the day, at least if you weren't facing the sun directly.

2.9 Nebulae

There's more to the Galaxy than just stars. In between the stars are large amounts of gas, and in places the gas becomes visible as a nebula. Astronomers classify nebulae either by how they form (as we do in the following sections) or by the physics that makes them visible:

space in roughly the same direction.

Figure 2.9: The Hercules Cluster, one of our favorite globular clusters. © *Eddie Guscott.*

- *emission nebulae*, the most common type, have atoms glowing at specific *emission lines* set by the quantum mechanics of that particular element.
- *reflection nebulae* are mostly composed of interstellar dust, which reflects starlight.
- *absorption nebulae* are also composed of dust, but they're visible because they're in front of either a starfield or another nebula and block the light we would expect to see.

2.9.1 Diffuse Nebulae

Stars have to come from somewhere, but they're a bit too big for delivery by stork. The Galaxy is filled with regions of relatively dense gas called molecular clouds (don't bother looking for them – they're only visible at radio wavelengths). When a cloud, or part of one, reaches a critical mass or density, it collapses under its own weight, heats up, and fragments. The pieces continue to collapse, grow hotter, and break into even smaller pieces until finally they become hot enough for nuclear fusion to begin. And fusion, after all, is what makes a star a star.

Stars, especially the hottest ones, produce huge amounts of ultraviolet light. When this light runs into the remaining (uncollapsed) gas surrounding the

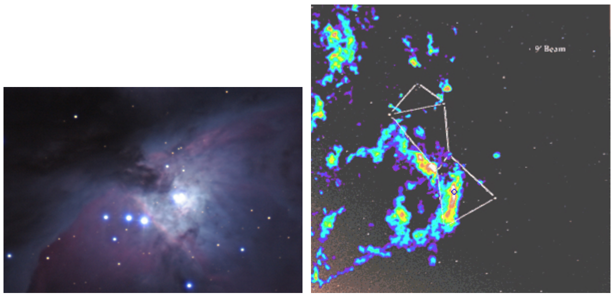

Figure 2.10: a) The Orion Nebula (M 42), the most famous star-forming nebula, as seen from Fuertes. It's one of our most popular winter targets. © *2006 Mike Roman* b) This tip makes icebergs look obvious. This is a radio map of the Orion-Monoceros molecular cloud superimposed on an image of Orion. The visible nebula is circled in blue in the lower half of Orion. *Image courtesy Harvard/CfA*

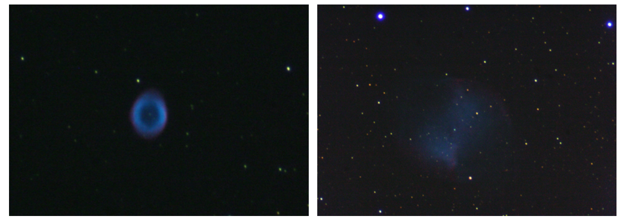

Figure 2.11: The Ring (left) and Dumbbell (right) Nebulae, two of the best planetary nebulae visible from Fuertes. © *2006 Mike Roman*

new stars, it gets absorbed by electrons in the gas atoms. These "excited" electrons eventually reemit the light and create an emission nebula a few light years across. There are many such nebulae in the sky, many of them quite beautiful, but the best are up during the winter.

Molecular clouds are often associated with large clouds of dust that produce absorption or reflection nebulae. Thus, a single view can include all three types of nebula physics: emission nebulae from the excited atoms, reflection nebulae illuminated by the new stars, and absorption nebulae if the actual star-forming region is in the background.

Star forming regions often produce multiple generations of stars, but sooner or later all the dense gas is gone. The stars remain behind as open clusters for a while before going their own way, but after a few hundred million years there is usually no trace of the original nebula.

2.9.2 Planetary Nebulae

Nothing lasts forever, not even stars. A star like the Sun can last for billions of years (and the really light ones, because they "burn" so slowly, can last trillions!), but sooner or later the star will run out of fuel. This triggers a chain of reactions that causes the outer layers of the star to inflate and cool; the star becomes a *red giant* that, having run out of hydrogen in its core, now starts fusing helium into carbon and oxygen. Red giants tend to be about the size of the Earth's orbit. There's some debate about whether or not the Earth will survive the Sun's red giant stage, but at the very least it will be thoroughly melted. Mercury and Venus are doomed.

Because red giants are so huge, their surface gravity is very weak. Surface pulsations regularly throw gas into space, and a solar wind much stronger than our Sun's produces a steadier flow. The overall effect is that a red giant whittles itself away. Once the mass-loss gets going, it takes only about a thousand years for the star to lose everything but its core, which (for lack of fuel and pressure) stops fusing and collapses to become a *white dwarf*. White dwarfs are supported against their weight by a wierd quantum effect called *electron degeneracy*. They are also really dense – they have the mass of a large fraction (say, half) of the Sun, but are only the size of the Earth.

Even after fusion has stopped, a white dwarf takes a long time to cool down, so it produces ultraviolet light. This light hits the gas the star threw off earlier and lights it up to create a special kind of emission nebula known as a *planetary nebula*[10]. Planetary nebulae only last for about a hundred thousand years before the gas spreads itself into invisibility. In the

[10]So called because the first ones discovered appeared circular, like planetary disks. We now know that spherical planetary nebulae are the exception rather than the rule; for reasons not yet entirely understood, most of the gas gets thrown in two or sometimes three, four, or six opposing directions.

meantime, though, the shell of gas looks very nice through a telescope, and even a short exposure photograph (or a large aperture on a dark night) will pick up the white dwarf in the center.

2.9.3 Supernova Remmnants

Very massive stars (eight or more times heavier than the Sun) have a way out of this fate. Their larger masses let them achieve much higher temperatures in their cores, hot enough that when they run out of helium they can start burning carbon and oxygen, followed by the even heavier elements produced from the previous cycles of fusion. In fact, massive stars can keep "burning ash" until they start producing elements like iron and nickel. It is, however, impossible to fuse iron or any heavier element and get energy out of the reaction under *any* conditions. In the end, even a very massive star is left with a large core that it can't support with energy from fusion.

Massive stars throw off gas into space just like less massive stars do (the bloated stage is called a *supergiant*; the color varies), but because the sequence of fusion stages proceeds much faster there's still a lot of star left when the core collapses. With the core gone, the outer layers fall in as well. The core stops collapsing when *neutron degeneracy* comes into play. The outer layers of the star pile onto the now rigid core, a shock wave gets produced (insert theorists' hand-waving here)...

...and the star explodes.

We haven't seen a supernova in our Galaxy in four hundred years, but they were seen every few centuries in ancient times, and some observers were even kind enough to note where they saw the "new star". When we look with telescopes at those positions, we see clouds of gas speeding outward from the star's original location.

Often the core survives as a neutron star, an object so dense it packs the mass of a star into something the size of a large city. These bizarre objects rotate many times a second, and do it so regularly that you need atomic clocks to measure the deviations. Their powerful magnetic fields create beams of radiation that can be seen as *pulsars* when they sweep past the Earth.

Figure 2.12: a) The Crab Nebula, a very young (900 years) supernova remmnant and the only one we normally see from Fuertes. *Image courtesy VLT* b) The Veil Nebula, a more typical remmnant (about 10000 years old) which has already spread into near-invisibility. © *Mikael Svalgaard*

Very massive stars don't become neutron stars because their cores are so massive that even neutron degeneracy can't handle the pressure (excuse the pun). These objects collapse indefinitely until they become *black holes*. Despite what Hollywood has to claim to the contrary, a black hole is not a cosmic vacuum cleaner. At a distance of, say, a few million kilometers, a black hole has slightly weaker gravity than the original star because some mass got thrown off in the supernova. It is only when you get very close to the hole that you start getting weird effects.

A *really* massive star produces neither a neutron star nor a black hole. The mechanics of the supernova are such that almost all the matter gets thrown out.

2.10 Galaxies

Galaxies come in all shapes and sizes, from small clumps of ten million stars to monstrosities with over a trillion. Despite some objections that the system is inappropriate in an age of multi-wavelength astronomy, most astronomers still use the basic classification of galaxies cxtablished by Edwin Hubble in the 1920s. Hubble defined galaxies as "spiral" (vaguely disklike, usually with the well-known arms) and "elliptical" (vaguely round, with no obvious features). There's also a slew of poorly defined cate-

Figure 2.13: a) The Andromeda Galaxy, with an image of the Moon shown for scale. Our telescope cannot see a field of view much larger than the Moon's disk. © *Adam Block, Tim Puckett* b) The Whirlpool Galaxy, a more easily observed spiral. *Image courtesy HST*

gories like "irregular", "dwarf irregular", and "dwarf spheroidal".

Through any amateur telescope, including the one at Fuertes, galaxies all look like fuzzy blobs. In fact, often you can't even see the entire galaxy, only the central regions (the Andromeda Galaxy is a good example – the "blob" there is only the inner core). If you want to see shapes, or spiral arms, you need either a really big telescope, photographic equipment, or both.

2.10.1 Spiral Galaxies

Spiral galaxies, like our own, are usually divided into three parts. At the center is the *bulge*, a sphere of moderately old stars. Surrounding that is the *disk*, which generally contains younger stars. The disk contains the spiral arms, regions where the interstellar gas is slightly denser and therefore star-forming regions are most common. It is the bright stars in these regions that make spiral arms so visible. In terms of the density of all stars (bright or faint), spiral arms are almost indistinguishable from from the rest of the disk. Surrounding the bulge and disk are the *halo*, a thin region of very old stars. Globular clusters (Section 2.8.2) orbit in this region, but otherwise it's hard to observe.

Spiral galaxies have plenty of variety beyond this basic layout. The relative sizes of disk and bulge very. Some have bars instead of, or in addition to, the usual bulge. The number and clarity of the arms can vary as well. Finally, spiral galaxies look very different depending on whether we see them face-on (like the Whirlpool, shown in Figure 2.13b) or edge-on, when the galaxy looks a bit like how we see the Milky Way.

2.10.2 Elliptical Galaxies

Elliptical galaxies look a bit simpler than than spirals – they're just balls of stars. Elliptical galaxies tend to have less star formation than spirals, as much of the gas has already been used up. Ellipticals include the largest galaxies in the universe, formed from the combined collisions of dozens – maybe hundreds – of smaller galaxies.

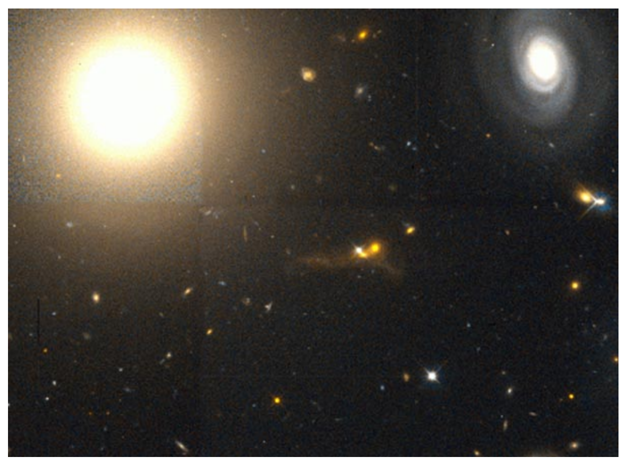

Figure 2.14: NGC 4881, a very large elliptical galaxy. *Image courtesy HST*

Chapter 3

Basic Observing With the 12-Inch Refractor

At 80 years old, Fuertes Observatory is something of a historic landmark. It's amazing that the telescope works almost as well as it did in the 1920s, and we do everything in our power to keep it that way. As a result, we have some standard procedures for using the telescope that minimize the danger of anything getting permanently damaged. One of our longstanding rules is that you will not be able to use the telescope by yourself until you are intimately familiar with the material covered by this chapter.

This chapter is no substitute for hands-on training sessions – use it as a reference ONLY.

3.1 Dome Procedures

This section covers the mechanics of using the dome and the telescope. How to get the telescope to a target is covered in Section 3.3.

3.1.1 Opening the Observatory

For the safety of the facility, its equipment, and its users, we have an official procedure for opening and closing Fuertes. This procedure is defined by the CAS Bylaws and posted on the dome wall. The steps are listed here in their official order, but some variations are possible. Which orders are safe and which are not will be noted as appropriate.

1. Pull the blue tarp off the telescope. The tarp should slide off without getting caught on anything; if it does, pull over one of the ladders and unhook it. Do *not* try to rip the tarp off. The tear you make will only make it more likely that the tarp will get caught in the future. Once the tarp is off, bundle it up and place it somewhere where nobody will trip on it – for example, under the worktable.

2. Open the deck door. The door has two locks: a restraining bolt below the door handle, and a catch inside the handle that only allows it to be opened from the inside. **Make sure that when you leave the door open the bolt is placed in the locked position** – this will keep the door from slamming shut and locking anybody out on the deck.

   I prefer to open the door before removing the tarp, because this lets the dome ventilate sooner and improves dome seeing (see Section 1.4.2).

3. Open the dome slit by climbing the tall, narrow ladder at the south end of the dome and turning the large wheel at the top. There's a metal bar wedged through the wheels that you will have to remove first[1]. Be forewarned that the wheel is

[1] This bar is our lock for the dome slit. Why need a lock? The story goes that some local high school students used to climb the outside of the observatory and force open the dome as a prank. Nobody fell, but the department decided to put an end to the fun before somebody cracked his or her skull.

Figure 3.1: Make sure the deck door cannot slam shut while somebody's outside!

heavy – everybody has their own way of getting enough leverage, so feel free to experiment. Once you've gotten the wheel turning it will be obvious when to stop; you'll feel a lot more resistance than usual.

4. The ladder you had to climb to open the dome slit also puts you next to the telescope aperture. This is a good time to remove the telescope's dust cover. There's nothing fancy here – just pull. Put both the dust cover and the dome locking bar someplace where you can find them a few hours later.

5. The next step is to prepare the motor that powers the dome. The motor contains a belt that runs between several wheels; to reduce wear, one of the wheels is elevated so that it doesn't put much pressure on the belt. To get the motor into a functional state, you need to work with the contraption[2] shown in Figure 3.2. There are three parts to keep an eye on – the wooden stick that keeps the wheel elevated, the rod used to tighten or loosen the wheel, and the hook that connects the rod to the rest of the motor.

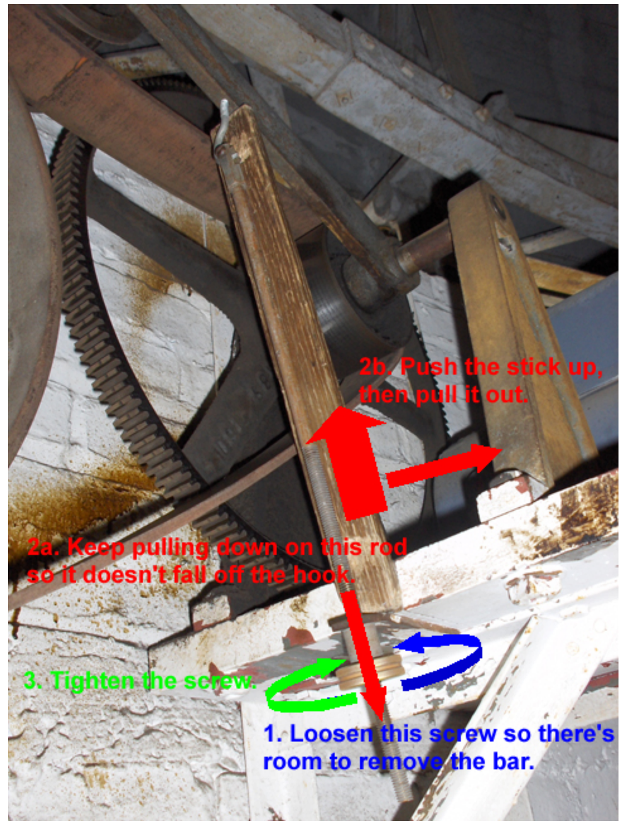

Figure 3.2: How to tighten the dome belt.

   (a) Begin by partly unscrewing the knob found at the bottom of the rod. Half an inch is more than enough slack; be careful not to unscrew too far or it will get stuck.

   (b) The next part is the trickiest – lift the wooden stick so you can take it out of the assembly, *while pulling down on the rod*. Every Fuertes observer has, at least once in his or her time here, forgotten this part. While you can get the stick out that way, the rod will probably fall off the hook, and it's very hard to get it back on again.

   (c) Once the stick is out and the rod is (still)

[2] To reach the motor, stand on the wooden bench beneath it. If that fails you can try standing on the nearby box for our 14-inch telescope. Be careful to stand only on the edges so as not to damage the scope.

on the hook, tightening the belt is a matter of simply screwing in the bottom knob as far as it will go.

6. Next to the dome motor is the power box. Push the lever up to hook the motor up to the dome's power supply. **Do not do this step until you *after* you have both opened the dome slit and tightened the dome drive.**

7. It's time to get the telescope ready. Climb a ladder until you can reach the eyepiece end of the telescope. There are two almost identical knobs, one with four screws in its face and one without. While holding on to the telescope end, slightly (at most a half-turn) loosen the knob without screws. Pull the end of the telescope down until it is at a comfortable height for working from the ground, and tighten the knob again. **Be sure to hold on to the telescope for the entire time that the knob is loose.** This step doesn't need to wait until the dome is set up, but it should happen after you've removed the tarp and the dust cover.

8. The eyepiece normally kept in the telescope is very old and of poor quality; it serves more as a dust cover than as an observing tool. Remove the eyepiece by pulling it straight out – don't twist! You can then insert a more suitable eyepiece from the equipment cabinet.

9. The equipment cabinet contains not only eyepices, but also binoculars, red flashlights, a laser pointer, and other useful equipment. Which of these you need will depend on the kind of observing session you are holding, but this is a good time to get them out.

10. Open the window in the telescope mount (the one facing the equipment cabinet) and find a small lever at the top (shown in Figure 3.4). Pushing the lever all the way to the left will start the clock drive. You may want to make sure that the drive is wound first (see Section 3.2.4 for more details on operating the clock drive). Although this step can be done at almost any time, it's best if you wait until just before you start observing – the clock drive can only run for a limited time between rewinds, and this way you won't waste it.

Figure 3.3: The equipment cabinet, full of many different astronomical gadgets.

11. To set up the dome, you probably turned on the white light near the door. While good for working with equipment, the light is much too bright for observing – it completely destroys night vision. Instead, you want to turn on the observatory's red lights[3] and turn off the white. The red lights are the following:

   - Three lights along the dome walls. The one by the deck door can be turned on with the switch underneath it; the other two need to be screwed in. Screw them in as little as possible – when it comes time to remove them, they will be painfully hot.
   - A string of lights along the sides of the deck. Turn these on with a switch located to the right of the door.
   - The worktable light; the switch is on the left side of the table.

[3]The eye's rod cells, which are what we use to see in the dark, are least sensitive to red light.

Figure 3.4: Start the clock drive by pushing the lever to the leftmost position. It will take the drive about a minute to get up to full speed.

- The stairwell light, controlled by a switch in the observatory lobby.
- The deck stair light, turned on by screwing in the bulb.
- The dome floor light, controlled by a switch to the left of the deck door.

The last three lights are only to help visitors find their way around; you probably want to leave them off for private observing. Likewise, you may want to turn some of the other lights off to improve dark adaption. I've occasionally observed with only a single wall light.

Figure 3.5: a) The desk light switch is hard to find. It's on the left end of the desk. b) The equally hidden deck stair light is much more important: it warns visitors to watch their step.

12. Once the clock drive is up to speed you can also calibrate the right ascension dial – depending on whether you're using a reference star or the observatory clock, you may want to do this before you switch lights. The calibration procedure is simple, but takes a while to explain, so it is left until Section 3.2.6. Calibration is not needed to use the telescope, especially for bright or commonly observed targets.

13. For a private observing session you may want to close the door leading downstairs to minimize dome seeing (Section 1.4.2). On a public night it's more important that our visitors know where to go.

3.1.2 Closing the Observatory

In many ways the closing procedure is the reverse of the opening procedure, although there are some things that are different.

1. Stop the clock drive by moving the control lever to the right and pressing until the drive stops. Be sure to wind up the drive (see Section 3.2.4) for the next group. This doesn't have to be the first step in shutting down, but it must be done before you put the telescope in its stowed position.

Figure 3.6: Apply pressure on the braking lever to stop the clock drive.

2. A general rule of Fuertes use is to leave everything as (or preferably better than) you found it. In particular, anything you took out of the cabinet belongs back in the cabinet, including:

   - Eyepieces
   - Filters
   - Other optics
   - Flashlights
   - Binoculars

   Double check that nothing's been left out on the deck, and remove the batteries from the laser pointer before storing it.

3. Make sure the historical eyepiece (the one you removed in the starting procedure) is back in the telescope. Make sure the TELRAD system (described in Section 3.2.1) is switched off.

4. Once the clock drive is off, the eyepiece is away, and the TELRAD is off, you can park the telescope. The telescope should be stored facing due south (XXIV on the right ascension dial) in a horizontal position. The tube should be on the east side of the dome.

5. The first step in getting the dome shut down is to rotate it until the slit is at the south end of the dome. This step may be done before the telescope is parked or the equipment is gathered.

6. Once the dome is parked, turn off the power to the dome motor. **Do not begin working with the motor, or closing the slit, until the power is off.**

7. Once the power is off, the dome drive's belt should be loosened for storage. This is essentially the reverse of the original procedure:

   (a) Loosen the bottom screw about two inches – make sure you don't unscrew it too far or it will get stuck.

   (b) Lift the motor's top bar (the one holding the wheel) with the wooden stick until it's high enough for you to wedge the stick into the motor. Keep the metal rod taut at all times to keep it from falling off the hook; new members will need to learn to resist the temptation to push up the bar with the rod. Trust me, it doesn't work.

   (c) Tighten the screw so that the stick won't fall out.

8. Once the telescope is parked you can put the brown dust cover back on the telescope. You may have to pat the cover a few times to get it to slide in all the way.

9. If the dome power has been shut off, you can close the slit by turning the large wheel at the base of the slit. Note that most people find this harder than opening it in the first place; again, experiment to find the best leverage. Once the dome is closed, slide the bar through the large wheel so that it goes through the two smaller ones in the dome wall. When you're done it should look like Figure 3.7.

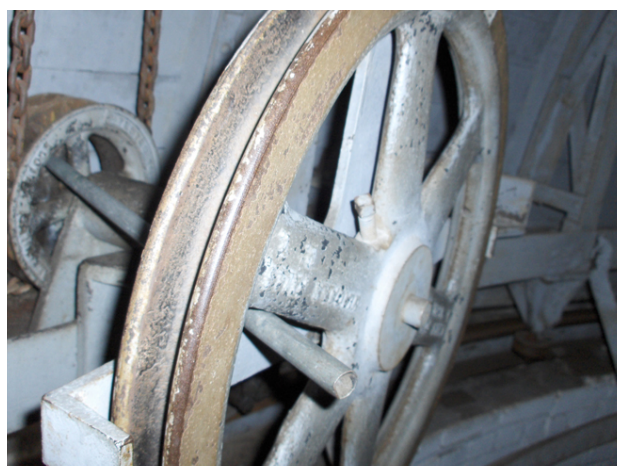

Figure 3.7: One of two correct positions for the dome bar. The other has the bar go through the next higher hole in the large wheel.

10. Ever wonder how that tarp got up on the telescope to begin with? I'm pretty sure there's a miracle involved. To cover the telescope, you

should use both ladders (doing this with a partner is much easier, but it's possible to do it alone).

(a) Park the shorter ladder under the declination setting circle, and park the taller ladder next to the black cylinder on the side of the telescope.
(b) Start bundling the tarp into a ball, but leave most of material hanging loose.
(c) Climb the taller ladder (while holding onto the "head" of the half-bundled tarp) until you can see over the side of the telescope.
(d) Throw the "head" across, preferably so that it clears the declination setting circle.
(e) Climb up the other ladder (or have a partner catch the "head"), then spread the tarp out to cover the major parts of the telescope. When you're done the tarp should look something like Figure 3.8.

Figure 3.8: If properly placed, the tarp should cover the setting circles (left figure) and the end of the finderscope (right).

11. Once you're sure that nothing's been left outside, close and lock the deck door.

12. Don't forget to turn out all the lights before you go!

3.2 Basic Telescope Use

3.2.1 Pointing the Telescope

A telescope is only as good as your ability to point it at something interesting. With a telescope three times as large as you are, and a dome blocking your view of most of the sky, pointing the Fuertes refractor is a challenge. Don't think that just because you've used a backyard telescope before you won't have any trouble with our behemoth.

Dome

The first step is to get the dome pointed in the right direction. Moving the dome is simple – there's a controller to the right of the equipment cabinet, and the cable is long enough that you can take it anywhere inside the dome. The controller has two buttons; the one closer to the cable will move the dome right, while the other will move it left.

Be careful when judging how long to hold the button, because the dome has plenty of inertia and takes a while to come to a stop. **Avoid pushing the button for the opposite direction while the dome is in motion – you may damage the motor.** If you keep these rules in mind, soon you'll have no trouble getting the dome to stop exactly where you want it.

Deciding where to stop the dome is a bit trickier, and in the end the only thing that will really help you is experience. Still, there are some tricks to help you match up the unobstructed view you get from the deck with the confined view through the dome slit:

- Stare at the location you want to move to, then walk into the dome without taking your eyes off that spot. Don't trip over the steps!
- If you need to turn your head, you can try pointing at the spot while you head inside. It may look a little goofy, but it works.
- Pick out nearby stars that form a distinctive pattern, then try to find it through the slit. Just remember that the pattern will probably look larger once you have the slit walls as a reference.
- Beware of altitudes – objects will often seem to be much higher above the horizon from inside the dome than from the deck. Very low objects might not be visible at all from the dome floor.
- Once you can see your target through the dome, you want to align the dome slit so that you can

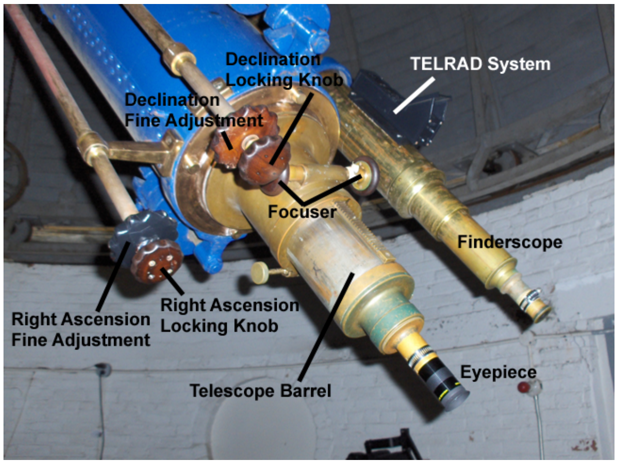

Figure 3.9: Our telescope has far too many knobs and gadgets. Here's a quick overview of which is which.

see your target "over the shoulder" of the central pier.

Once the dome is in (roughly) the right place, move the telescope to point in the same general direction. This may involve *flipping*, as explained in Section 3.2.2. Once the telescope is in place, you may find that your estimate of the dome position was off slightly. Go back between deck, dome switch, and telescope as many times as needed.

Telescope Controls

Once you've got the dome in the right spot, the next step is getting the telescope at the right part of the sky. This means learning the controls summarized in Figure 3.9. Be careful – the relative positions of the controls will change depending on where the telescope is pointed.

The most important controls are the two locking knobs, one for the right ascension axis and one for the declination axis (if you're not familiar with these two terms, you may want to read Sections 1.1.3 and 1.2.2 before continuing). **Twisting either knob left by a quarter- or half-turn will unlock the telescope,** allowing you to move it along that axis simply by pushing or pulling the telescope barrel. Twisting a knob right as far as it will go will prevent the telescope from moving. How do you tell the two knobs apart? The right ascension knob has four screws in its face.

There are some rules to remember when moving the telescope. The most important is to **always hold on to the barrel, or the knobs, while the telescope is unlocked** . Letting go of the telescope is inviting it to drift until it hits something. Do not hold on to the finderscope, as you may misalign it. The second rule is to avoid applying too much pressure on the telescope when it is locked – the locks aren't perfect, and forcing the telescope to move while locked will degrade the locks further.

Behind each locking knob are the fine adjustment controls. At the time of writing they are broken, and should not be used. If they ever get repaired, though, turning them will tweak where the telescope is pointed at moderate or high powers. Don't bother using fine adjustment at low power or while looking through the finderscope, as the effect will be too small to notice.

There is actually one more way to move the telescope. Mounted on the central pier, facing the door, is a large wheel that resembles the helm of a ship. Rotating this wheel will turn the telescope through large angles in right ascension. Note that the "ship's wheel" is meant to be used with the telescope locked. **Make sure no one is looking through the telescope before you turn this wheel.** During public nights, keep an eye out for children, who sometimes assume the wheel is a toy.

Use of the TELRAD and finderscope will be explained in the following sections. Use of the focuser is covered in Section 3.2.3, and eyepieces (which control magnification, among other things) are covered in detail in Section 4.1.

Telrad

The first step in telescope pointing is correctly identifying which point of light is your target; see the tips under "Dome" for some advice on getting it right. Once you can see your target, you can try to get the telescope pointed at it by sighting along the tube. Few people can do so reliably, so instead we use the

TELRAD.

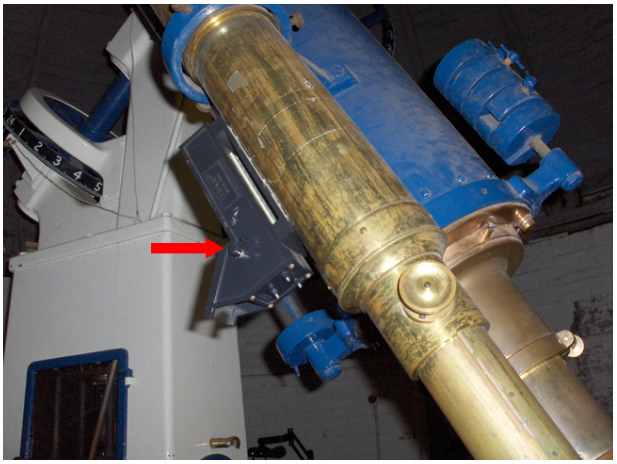

Figure 3.10: The TELRAD system. The switch is marked.

The TELRAD is a small black box, mounted on the side of the finderscope, that projects a crosshair onto the sky. Turn on the TELRAD by rotating the switch shown in Figure 3.10. It's essentially a dimmer switch – after the initial "click", the more you rotate it, the brighter the image. Turning the switch until it clicks and stops shuts it off. Most novice users find that they can only use the TELRAD at full power, but you should practice working with the brightness as low as possible.

To use the TELRAD, sight along it as shown in Figure 3.11. You should see a bull's eye projected onto the plastic panel. If you don't, move your head until it appears. You'll find that there's a very small "sweet spot" in which your eye needs to be for the TELRAD to work.

Once you see the bull's eye, using the TELRAD is simple – just move the telescope until your target is inside the innermost circle. Lock the telescope, then look through the finderscope – you should be able to see your target, although it probably won't be centered. **Don't expect to see it in the main scope** – the field of view is so narrow that no unmagnified pointing aid will help you.

Don't forget to turn off the TELRAD when you're done with it. There's no point in draining the batteries.

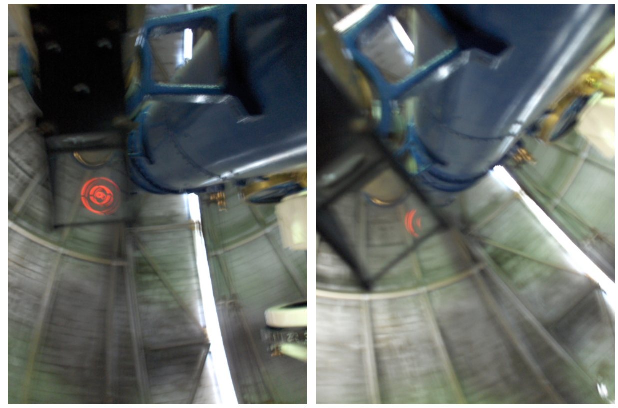

Figure 3.11: a) The TELRAD system as it should appear. b) If your head isn't completely aligned, you may not see the bull's eye, or see it only at the edge of the panel.

Finderscope

The finderscope is the only observing aid precise enough to get an image in the main telescope. Once you can see your target in the finderscope, you should move the telescope until the target is centered in the field (on all but the darkest nights, you can see black crosshairs marking the center). Be careful, because a slight motion will have a much bigger effect on the magnified finderscope view than it did through the TELRAD. You may want to only unlock one telescope axis at a time so that if you overshoot it's easy to go back.

When you're done, **lock the telescope** and check your work in the main telescope.

Main Scope

When you're first pointing the telescope, you probably want to have it at low power so you have a large field of view. Often low power is also what you will show to visitors or use for your own observing; if so, the most you need to do is adjust the image so it's better centered. Unless you have years of experience with this telescope you will want to only unlock one telescope axis while making these adjustments – if you slip with two unlocked axes and the target goes out of sight, you will probably need to start over.

If you want to observe at a higher magnification, the procedure is analogous to what you did with the finderscope – center as best you can at low power, then switch to higher magnification. Repeat as necessary.

3.2.2 Flipping the Telescope

Our telescope is supported by a German equatorial mount, a design that places the counterweight on a long boom on the opposite side of the mount from the telescope. The telescope should never be moved so that the counterweight is higher than the telescope tube; otherwise the mount may get damaged by the stress. Since the tube and counterweight are level when the telescope is pointed due south (or north), this presents a problem whenever you want to **switch between the eastern and western halves of the sky**.

We get around this problem with a procedure called flipping.

1. Begin by moving the telescope so it points due south, as shown in Figure 3.12 (this figure is for an east-to-west flip, but the reverse procedure is just the mirror image). You may want to use the "ship's wheel" in conjunction with the right ascension dial to get the pointing right.

2. Keep the telescope locked in right ascension, and move it until the tube is aligned with the polar axis of the mount (see Figure 3.13). Alternately, raise the end of the tube as high on the south side of the dome as you can while still being able to properly lock it.

3. Once the telescope is locked in a polar-aligned position, use the "ship's wheel" to rotate the telescope 180 degrees in right ascension. Make sure that the telescope tube stays above the counterweight the entire time. In other words, if you're turning the wheel in the right direction the counterweight should pass over your head.

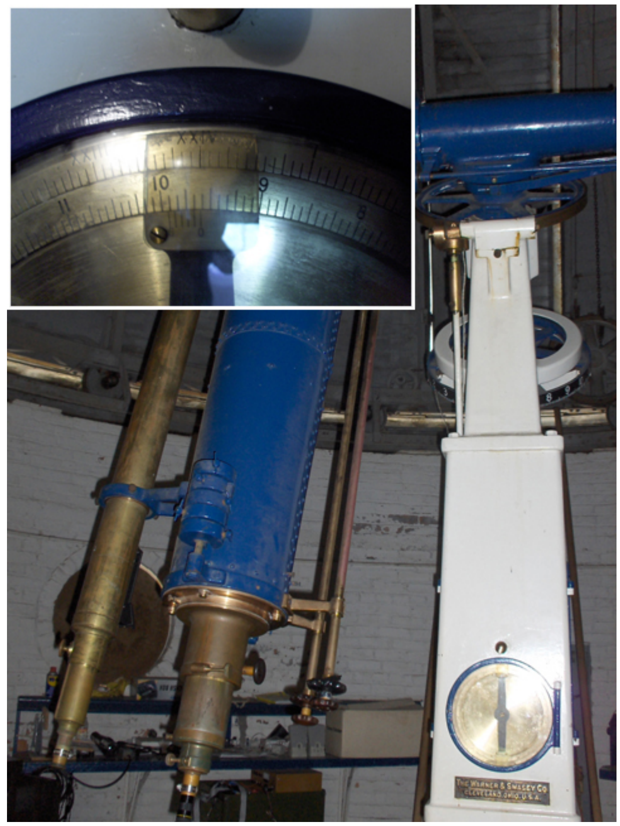

Figure 3.12: Start a flip by moving the telescope until it points south. The right ascension dial (shown in the inset) should point to XXIV.

4. Unlock the telescope and move it to a more convenient position.

The telescope has now been flipped. If you want to return to the other half of the sky, just repeat this procedure to flip it back. You'll find that some parts, like which direction to turn the wheel, will be mirror images of the original flip.

3.2.3 Focusing the Telescope

Sometimes when you change eyepieces or use other equipment, the focus will change. You can refocus by turning either of the two knobs on the side of the telescope barrel (marked in Figure 3.9). Be careful

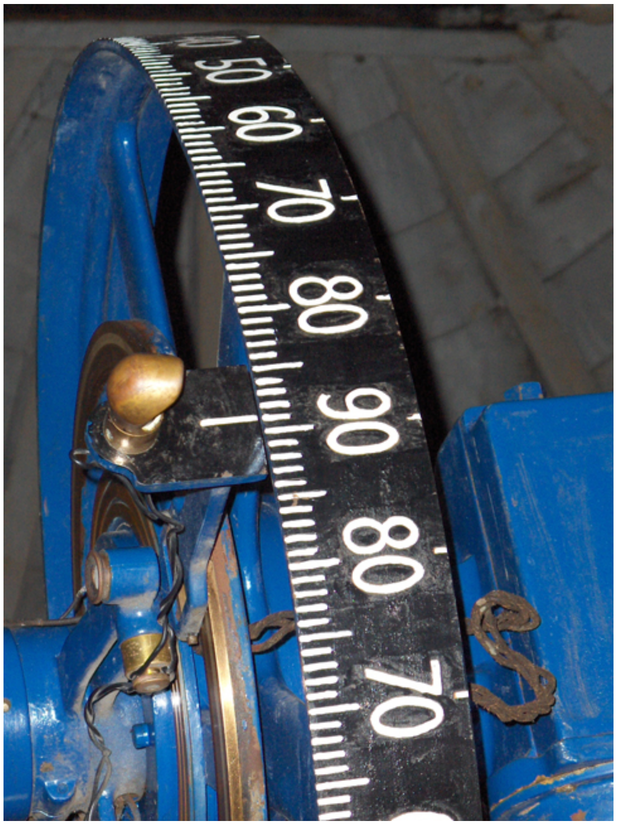

Figure 3.13: When the tube is aligned with the polar axis, the declination setting circle should read somewhere close to 90.

– although the telescope has a very large range of focus, the distance in which the focus will appear to change is very narrow and easy to overshoot. Also, on nights of rapidly changing seeing the image will shift in and out of focus; simply try to find a level that works "on average".

3.2.4 The Clock Drive

Despite its age, our clock drive is an extremely precise tracker (provided we oil it every year or two). Our telescope can stay pointed at the same field of view for over an hour with no detectable drift even at high power. Running the clock drive is fairly easy, but tiring – its ultimate energy source is humans!

Starting and Stopping the Clock Drive

To start the clock drive, open the window in the telescope mount (on the side facing away from the deck entrance). There should be a small lever at the top, as shown in Figure 3.14. Pushing the lever all the way to the left will start the clock drive. To stop the clock drive, push the same lever to the right and hold it to apply braking pressure.

Figure 3.14: Start the clock drive by pushing the lever to the leftmost position. It will take the drive about a minute to get up to full speed.

Winding the Clock Drive

The clock drive is powered by falling weights, which can be seen by opening the door in the lower part of the telescope mount. The position of the weights tells you the state of the drive, as in Figure 3.15. Try not to keep the door open for too long – there's a very smelly tub of oil stored inside.

To wind the clock drive, open the window in the telescope mount (the one facing away from the deck door). Somewhere in the right side of the compartment will be a crank. Take the crank and place it in the square hole on the lower left side of the compartment. Turn the crank counterclockwise until you fill a sharp resistance. The clock drive can be wound while running; the quality of the tracking will not be

Figure 3.15: a) The position of the weights as they have been fully wound. b) If the weights are in this position you still have about an hour of observing. c) If the weights get this low you should probably wind the drive. d) If the weights are this low the drive may be slowing down. Wind the weights immediately and check if you need to recalibrate right ascension (as in Section 3.2.6).

affected.

3.2.5 Observatory Clock

One of our most-asked about gadgets (after the clock drive) is our dual observatory clock. "Why is one time wrong?" visitors always ask. It's not wrong, it's siderial[4]!

Normally there's nothing to do with the clock other than read it. When we come into and out of daylight savings time, or when there's a power outage, we need to reset the clock. To reset either clock, push either "time set" button to cycle forward in time. To get the setting more precise than a minute, use the "display seconds" switch. The "on hold" switch, as you may guess, freezes the clock so that you can wait for a particular second.

[4]Siderial time is a measure of which stars are in the sky at any given time. For a more detailed explanation, see Section 1.1.3.

Figure 3.16: a) The crank may be on the compartment floor, as shown, or standing against the wall. b) Place the crank into the hole to wind the drive.

Figure 3.17: Our clock shows both standard and local siderial time. However, it's not designed to be readable when illuminated by a camera flash.

If you're wondering where to get the siderial time from, most astronomy programs (including some on the dome computer) calculate it. Alternately, you could calibrate the right ascension using a reference star (see Section 3.2.6) and then read the siderial time off the dial[5], but this is a less precise approach.

[5]The siderial time is the right ascension of due south, so read the dial at the XXIV mark.

3.2.6 Coordinates

Setting Circles

Both axes of the telescope have large setting circles mounted on them. The right ascension circle cannot be calibrated, so it is fairly useless; we instead use the right ascension dial built into the pier. The declination circle, however, is quite accurate, and can be used to **measure the telescope's declination to about a quarter of a degree**. In fact, a good way to quickly check whether you're centering on the right star is to compare the declination of the star to the declination of the telescope.

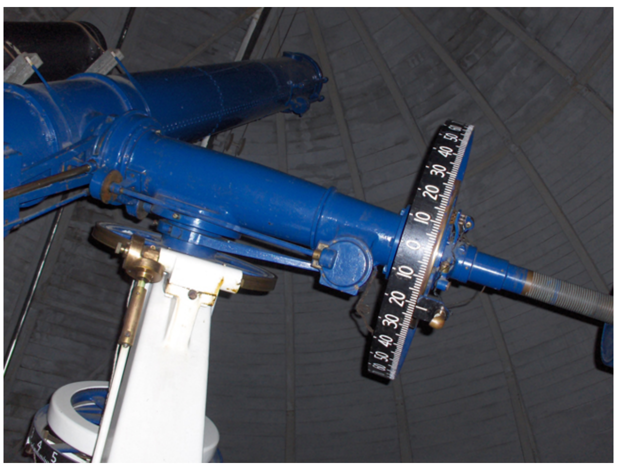

Figure 3.18: The declination setting circle is a valuable navigational aid, in part because it never needs to be recalibrated.

The Right Ascension Dial

We measure the telescope's right ascension using the brass dial mounted on the side of the telescope mount. Because the relationship between a telescope's position and its right ascension changes as the Earth rotates[6], the dial is connected to the clock drive. If the clock drive is not running, the dial will be wrong.

[6]see Section 1.1.3 for an overview of how right ascension behaves with time

Therefore, anyone who wants to use the right ascension dial will **need to calibrate it every time he or she opens the observatory** (as well as any time the clock drive runs out). The first step is to find the right ascension at which the telescope is pointed. One way to do this is to center the telescope on a bright star, then look up the star's coordinates in the star atlas. The other way is to point the telescope due south and read the time off our siderial clock. If the clock is properly set, the siderial time will be the right ascension the telescope sees.

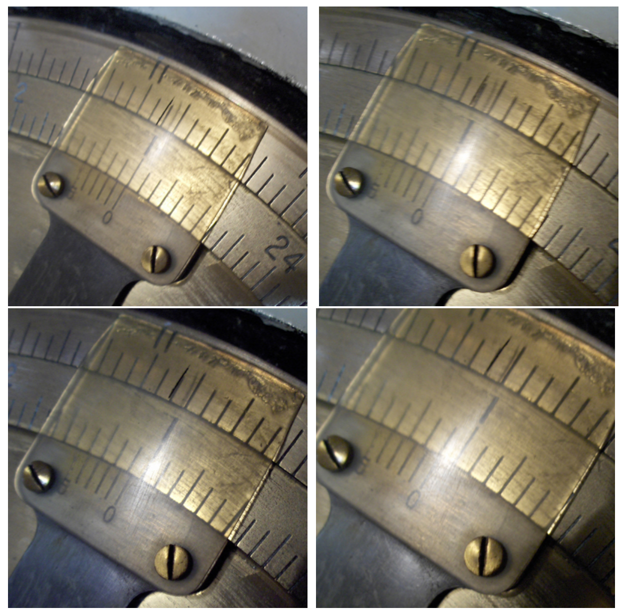

Figure 3.19: a) If the zero mark falls on a tick mark on the outer ring, the right ascension is obvious. In this example, it's exactly one hour. b) Now the telescope is at 1h1m. c) 1h3m. Can you see why it's not 1h18m? d) There's two ways to look at this one. See if you can follow both.

Once you know the telescope's right ascension, turn the inner ring on the dial until it displays the correct value. How do you know what value is diaplayed? The tick marks on the inner ring are spaced 5 minutes apart and labeled every hour. The mark labeled "0" on the plastic overlay represents the position of the telescope. So, by looking at where the "0" mark falls compared to the marks on the inner ring, you can get the right ascension to 2-3 minutes.

But you can do better! The plastic has some more tick marks, 1-5. You will notice that these are *not* spaced 1 minute apart – they're actually 4 minutes apart. You can still use them to measure the right ascension. Suppose, for example, that the telescope is set to a right ascension of 1h1m. You know from the preceding paragraph that the "0" mark will be between the 1-hour mark on the dial and the next tick mark over, which would correspond to 1h5m. However, as shown in Figure 3.19b, the "1" mark will line up *with the next line over.*

Let me emphasize this again: ***which*** **marks on the dial line up with one of the 1-5 marks is not important. Where the "0" mark is, and which of the 1-5 marks lines up with *anything*, is important.** Figure 3.19 gives two more examples. This system may look a little confusing, but once you get the hang of it you will be able to set the right ascension, and read it, to a precision of half a minute. That's seven arcminutes, or an eighth of a degree!

3.3 Star-Hopping

The pointing procedure described in Section 3.2.1 only works for objects you can see with the naked eye; for most of our targets we need to try something else. While sometimes we can get to a location using the coordinates (we call it "dialing in"), this tends not to work unless the target is bright enough to be seen in the finderscope or the observer is *very* familiar with that part of the sky.

Instead, we generally use something called *star-hopping*. Star-hopping can be fun (the other reason we rely on it so much), but it requires a bit of planning. Start by taking our *Uranometria 2000.0* atlas[7], which is stored on the table in the southwest corner of the dome. On the back two pages is a chart of the entire northern sky; use it to find the page containing your object.

You can easily point the telescope at any star brighter than about 4th (or, on a dark night, 5th) magnitude. However, there's only a few such stars in the sky and most deep-sky objects aren't next to them. Using the atlas, you need to find a way to get from your reference star to a nearby star, then from that star to another nearby star, and so on until you get to your target. Use the finderscope to move between these landmarks (skymarks? starmarks?) – the main telescope has too narrow a field of view.

[7]For all but the most southerly targets, you will want Volume 1.

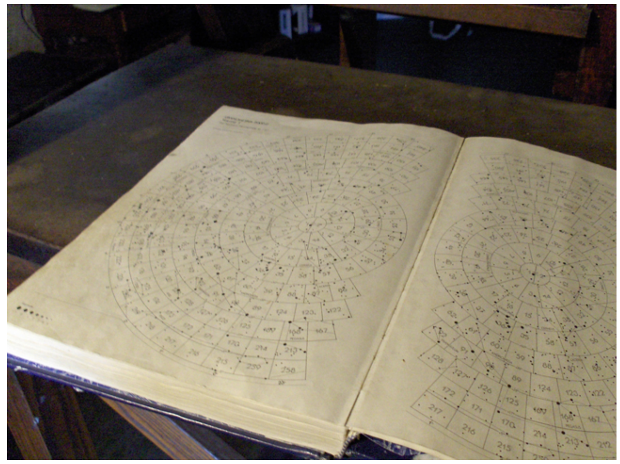

Figure 3.20: Our atlas has a nice all-sky map for an index.

Sounds simple, right? It isn't, and you will find that most of your training time is spent practicing star-hopping. The most common pitfalls include:

Using landmarks that are too faint. On a dark night even the finderscope can see stars fainter than the chart's 10th magnitude limit, so you will be trying to pick out a marginally brighter star from a field of completely unmarked stars. On a bright night you may not see the star at all!

Performing steps that are bigger than a degree. When you move more than about one and a half times the width of your finderscope's field of view, you will probably lose track of distance. This will make it hard to recognize your destination star unless it's quite bright.

Going the wrong way. The equatorial coordinate system, while indispensible for star charts, is

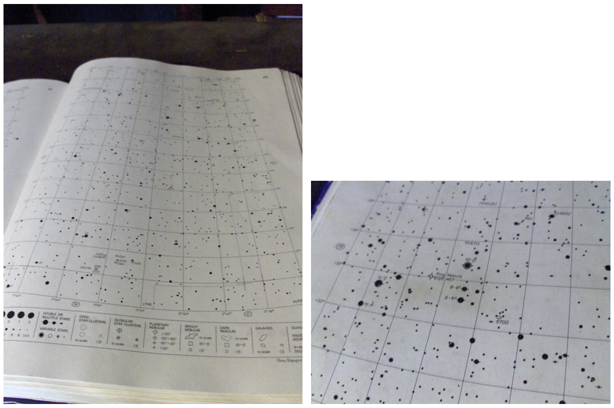

Figure 3.21: a) The main pages of the atlas list stars down to 10th magnitude. For the larger nebulae they also give outlines. b) A close-up of page 117. Our finderscope's field of view is a bit larger than the square of stars labeled $8 - \nu^1$ and $9 - \nu^2$.

very confusing in the real world (more details in Section 1.1.3). Likewise, some users forget that our telescope pivots – move the eyepiece left, and the telescope will look right. While you can think through the directions, the best way around this problem is to find a distinct (and non-symmetric!) star pattern, and use it as a compass while you practice moving the telescope.

Moving diagonally. If you're a novice user, stick to moving straight north/south or straight east/west. Being able to move in both directions at once gives you much more room for irreversible mistakes, and requires you to be absolutely sure as to which direction is which.

Assuming the target will be visible. Our finderscope has a very small aperture, and it won't pick up many faint nebulae and galaxies. Learn to recognize the stars around your target and use them to center the finderscope where the galaxy "ought to be".

Brightness differences on the chart are smaller than they appear.

Distances on the chart are larger than they appear.

The bottom line is to practice, practice, practice! Find out which objects are easier and which are challenging, and try those appropriate to your experience level. Try new objects to make sure you aren't just memorizing a few paths. Star hopping is the essence of Fuertes observing... and you *will* be tested on it.

3.4 Telescope Maintenance

3.4.1 Aligning the Telrad

There are three screws in the back of the TELRAD system. If you believe the TELRAD is not properly aligned, you can use these screws to realign it. First, center a bright star in the finderscope as precisely as you can (and make sure the clock drive is running!). You will probably need to sight along the tube to do this. Then, turn on the TELRAD and look through it so that you can see the bull's eye. Adjust the screws until the bull's eye is centered on the star. Check the finderscope again to make sure it is still centered.

3.4.2 Aligning the Finderscope

The finderscope is attached to the telescope via six screws along its length. If the finderscope needs to be realigned, center a bright star in the main telescope as precisely as you can (and make sure the clock drive is running!). Then, adjust the sets of screws to change the angle at which the finderscope is pointed, looking through to check if you're improving the alignment. Be careful that you don't loosen the finderscope!

Because of the risks, I recommend that you don't realign the finderscope unless it's absolutely necessary.

3.4.3 Other Tasks

In general, the best thing to do when maintenance comes up is to contact the Astronomy Department. Some of the Department staff know Fuertes inside and out, and they are more qualified to fix things than the average CAS member.

Chapter 4

Back-End Equipment For the 12-Inch Refractor

4.1 Eyepieces

Eyepieces are the most crucial equipment we have at Fuertes – without them, the telescope would be useless. CAS has countless eyepieces (see Appendix B for a complete listing), and it's important to know which is best for what. Since a lot depends on the conditions on any given night, you will need to experiment, but there are some general guidelines you should know.

Figure 4.1: Some common eyepieces.

4.1.1 Eyepiece Effects

Magnification

The magnification of any eyepiece is the focal length of the telescope (4572 mm for the main refractor at Fuertes) divided by the focal length of the eyepiece. A 40 mm eyepiece therefore has a magnification of 4572/40 =114x, while a 25 mm eyepiece has a magnification of 4572/25 =183x. For galaxies and nebulae a magnification of about 100x is usually good, while for planets you want a magnification of 200x or more if seeing allows it (seeing is described in Section 1.4.2).

When you increase the magnification by, say, two, you spread the light you see over a four times larger area of your eye. So you would expect that objects would appear much fainter and less distinct at higher magnification, and in many cases this is exactly what happens. This is a big reason why we tend to avoid high magnifications.[1]

However, there's more to eyepiece observing than basic physics. The mind's perception of brightness depends in a complicated way on many factors other than the amount of light entering your eye, such as the contrast of the image, the shape of the image, the fraction of your eye's field of view occupied by the image, and the amount of background light. Some

[1] The other is that eyepieces magnify distortions from seeing, and obvious distortions reduce the subjective image quality.

objects will actually appear more distinct when some people increase the magnification (for example, the Orion Nebula is easiest for *me* to see at a power of 200-250x).

Again, experiment with different eyepieces for different objects under different conditions. When in doubt, however, **"higher power is fainter" is a very reliable rule of thumb**. We've gotten excellent results with galaxies by lowering the magnification as much as we could.

Field of View

The *apparent field* of an eyepiece describes how big the image looks. Typical values are 45-50 degrees, although we have one "super wide-field" eyepiece that offers 68 degrees. If divided by the magnification, the apparent field gives you the true field of view. Our 40mm wide-field eyepiece, for example, has a true field of $68/114 = 0.6$ degrees, or 36 arcminutes (one arcminute $= 1/60$ degrees. The Moon is 29-33 arcminutes across).

Sometimes the true field is limited by the *field stop*, which you can think of as the size of the entrance to the eyepiece. The field stop prevents the true field from becoming larger than the field stop diameter divided by the telescope focal length. As the field stop can never exceed the barrel size, a 2-inch eyepiece has a **maximum possible field** of 50.8 mm/4572 mm = 1/90 radians = 38.2 arcminutes. For a 1.25-inch eyepiece the same calculation gives 23.9 arcminutes.

The Eyepiece-Eyeball Interface

Your eyepiece's apparent field, no matter how large, is useless if your eye can't catch all the light. The *eye relief* of an eyepiece is how close you need to place your eye to the eyepiece; holding it farther away results in annoying "tunnel vision". Short eyepieces tend to have low eye relief. Wearers of eyeglasses should **beware eyepieces with eye relief lower than about 10 mm**.

The *exit pupil* of an eyepiece is the size of the light beam when it comes into focus. This is the telescope aperture divided by the magnification; for example, a 200x eyepiece on our 12-inch telescope would have an exit pupil of 1.5 mm. If the exit pupil is similar to or larger than your eye's pupil, some light will "spill off" and be lost.[2] If the exit pupil is smaller than about 0.5 mm, the narrow beam will begin to highlight aberrations in your eyeball, creating distracting over-images.

Some amateur astronomy guides assign telescopes a "minimum magnification" at which the exit pupil exceeds a nominal 7 mm dark-adapted eye pupil. Like the surface brightness argument covered under "Magnification", this reasoning has flawless physics but shabby biology.

First, the average 7 mm pupil is just that – an average. The pupil gets smaller with age (as many of the aforementioned guides point out), but it also varies from individual to individual depending on conditioning and, for all we know, genetics. There are people whose pupils can grow to 9 mm, and some who can't get past 3 mm even in youth.

The minimum magnification calculation also assumes that the eye is perfectly aligned with the eyepiece, which of course is never the case. In fact, one of the advantages of an oversized pupil is that it is easier to find. There are other complications that make exit pupils a tricky statistic to work with; Sky and Telescope has a good article at http://skytonight.com/howto/basics/3304201.html that goes into more detail than I've quoted here.

In our case, all these arguments are moot. The selection of eyepieces we have at Fuertes, ranging from 55 mm to 8.4 mm, gives us exit pupils of 3.7 mm to 0.6 mm, respectively. We therefore don't cross either the high or the low limit, and we probably never will. Unless, that is, we acquire a short focal length telescope for observing trips.

4.1.2 Changing Eyepieces

Changing eyepieces is extremely simple. Remove the old eyepiece by pulling it straight out of the telescope – don't twist it or you may unscrew the eyepiece barrel from the rest of the eyepiece. Push the new eyepiece straight into the telescope. **Be sure to put**

[2] Past this threshhold surface brightnesses remain roughly the same, so the loss is not as bad as it sounds.

the previous eyepiece in a suitable container so it doesn't get lost or dirty.

Two-Inch Eyepieces

Our telescope is normally used with 1.25-inch eyepieces. To use our larger eyepieces, you will need to unscrew the holder for the smaller eyepieces as shown in Figure 4.2a. Be careful that you don't try to remove the wrong part of the telescope.

Figure 4.2: To use two-inch eyepieces, remove the 1.25-inch section (left) and replace it with the two-inch adapter (right).

Stored among the eyepieces is an adapter ring, shown in Figure 4.2b. Screw this adapter in where you removed the 1.25-inch adapter and you should be ready to insert eyepieces. The only difference is that you need to tighten the screws on the side of the adapter to make the eyepiece stay in place.

4.1.3 Eyepiece Maintenance

4.1.4 Eyepiece Types

Eyepieces come in a wide variety of optical configurations, and knowing which type is which can help narrow down which of our two dozen eyepieces is best for the job. Read this section with a grain of salt – there is quite a bit of variety within each eyepiece category, enough that an eyepiece's classification can become pretty arbitrary.

4.1.5 Plössl

The most popular general-purpose eyepiece, the Plössl features fairly good eye relief, a reasonable field of view, and sharp images. The image quality and long eye relief make these good eyepieces for public viewing sessions.

4.1.6 Orthoscopic

This aging design used to fill the same general-purpose niche as the Plössl. Orthoscopics have narrow fields of view and (slightly) less eye relief than Plössls, but they produce very sharp images and preserve colors well. They are often used for planets and double stars, where image quality matters and field of view is irrelevant.

4.1.7 Kellner

Kellners have decent eye relief, but fall short of orthoscopics. They perform fairly well at low and medium powers, producing a sharp image, but their main advantage is low cost.

4.1.8 Erfle

Erfle eyepieces deliver wide fields of thew at the cost of optical quality. At high powers Erfles may produce "ghost" images.

4.1.9 König

König eyepieces are a proprietary configuration of University Optics that performs well on long focal length telescopes (like ours). They feature a wide field of view and contrast levels rivaling those of orthoscopics.

Zoom

Zoom eyepieces, as the name suggests, have an adjustable focal length. What they gain in the convenience of not having to switch eyepieces, they lose in almost all indicators of optical quality. We have a zoom eyepiece, but we use it mainly as a paperweight.

Figure 4.3: Our zoom eyepiece.

4.2 Filters

Filters are a very useful, if often overlooked, tool. Placed somewhere in the telescope's optical path (usually at the end of the eyepiece), they reduce or otherwise alter the light coming through. Filters are normally used to enhance contrast, either between different features or between an object and the sky. Filters can never make the target brighter, but they can make distractions fainter.

Figure 4.4: Fuertes has at its disposal a wide variety of filters.

The biggest problem with filters is that they can become too good at what they do. Because filters are placed outside the telescope's focus, specks of dirt on the filter will not appear in the image. However, they do block some of the light and therefore reduce the overall transparancy of the filter. You should occasionally clean filters as described in Section 4.2.2 to make sure the filter only filters out what you don't want to see.

4.2.1 Using Filters

Directly in the Eyepiece

The most common way to use a filter is to simply attach it to the eyepiece in use. All filters have a thread on one end, and it's become standard in the industry to give eyepiece barrels a matching thread. Simply place the filter on the end of the eyepiece (the end *without* the lens, mind you) and screw it in all the way. The filter should not affect the eyepiece focus in any way. Naturally, this system requires that the filter and eyepiece have the same size (either 1.25 inches or 2 inches).

You might notice that the other end of a filter is also threaded. This makes it possible to thread filters onto a filter-and-barrel combination, creating stacks of filters. While such filter stacks are sometimes very useful, they also tend to block enormous amounts of light.

Filter Wheel

Some astronomers use filter wheels to cycle through a set of commonly used filters. So do we... except our "wheel" is not very circular (see Figure 4.6). Use of our five-slot filter slider is not very different from normal eyepiece use – screw the filter into one of the slots. The main thing to watch out for is that the hole in the filter slider's tube will only accomodate filters on one side of the bar. Once you have the filters set up, simply place the eyepiece in one end of the tube, tighten the screw, and place the other end inside the telescope (this is the same arrangement used for diagonals and Barlow lenses – see Figure 4.10 for some pictures).

Figure 4.5: a) Most eyepieces have threaded barrels. b) All filters have matching threads. c) Just screw in the filter, and you're ready to go. Note that the far end of the filter has threads, allowing for more filters to be attached.

The filter wheel only supports 1.25-inch filters and eyepieces, and there's not enough room to stack filters. Also, it's usually a good idea to leave one slot empty so you can switch to an unfiltered view.

4.2.2 Filter Maintenance

4.2.3 Types of Filters

Grey and Polarizing Filters

Grey filters (sometimes called "Moon filters" after most common target) reduce the amount of light passing through them without otherwise distorting the image. They are good for any bright object except for the Sun. **Use of a gray filter for the Sun will not reduce the dangers of solar observing and may damage both filter and eyepiece in**

Figure 4.6: Our filter slider, without filters. Notice that the hole for the bar is larger on the side facing away from the camera. Make sure you put the filters on that side.

addition to your eye. We have a single grey filter, suitable for a 1.25-inch eyepiece.

Figure 4.7: A common and a not-so-common polarizing filter design. In both cases, you change the angle between the two polarizers (and therefore the darkness of the filter) by twisting the two ends.

Polarizing filters are essentially adjustable grey filters; you can set the transparency of the filter simply by twisting the two ends[3]. Unfortunately the filter is normally buried inside the telescope, so you have to remove the eyepiece in order to adjust the brightness. I've found that holding the eyepiece just behind

[3] Be careful not to twist too far, or the sections will either lock together or fall apart. A quarter-turn should take you through the full range of brightness.

the telescope and looking through at the (admittedly very out-of-focus) image is a good way to get the filter set right the first time.

Color Filters

Figure 4.8: A selection of color filters.

Color filters are the most useful (and most confusing) aspect of filter use. They block light of particular colors, increasing contrast between features that have the blocked color and features that don't. **Color filters are normally used for planetary targets,** although there are some scattered reports of them being useful for the Moon, comets, or close double stars. Unfortunately most color filters absorb two-thirds of the light that passes through them, making them useless for nebulae and other faint objects.

At Fuertes we have eight color filters bought from Orion Telescopes and Binoculars. All the filters must be used with 1.25-inch eyepieces. The colors of these filters are described by "Wratten numbers" developed by Kodak a century ago. Information about which filter colors are good for what can be found in Appendix D, although the reader will quickly realize that different observers get different results. A good rule of thumb, though, is to **choose a complementary color to that of the feature you want to see**.

Light Pollution Filters

Light pollution is a increasingly common feature of modern life. The *World Atlas of Artificial Sky Brightness* estimates that the Cornell campus has a sky 4-10 times brighter than it would naturally be. While light pollution has no effect on bright objects like planets, star clusters, and some of the brighter nebulae, the increased sky background makes it more difficult to discern faint nebulae and galaxies.

There's not much that we can do about galaxies, but emission nebulae tend to produce light at only a very narrow set of wavelengths (the so-called *emission lines*, explained in Section 2.9.1). Light pollution filters take advantage of this fact by only letting through the most common nebula emission lines and rejecting other light. The result is that the brightness of the nebula gets cut back only a few percent, while the brightness of the sky can be slashed by a factor of two or more.

Broadband filters are relatively cheap light pollution filters that allow a relatively wide range of wavelengths to go through. They have very little effect on nebulae, but unfortunately they let about a third to a half of the light pollution through as well.

The more aggressive *narrowband filters* only let through wavelengths close to those of the target lines. They cut back greatly on light pollution, but they also tend to leave out some nebula emission. In particular, the narrowband filter we have leaves out the Hydrogen-α line that dominates star-forming nebulae. Choose your filter with care.

Line Filters

Line filters can be thought of as very extreme narrowband filters – rather than letting through a mix of common nebula lines, they focus on one. Naturally, they almost completely block light pollution. Just as naturally, they're only effective with nebulae that emit primarily in the line in question.

Our [OIII] filter picks out green light coming from O^{2+} ions. This is a well-known line in planetary nebulae and supernova remmnants, but some star-forming regions have it as well.

Our H-β filter picks out blue light coming from hydrogen atoms. This line doesn't usually dominate, and it is sometimes said that this filter is good for only two targets: the Horsehead Nebula and the California Nebula.

Our H-α filter picks out red light coming from hydrogen atoms. This line dominates most star-forming regions. This filter is also great to use on the Sun **in combination with a solar filter** ; much of the Sun's lower atmosphere emits at this wavelength.

4.3 Extra Optics

There's more to visual observing than different choices of eyepieces. At Fuertes we have several pieces of equipment that alter the behavior of the telescope optics.

4.3.1 Diagonal

The most common of these tools is the diagonal (sometimes called the "star diagonal"). The diagonal is essentially just a flat mirror that deflects the telescope's light beam by 90 degrees. This allows observers to look in the eyepiece without having to look along the telescope tube, a very useful thing when the telescope is pointed straight up.

Figure 4.9: Our trusty diagonal, a great way of doing zenith observing without doing the limbo.

Figure 4.10: a) Eyepiece in the telescope. b) Empty diagonal in the telescope. c) Diagonal with eyepiece in the telescope.

Use of the diagonal is simple. Normally you simply insert an eyepiece directly in the telescope, as shown in Figure 4.10a. Instead, place the diagonal where the eyepiece normally goes (Figure 4.10b). The eyepiece then goes into the other end of the diagonal, where you tighten the side screw to get a snug fit. Some observers like to first put the eyepiece and diagonal together, then place the entire assembly in the telescope. Either way, the final setup should look something like Figure 4.10c.

A nice thing about diagonals is that they don't interfere much with other accessories. For example, you can still attach filters to the eyepiece before placing the eyepiece-filter combination in the diagonal. The one problem, however, is focus.

If you follow the procedure shown in Figure 4.10 exactly, then you've increased the distance between the eyepiece and the telescope optics by the length of the diagonal. The solution, as shown in Figure 4.11, is simple: use the focus knob to move the back end of the telescope toward the front end, cancelling the effects of giving the light more equipment to shine through.

4.3.2 Barlow Lens

The Barlow lens is often called a vital telescope accessory. It increases the effective focal length of a telescope by a factor of roughly[4] two or three, depending on the model. This essentially increases the magnification, allowing a single eyepiece to serve multiple

[4]The exact factor depends on the distance between the lens and the telescope's focal plane, which varies from telescope to telescope.

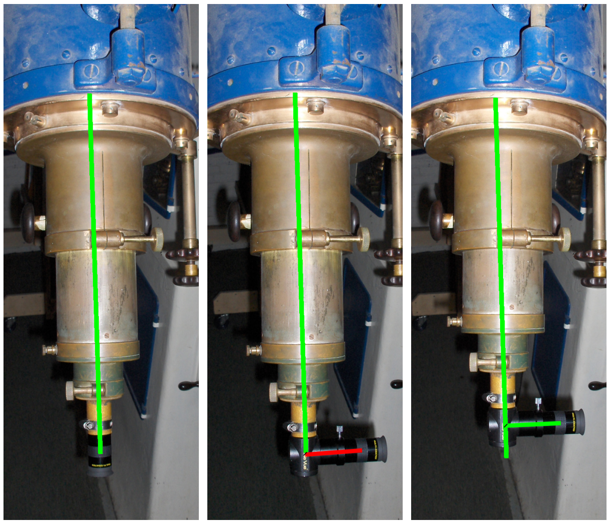

Figure 4.11: a) A given eyepiece will be in focus when it's a certain distance away from the front lens. b) Inserting a diagonal, however, moves the eyepiece farther away – it's no longer in focus. c) To restore the focus, move the eyepiece inward.

roles. However, our telescope has a problem with magnifying too much (Section 1.3.2), so for most of our applications a Barlow lens is worse than useless.

With the recent surge in Fuertes astrophotography we have begun using the Barlow lens more because it allows us to change the plate scale of the telescope (see Section 1.6.1 for more on plate scales). This gives us more control over how much sky falls onto a single pixel or grain.

Use a Barlow lens in much the same way as a diagonal – put the eyepiece in one end, tighten the screw, and place the other in the telescope. As with the diagonal, you will need to refocus, although because the lens changes the effective focal length it is a bit harder to work out where the new focus is located.

4.3.3 Binoviewer

Our catchiest accessory is the binoviewer, which allows visitors to use both eyes to look at the sky. Unfortunately the binoviewer requires two matching 1.25-inch eyepieces, which has restricted its use to a

Figure 4.12: Our 2x Barlow lens.

single focal length so far. The binoviewer is also more fragile than our other equipment – there have been several incidents in which visitors, pulling or hanging on the telescope, have dislocated the viewer. If you want to use this gadget on a public night, keep an eye on it.

To use the binoviewer, ...

4.4 Imagers

4.4.1 Observation Planning

4.4.2 Film Imagers

General Procedures

4.4.3 Digital Imagers

General Procedures

Cookbook Camera

Solar System Imager

Figure 4.13: Our binoviewer in its case.

Chapter 5

Observing Without the Refractor

5.1 Stargazing

5.2 Laser Pointer

5.3 Binoculars

5.4 The C14

5.5 Downstairs Meades

Chapter 6

Solar Equipment and Procedures

6.1 Safety First

6.2 Pointing the Telescope

6.3 Different Filters

Appendix A

Telescope Characteristics

William Porter Church Telescope

Manufactured:	Warner & Swasey	1923
Optical Configuration:	Refractor	
Mount:	German Equatorial	Anchored
Drive:	Single-axis	Weight-driven
Aperture:	304.8 mm	(12 inches)
Focal Length:	4572 mm	(15 feet)
Focal Ratio:	15	
Accessories:	1.25”	2”
Maximum Field:	23.9 arcmin	38.2 arcmin
Finderscope:	UNKNOWN	
Magnification:	114x	(40 mm eyepiece)
Magnification:	183x	(25 mm eyepiece)
Magnification:	254x	(18 mm eyepiece)
Magnification:	352x	(13 mm eyepiece)
Plate Scale:	45 arcsec per mm	
Field of View:	26 arcmin	(bare 35mm film)
Field of View:	6.4 arcmin	(Solar System Imager)
Field of View:	4.8x3.6 arcmin	(Cookbook Camera)
Diffraction Limit:	0.45 arcsec	
Good Atm. Seeing:	1.5 arcsec	
Average Atm. Seeing:	3 arcsec	
Poor Atm. Seeing:	4 arcsec	
Startup Dome Seeing:	UNKNOWN	
Typical Dome Seeing:	$\sim$ 5 arcsec	
Optimized Dome Seeing:	UNKNOWN	
Mount Vibrations:	None Detectable	

C14 XLT

Manufactured:	Celestron	UNKNOWN
Optical Configuration:	Schmidt-Cassegrain	
Mount:	UNKNOWN	Partly anchored
Drive:	UNKNOWN	
Weight:	45 lb	(20 kg)
Aperture:	355.6 mm	(14 inches)
Obstruction:	10%	
Focal Length:	3910 mm	(12.8 feet)
Focal Ratio:	11	
Accessories:	2" only	
Maximum Field:	44.7 arcmin	
Finderscope:	9x50	
Magnification:	98x	(40 mm eyepiece)
Magnification:	156x	(25 mm eyepiece)
Magnification:	217x	(18 mm eyepiece)
Magnification:	301x	(13 mm eyepiece)
Plate Scale:	53 arcsec per mm	
Field of View:	31 arcmin	(bare 35mm film)
Field of View:	7.5 arcmin	(Solar System Imager)
Field of View:	5.6x4.2 arcmin	(Cookbook Camera)
Diffaction Limit:	0.39 arcsec	
Good Atm. Seeing:	1.5 arcsec	
Average Atm. Seeing:	3 arcsec	
Poor Atm. Seeing:	4 arcsec	
Startup Deck Seeing:	N / A	
Typical Deck Seeing:	UNKNOWN	
Optimized Deck Seeing:	N / A	
Mount Vibrations:	UNKNOWN	

Appendix B

Eyepiece Characteristics

Eyepiece Name	Size	Type	Focal Length	Eye Relief	FOV	12” Magn.	12” FOV	Notes
University Plössl 55mm	2”	Plössl	55 mm	?	?	83x	?	Not on internet??
Meade Super Wide 40mm	2”	Custom	40 mm	31 mm	68°	114x	35.7′	
Meade Super Plössl 32mm	1.25”	Plössl	32 mm	13 mm	52°	143x	21.8′	Eyeguard
University König 32mm	2”	König	32 mm	?	60°	143x	25.2′	
Tele Vue 32mm Plössl	1.25”	Plössl	32 mm	22 mm	50°	143x	20.3′	27 mm field stop
Celestron Plössl 30mm	1.25”	Plössl	30 mm	?	?	152x	?	Another obscure model
Edmund Scientific RKE28mm	1.25”	Kellner	28 mm	24.5 mm	45°	163x	10.0′	13.3 mm field stop
Celestron 26mm Plössl	1.25”	Plössl	26 mm	22 mm	50°	176x	17.1′	
Meade Super Plössl 26mm	1.25”	Plössl	26 mm	10 mm	52°	176x	17.7′	Eyeguard. Three copies.
Orion Explorer II 25mm	1.25”	Custom?	25 mm	14 mm	50°	183x	16.4′	
Celestron 25mm Kellner	1.25”	Kellner	25 mm	?	40°?	183x	13.1′	
Zoom Eyepiece	1.25”	Custom	8.4-21 mm	?	?	544-218x	?	10-15 mm field stop?
Celestron 20mm Erfle	1.25”	Erfle	20 mm	?	58°	229x	15.2′	
University 20mm Wide View	2”	Plössl	20 mm	?	?	229x	?	
Meade OR18mm	1.25”	Ortho?	18 mm	?	?	254x	?	
Criterion A.R. 18mm	1.25”	?	18 mm	?	?	254x	?	At least 20 years old
Edmund Scientific RKE15mm	1.25”	Kellner	15 mm	13.4 mm	45°	305x	8.9′	11.9 mm field stop
Meade Super Wide 13.8mm	1.25”	Custom	13.8 mm	9 mm	67°	331x	12.1′	Eyeguard
Tele Vue 13mm	1.25”	Plössl?	13 mm	9 mm?	50°?	352x	8.5′?	Identification uncertain
1/2” FL	1.25”	?	12.7 mm	?	?	360x	?	
Edscorp Or 12.5mm	1.25”	Ortho	12.5 mm	?	?	366x	?	
Celestron 12mm Ortho	1.25”	Ortho	12 mm	?	?	381x	?	
Edmund Scientific RKE12mm	1.25”	Kellner	12 mm	10.7 mm	45°	381x	6.3′	9.7 mm field stop
Criterion A.R. 9mm	1.25”	?	9 mm	?	?	508x	?	At least 20 years old
Meade OR9mm	1.25”	Ortho?	9 mm	?	?	508x	?	

Table B.1: Table of all eyepieces at Fuertes at the time of writing. See Section 4.1 for an overview of eyepieces and their use. Fields of view marked like this are limited by an obstructed light path. For 2-inch eyepieces the limit is 38.2′unless a field stop is specified; for 1.25 it's 23.9′.

Appendix C

Imager Characteristics

Solar System Imager I

Manufactured:	Orion	UNKNOWN
Type:	CCD	
Mount:	1.25”	
Size:	8.47 mm	640x480 pixels
Weight:	UNKNOWN	
Shutter:	No	
Cooling System:	None	
Min. Exposure:	0.0001 s	
Max. Exposure:	0.5 s	
Pixel/Grain Size:	13x18 microns	
12” Pixel Scale:	0.60x0.79 arcsec	
12” FOV:	6.4 arcmin	
C14 Pixel Scale:	0.70x0.94 arcsec	
C14 FOV:	7.5 arcmin	
Sampler:	UNKNOWN	
Read Noise:	UNKNOWN	
Gain:	UNKNOWN	
Dark Current:	UNKNOWN	
Readout Time:	<33 ms	
Well Capacity:	UNKNOWN	
12” Saturation:	UNKNOWN	
C14 Saturation:	UNKNOWN	

Table C.1:

Cookbook Camera

Manufactured:	CAS	2002-2006
Type:	CCD	
Mount:	1.25”	
Size:	6.4x4.8 mm	378x242 pixels
Weight:	2 lb	(1 kg)
Shutter:	No	
Cooling System:	1-Stage Thermoelectric “Peltier”	
Coolant:	Water	[Closed Cycle]
Min. Exposure:	0.001 s	
Max. Exposure:	9999.9 s	(2.7 hours)
Pixel/Grain Size:	17x20 microns	
12” Pixel Scale:	0.77x0.90 arcsec	
12” FOV:	4.8x3.6 arcmin	
C14 Pixel Scale:	0.90x1.06 arcsec	
C14 FOV:	5.6x4.2 arcmin	
Sampler:	Correlated Double Sampling	
Read Noise:	$\sim$20 electrons	
Gain:	UNKNOWN	
Dark Current:	UNKNOWN	
Readout Time:	UNKNOWN	
Well Capacity:	$\sim$150000 electrons	
12” Saturation:	$\sim$0.19 Jy/arcsec^2 s	
C14 Saturation:	$\sim$0.10 Jy/arcsec^2 s	

Table C.2:

Target	Surface Brightness		Cookbook		SSI	
	Mags/arcsec^2	Jy/arcsec^2	Dome	C14	Dome	C14
Dark Sky:	22	5.8×10^{-6}	34000 s	17000 s		
Mt. Pleasant Sky:	21	1.2×10^{-5}	16000 s	8300 s		
Ithaca Sky:	20	3.5×10^{-5}	5600 s	2900 s		
0th Mag Star:	1.2	1200	1.6×10^{-4} s	8.8×10^{-5} s		
6th Mag Star:	7.2	4.7	0.042 s	0.022 s		
10th Mag Star:	11	0.12	1.6 s	0.88 s		
15th Mag Star:	16	0.0012	160 s	88 s		
20th Mag Star:	21	1.2×10^{-5}	16000 s	8800 s		
Sun:	-20	$[2.2\times10^6]$[a]	8.8×10^{-8} s	4.5×10^{-8} s		
Moon:	-5.5	570000	3.4×10^{-7} s	1.8×10^{-7} s		
Mars:	4.1	82	0.0024 s	0.0013 s		
Saturn:	6.3	11	0.018 s	0.0091 s		
Uranus:	8.4	1.6	0.12 s	0.064 s		
Orion Nebula:	13	0.023	8.5 s	4.5 s		
Ring Nebula:	17	3.8×10^{-4}	520 s	270 s		
Crab Nebula:	20	2.4×10^{-5}	8200 s	4400 s		
M 13:	21	1.6×10^{-5}	12000 s	6600 s		
M 81:	21	1.1×10^{-5}	18000 s	9600 s		
California Nebula:	24	1.4×10^{-6}	140000 s	73000 s		

Table C.3: Approximate saturation times for various camera/telescope combinations. Assumes zero dark current and perfect detective efficiency. For stars, $2''$seeing is assumed.

[a]This is *after* passage through a 0.001% solar filter!

Appendix D

Filter Characteristics

If you want a quick-look view of all filters or color filters, see Table D.1 or D.2, respectively.

Color Filter Descriptions

For the thoughts of an experienced observer on these filters, visit Susan Carroll's site at http://sciastro.net/portia/advice/filters.htm. I unfortunately cannot reproduce her remarks here.

Wratten#38A (Deep Blue)

The manufacturer writes,

> Slightly improves view of lunar surface. Improves views of the Great Red Spot on Jupiter. Intensifies subtle details in the cloud belts of Saturn. Brings out dust storms on the surface of Mars. Good for enhancing very bright objects.

Wratten#80A (Medium Blue)

The manufacturer writes,

> Primarily for studying structures of planetary features in upper atmospheres of Jupiter and Saturn. Very popular for Jupiter's Great Red Spot or the festoons in Jupiter's belts. Reduces red, green, and yellow wavelengths.

The website of the Antelope Valley Astronomy Club[1] (AVAC) adds,

> A Wratten #44A, 47B, or 80A is used to detect high altitude clouds on Mars, white ovals and spots in the belts of Jupiter, and the zones of the clouds of Saturn, and to reduce the glare of the bright Moon. The 80A is the filter to have if you only buy one filter.

[1]The club site is http://www.avastronomyclub.org/, but their filters page seems to be gone. However, a nearly identical page is at http://www.astro-tom.com/technical_data/filters.htm, listed as taken from an unknown source.

Wratten#58 (Green)

The manufacturer writes,

> Reduces red and blue wavelengths. Excellent for increasing contrast of Martian polar caps, low-flying martian clouds and yellowish Martian dust storms. Great for studies of low-contrast blue and red Jovian features and for Venus and the Moon. Reduces chromatic aberration inherent in some refractors.

The AVAC website adds,

> A Wratten #58 allows you to see more clearly the edges of the Martian polar caps and enhances the belts and the Great Red Spot in the clouds of Jupiter.

Wratten#56 (Light Green)

The manufacturer writes,

> Improves detail on lunar surface. Improves low-contrast details in the Jovian equatorial bands. Enhances cloud detail on Venus. Brings out contrast on the surface on Saturn. Greatly increases the contrast of the Martian polar ice caps.

Wratten#8 (Light Yellow)

The manufacturer writes,

> Enhances low-contrast detail on Venus. Enhances images of comet dust tails and heads. Enhances detail ofthe maria on Mars. Brings out orange and red features of Jupiter and Saturn. Brings out the surface detail on Uranus and Neptune in larger telescopes.

The AVAC website adds,

> A Wratten #8, 12, or 15 can improve the markings in the clouds of Venus and enhance dust storms on Mars.

Wratten#15 (Deep Yellow)

The manufacturer writes,

> Reduces blue wavelengths. Mainly for lunar viewing. Improves contrast and reduces irradiation between features of varying brightness. Also for penetrating the atmospheres of Mars, Jupiter, or Saturn.

[If anyone knows what “penetrating the atmosphere” means, please tell me.] The AVAC website adds,

> A Wratten #8, 12, or 15 can improve the markings in the clouds of Venus and enhance dust storms on Mars.

Wratten#23A (Light Red)

The manufacturer writes,

> Sharpens edges of yellow dust clouds on Mars. Improves detail on lunar surface. Highlights the polar areas and blue clouds of Saturn and Jupiter. Corrects the blue coloration of Mylar solar filters, for a more natural appearance. Ideal for observing Mercury and Venus through evening skyglow. Enhances contrast on Mercury and Venus during daylight hours.

The AVAC website adds,

> A Wratten #23A, 25, or 25A are used to enhance contrast on Mars, Jupiter, and Saturn. A red filter, however, is fairly dark, so it works best on larger aperture telescopes that give brighter images. Switching between red and blue filters can sometimes bring out subtle coloration on the surface of the Moon.

Wratten#25 (Red)

The manufacturer writes,

> Ideal for observation of the polar ice caps of Mars and features on the Martian surface. Also for the bluer clouds of Jupiter and SAturn. Darkens blue wavelengths.

The AVAC website adds,

> A Wratten #23A, 25, or 25A are used to enhance contrast on Mars, Jupiter, and Saturn. A red filter, however, is fairly dark, so it works best on larger aperture telescopes that give brighter images. Switching between red and blue filters can sometimes bring out subtle coloration on the surface of the Moon.

Filter Name	Size	Type[a]	Trans.[b]	Source	Group	Purpose
Moon	1.25"	Grey	13%	Orion		Reduces light levels. Not powerful enough for full moon.
Variable Polarizing System	1.25"	Polarizing	?-?	Meade		Reduces light levels. Poor quality. Use only if grey filter too weak.
Variable Polarizing Filter	2"	Polarizing	1-40%	Orion		Reduces light levels.
Wratten#80A (Medium Blue)	1.25"	Color	30%	Orion	Starter Set	Jupiter/Saturn, especially Great Red Spot.
Wratten#58 (Green)	1.25"	Color	24%	Orion	Starter Set	Moon, Venus, Mars, Jupiter. Reduces chromatic aberration.
Wratten#25 (Red)	1.25"	Color	14%	Orion	Starter Set	Mars, Jupiter, Saturn.
Wratten#15 (Deep Yellow)	1.25"	Color	67%	Orion	Starter Set	Moon, Mars, Jupiter, Saturn.
Wratten#8 (Light Yellow)	1.25"	Color	83%	Orion	Advanced Set	Venus, Mars, gas giants, comets
Wratten#23A (Light Red)	1.25"	Color	25%	Orion	Advanced Set	Moon, Mars, Jupiter, Saturn. Twilight or daylight observing. Corrects for mylar filter color.
Wratten#38A (Deep Blue)	1.25"	Color	17%	Orion	Advanced Set	Moon, Mars, Great Red Spot, Saturn, bright objects.
Wratten#56 (Light Green)	1.25"	Color	53%	Orion	Advanced Set	Moon, Venus, Mars, Jupiter, Saturn.
Skyglow	1.25"	B-LP	95% nebulae 45% stars	Orion		Increases contrast of nebulae against light pollution.
Ultrablock	2"	N-LP	90% non H-α 60% nebulae 10% stars	Orion		Strongly increases contrast of some nebulae against light pollution, but also blocks Hydrogen-α emission.
Light Pollution Reduction	1.25"	B-LP		Celestron		Increases contrast of nebulae against light pollution.
OIII	1.25"	Line	98% OIII 60% nebulae 15% stars	1000 Oaks		Increases contrast of planetary nebulae and supernova remmnants.
Horsehead Nebula (H-β)	1.25"	Line	97% H-β 32% nebulae 3% stars	Lumicon		Increases contrast of a few emission nebulae.
Solar Filter	12"		0.001%	?	Downstairs	**Needed for solar observing.**
H-α Prominence	1.25"		?	1000 Oaks	Downstairs	Enhances solar chromosphere.
V-Block Anti-Fringe	1.25"		70%	Orion		Reduces chromatic aberration.

Table D.1: Table of all filters at Fuertes at the time of writing. See Section 4.2 for an overview of filters and their use.

[a] N-LP = Narrowband Light Pollution; B-LP = Broadband Light Pollution

[b] Transmission. Does not take into account accumulated dirt. "Nebula" transmission is the average of Hydrogen-α, Hydrogen-β, and OIII

Target	Feature	Wratten#8 (Light Yellow)	Wratten#15 (Deep Yellow)	Wratten#23A (Light Red)	Wratten#25 (Red)	Wratten#38A (Deep Blue)	Wratten#56 (Light Green)	Wratten#58 (Green)	Wratten#80A (Medium Blue)
	Daytime sky		Minor	Good					
Moon	Contrast	Good	Fair	Fair		Minor	Good		Fair
Moon	Subtle colors			Fair	Fair				
Venus	Markings	Good	Good		Fair	Fair	Fair	Good	
Mars				Fair	Fair			Good	
Mars	Plains	Good	Good	Fair	Fair				
Mars	Dust storms	Fair	Fair	Good		Good	Good	Good	
Mars	Clouds					Fair		Good	Fair
Mars	Polar caps		Fair	Fair	Superb		Great	Superb	
Jupiter		Fair	Fair	Fair	Great			Good	Good
Jupiter	Zones	Fair	Fair				Fair		
Jupiter	Belts	Fair	Fair	Fair		Good	Fair	Fair	Good
Jupiter	Poles			Fair					
Jupiter	Great Red Spot		Fair	Fair		Great		Fair	Superb
Jupiter	White ovals						Fair		Fair
Saturn		Fair	Fair	Fair	Good		Fair	Fair	Good
Saturn	Bands	Fair				Fair	Fair		Great
Saturn	Poles	Fair		Fair				Fair	Good
Saturn	Rings					Fair			Fair
Uranus		Good							
Neptune		Good							
Comets	Heads	Fair							
Comets	Dust tails	Fair							

Table D.2: A quick summary of what objects are improved by what color filters. The description (e.g. good vs. great) is based on the frequency with which the target type is mentioned in reference materials and on the phrasing of the reference (e.g. “the ultimate Mars filter” vs. “works well on Mars”).

Appendix E

Common Targets

E.1 Solar System Objects

Planet	Type	Diam.[a]	Magnitude	S. Brightness	Synodic Period
Mercury	Terr. Planet	5.1″	-2.2	1.1 Mag/″^{2}	116 days
Venus	Terr. Planet	37.8″	-4.6	3.0 Mag/″^{2}	584 days
Mars (best)	Terr. Planet	15.8″	-1.6	4.2 Mag/″^{2}	780 days
Mars (worst)	Terr. Planet	3.6″	1.8	4.2 Mag/″^{2}	780 days
Ceres	Asteroid	SL	6.8?	8.0 Mag/″^{2}?	466 days
Pallas	Asteroid	SL	7.6?	8.8 Mag/″^{2}?	466 days
Juno	Asteroid	SL	8.6?	9.8 Mag/″^{2}?	474 days
Vesta	Asteroid	SL	6.2?	7.4 Mag/″^{2}?	504 days
Jupiter (best)	Gas Giant	43.3″	-2.6	5.4 Mag/″^{2}	399 days
Jupiter (worst)	Gas Giant	30.9″	-1.7	5.4 Mag/″^{2}	399 days
Saturn	Gas Giant	20.3″	0.0	6.3 Mag/″^{2}	378 days
Uranus	Ice Giant	3.9″	5.7	8.4 Mag/″^{2}	370 days
Neptune	Ice Giant	2.3″	7.8	9.3 Mag/″^{2}	367 days
Pluto	Kuiper Object	SL	13.9	15.1 Mag/″^{2}	367 days

Table E.1: Table of solar system bodies and some basic visibility information. All statistics are given under the best possible viewing geometry unless otherwise stated. Surface brightnesses marked like this assume a 2″seeing disk and a seeing-limited telescope.

[a] SL = Seeing-limited

Planet	Type	Diameter		Mass	Gravity	Orbit		Year	Solar Day[a]
Mercury	Terr. Planet	4880 km	0.383 $D_\oplus$	0.055 $M_\oplus$	0.377 G	57.9×10^6 km	0.387 AU	88 days	176 days
Venus	Terr. Planet	12104 km	0.950 $D_\oplus$	0.815 $M_\oplus$	0.904 G	108×10^6 km	0.723 AU	225 days	-117 days
Mars	Terr. Planet	6806 km	0.533 $D_\oplus$	0.107 $M_\oplus$	0.376 G	228×10^6 km	1.52 AU	1.88 years	24.7 hours
Ceres	Asteroid	1884 km	0.148 $D_\oplus$	0.0002 $M_\oplus$	0.0276 G	414×10^6 km	2.77 AU	4.60 years	9.08 hours
Pallas	Asteroid	1063 km	0.083 $D_\oplus$		0.0184 G	510×10^6 km	3.41 AU	4.62 years	7.81 hours
Juno	Asteroid	480 km	0.038 $D_\oplus$		0.0122 G	502×10^6 km	3.36 AU	4.36 years	7.21 hours
Vesta	Asteroid	1064 km	0.083 $D_\oplus$		0.0224 G	353×10^6 km	2.36 AU	3.63 years	5.34 hours
Jupiter	Gas Giant	142984 km	11.2 $D_\oplus$	318 $M_\oplus$	2.36 G	778×10^6 km	5.20 AU	11.9 years	9.93 hours
Saturn	Gas Giant	120536 km	9.45 $D_\oplus$	95.2 $M_\oplus$	0.914 G	1.43×10^9 km	9.54 AU	29.5 years	10.8 hours
Uranus	Ice Giant	51118 km	4.01 $D_\oplus$	14.5 $M_\oplus$	0.886 G	2.87×10^9 km	19.2 AU	84.1 years	-17.2 hours
Neptune	Ice Giant	49528 km	3.88 $D_\oplus$	17.1 $M_\oplus$	1.14 G	4.50×10^9 km	30.1 AU	165 years	16.1 hours
Pluto	Kuiper Object	2390 km	0.19 $D_\oplus$	0.0021 $M_\oplus$	0.059 G	5.91×10^9 km	39.5 AU	248 years	-6.39 days
Quaoar	Kuiper Object	1688 km	0.13 $D_\oplus$	0.0002 $M_\oplus$	0.02 G	6.49×10^9 km	43.4 AU	286 years	
Eris	Kuiper Object	2400 km	0.19 $D_\oplus$	0.0026 $M_\oplus$	0.071 G	10.1×10^9 km	67.7 AU	557 years	
Sedna	Unknown	$\sim$3000 km		0.005 $M_\oplus$	0.04 G?	78.6×10^{12} km	525 AU	12100 years	10 hours?

Table E.2: Table of solar system bodies and their physical characteristics. $D_\oplus$= Earth diameter, $M_\oplus$= Earth mass, G = Earth surface gravity, AU = Astronomical Unit (mean distance from Earth to Sun)

[a]For Mercury and Venus the siderial day is often erroneously quoted as the solar day.

E.2 Binary Stars

Star	Chart	Sep.	Magnitudes	Colors	Distance	Separation	Period
o Cygni	84	$5.63'$	BIN 4.8	BIN White	840 ly	$\geq$85000 AU	
o Cygni	84	$1.76'$	3.8 / 7.0	Orange/ Blue	840 ly	$\geq$25000 AU	
ϵ Lyrae	82	$3.23'$	BIN BIN	BIN BIN	160 ly	$\geq$9500 AU	$\geq$50000 years
ϵ_1 Lyrae	82	$2.7''$	5.1 / 6.1	White / White	160 ly	$\sim$135 AU	$\sim$1200 years
ϵ_2 Lyrae	82	$2.5''$	5.1 5.4	White White	160 ly	$\sim$140 AU	$\sim$580 years
ϵ Pegasi	211	$81.8''$	0.7-3.5/ 8.5	Yellow / Violet	670 ly	$\geq$16000 AU	
Castor	100	$76''$	BIN 8.9-9.6	BIN Red	52 ly	$\geq$1200 AU	
Castor	100	$3.9''$	1.6 / 2.6	White / White	52 ly	100-120 AU	4-500 years
γ Persei	38	$57''$	2.9 10.8	Yellow White	255 ly	$\geq$4400 AU	
δ Cephei	57	$40.9''$	3.5-4.4/ 6.3	Orange/ Blue	980 ly	$\geq$12000 AU	
Albireo	118	$34.3''$	3.2 5.4	Orange Blue	380 ly	$\geq$4000 AU	$\geq$53000 years
θ Serpentis	251	$22.2''$	4.5 / 5.4	White / White	150 ly	$\geq$1000 AU	
Cor Caroli	108	$18.8''$	$\sim$2.9 5.6	White Green	110 ly	$\geq$635 AU	
Polaris	1	$18.4''$	1.9-2.1/ 8.2	White / White	430 ly	$\geq$2400 AU	
Mizar	48	$14.4''$	2.3 3.9	White White	79 ly	$\geq$340 AU	$\geq$2400 years
γ Andromedae	62	$9.8''$	2.3 / 4.8	Gold / Green	355 ly	$\geq$1000 AU	$\geq$6500 years
γ Delphini	209	$9.3''$	4.5 5.5	Gold Green	100 ly	$\sim$420 AU	$\sim$3200 years
Sirius	273	$7.2''$	-1.4 / 8.4	White / White	8.60 ly	18.9 AU	50.05 years
36 Ophiuchi	337	$4.9''$	5.1 5.1	Orange Orange	19.5 ly	$\sim$80 AU	$\sim$550 years
σ Cassiopeiae	35	$3.0''$	5.0 / 7.1	Blue / Blue	1500 ly	$\geq$1400 AU	
1 Arietis	128/9	$2.8''$	5.8 6.6	Green White	570 ly	$\geq$450 AU	
ϵ Bootis	153	$2.6''$	2.5 / 4.9	Orange/ White	210 ly	$\geq$160 AU	
12 Aquarii	299	$2.5''$	5.8 7.3	Yellow White	540 ly	$\geq$410 AU	$\geq$3000 years
γ Virginis	239	$1.7''$	3.5 / 3.5	White / White	40 ly	46 AU	171 years

Table E.3: Table of popular visual binary stars. BIN = component is itself a visual binary, ly = light year, AU = Astronomical Unit (mean distance from Earth to Sun)

Star	Chart	Sep.	Magnitudes	Colors	Distances
Mizar & Alcor	48	$21.6'$	BIN 4.0	BIN White	79 ly 81 ly
24 Coma Berenices	148/9	$20.6''$	5.0 / 6.6	Orange/ Blue	615 ly/2600 ly

Table E.4: Table of popular optical doubles. BIN = component is a visual binary, ly = light year, AU = Astronomical Unit (mean distance from Earth to Sun)

E.3 Open Clusters

Cluster	Chart	Hop From	Size (vis/phot)	Brightest Star	N($V \leq 12.0$)
Perseus Double	37	η Persei		7	
Coathanger[a]	161	1 Vulpeculae			
Wild Duck	250	β Scuti	$6'/16'$	9	40
M 25	340		$12'/32'$	6	350
M 29	85	γ Cygni			
M 34	62	β Persei		9	
M 35	137	η Geminorum		9	
M 36	97	θ Aurigae		9	
M 37	98	θ Aurigae			
M 38	97	θ Aurigae			
M 39	86	ρ Cygni		7	
M 41	318	15 Canis Majoris		8	
Beehive (M 44)	141	γ Cancri			
Pleiades (M 45)	132	Pleiades		3.0	
M 46	275	α Monocerotis			
M 47	275	α Monocerotis			
M 50	273	θ Canis Majoris		12	
M 52	15	β Cassiopeiae		9	
M 93[b]	230	ξ Puppis		8	
M 103	36-7	δ Cassiopeiae		10	
NGC 457[c]	36	δ Cassiopeiae		7	
NGC 663	16/37	δ Cassiopeiae			
NGC 1907	97	θ Aurigae		9	
NGC 2158	137	η Geminorum			
NGC 2244	227	8 Monocerotis			
Christmas Tree (NGC 2264)	183	ξ Geminorum			
NGC 6910	85	γ Cygni		12	
NGC 7789	35	β Cassiopeiae		11	

Table E.5: Observational properties of open clusters.

[a]According to some sources an asterism rather than a true cluster. Also called Al Sufi's Cluster or Brocchi's Cluster.

[b]Sometimes called the Butterfly Cluster, although this name properly belongs to M 6.

[c]This object is variously called the Owl Cluster, the E.T. Cluster, or the Dragonfly Cluster. We've had fierce debates on which is the most appropriate name.

Cluster	Population	Distance	Diameter	Age
Perseus Double				
Coathanger[a]				
Wild Duck (M 11)	3000-10000?	6100 ly	95 ly	200-250 Myr
M 25	4-600?	2000 ly		90 Myr
M 29				
M 34				
M 35				
M 36				
M 37				
M 38				
M 39				
M 41				
Beehive (M 44)				
Pleiades (M 45)				
M 46				
M 47				
M 50				
M 52				
M 93[b]				
M 103				
NGC 457[c]				
NGC 663				
NGC 1907				
NGC 2158				
NGC 2244[d]				
Christmas Tree (NGC 2264)				
Rocking Horse (NGC 6910)				
NGC 7789				

Table E.6: Physical properties of open clusters.

[a] According to some sources an asterism rather than a true cluster. Also called Al Sufi's Cluster or Brocchi's Cluster.

[b] Sometimes called the Butterfly Cluster, although this name properly belongs to M 6.

[c] This object is variously called the Owl Cluster, the E.T. Cluster, or the Dragonfly Cluster. We've had fierce debates on which is the most correct name.

[d] In Rosette Nebula

E.4 Globular Clusters

Cluster	Chart	Hop From	Size (vis/phot)	Magnitude	S. Brightness (cen/avg)	Population
M 2	255	β Aquarii	20″/	6.47	15.92/	
M 3	110	η Bootis	33″/	6.19	16.34/	
M 4	336	α Scorpii	50″/	5.63	17.88/	
M 5	244		25″/	5.65	16.05/	
Hercules (M 13)	114	η Herculis	47″/	5.78	16.80/	
M 15	210	ϵ Pegasi	4″/	6.20	14.21/	
M 22	340	λ Sagitarii	1.4′/	5.10	17.32/	
M 28	340	λ Sagitarii	14″/	6.79	16.08/	
M 30	346	ζ Capricorni	4″/	7.19	15.28/	
M 53	150	α Comae Berenices	22″/	7.61	17.39/	
M 54	378	ζ Sagitarii	7″/	7.60	14.82/	
M 55	379		3′/	6.32	19.13/	
M 56	118	β Cygni	20″/	8.27	18.06/	
M 72	299	ϵ Aquarii	32″/	9.27	18.90/	
M 79	315	β Leporis	10″	7.73	16.23/	
M 92	80	ι Herculis	14″/	6.44	15.58/	
NGC 6934	209	ϵ Delphini	15″/	8.83	17.26/	
NGC 7006	209	γ Delphini	14″	10.56	18.50/	

Table E.7: Table of globular clusters. ly = light year, Gyr = billions of years

E.5 Diffuse Nebulae

Nebula	Chart	Hop From	Size	Magnitude	S. Brightness	Type	Lines	Distance
Horsehead								
Lagoon (M 8)	339							
Eagle (M 16)[a]	294	γ Scuti						
Trifid (M 20)	339	μ Sagitarii						
Orion (M 42)	225	M 42						
Mairan's (M 43)	225	M 42						
M 78	226	ζ Orionis						
NGC 1931	97	θ Aurigae						
NGC 1973	225	M 42						
NGC 2359	274	*gamma* Canis Majoris						
Bubble (NGC 7635)	34	ι Cephei						
Cocoon (IC 5146)	86							

Table E.8: Table of diffuse nebulae. ly = light year

[a]Sometimes called the Star Queen.

E.6 Planetary Nebulae

Nebula	Chart	Hop From	Size	Magnitude	S. Brightness	Lines	Distance	Diameter	Age	Origina
Dumbbell (M 27)[a]	162	η Sagittae								
Ring (M 57)	117	β Lyrae								
Little Dumbbell (M 76)[b]	37	51 Andromedae								
Owl (M 97)	46	β Urasae Majoris								
Eskimo (NGC 2392)	139	δ Geminorum								
NGC 6210	156	β Herculis								
Cat's Eye (NGC 6543)[c]	30	ζ Draconis								
Blinking Planetary (NGC 6826)	55	θ Cygni								
Blue Flash (NGC 6905)	163									
Helix (NGC 7293)	347									
Blue Snowball (NGC 7662)	88									

Table E.9: Table of planetary nebulae. ly = light year, $M_{\odot}$= solar mass

[a] Sometimes called the Diabolo Nebula.
[b] Sometimes called the Barbell Nebula or the Cork Nebula.
[c] Sometimes called the Sunflower Nebula or the Snail Nebula.

Parent Nebula	Magnitude	Distance	Age	Mass	Original Mass	Temperature

Table E.10: Table of white dwarfs. ly = light year, $M_{\odot}$= solar mass

E.7 Supernova Remmnants

Nebula	Chart	Hop From	Size	Magnitude	S. Brightness	Lines	Distance	Diameter	Year	Original Mass
Crab (M 1)	136	β Tauri					$\sim$6300 ly?	10 ly	1054	

Table E.11: Table of supernova remmnants. ly = light year, $M_{\odot}$= solar mass

E.8 Galaxies

Galaxy	Chart	Hop From	Size	Magnitude	S. Brightness	Type	Distance	Diamete
Andromeda (M 31)	60	ν Andromedae					2.6 Mly	130 kly?
M 32	60	M 31						
Triangulum (M 33)	91	α Trianguli						
Whirlpool (M 51)	76	η Ursae Majoris					23 Mly	97 kly?
Sunflower (M 63)	76	α Canum Venaticorum						
M 65	191	θ Leonis						
M 66	191	θ Leonis						
M 77	220	δ Ceti						
Bode's (M 81)	23-4						11.8 Mly	73 kly?
Cigar (M 82)	23-4						11.8 Mly	30 kly?
Sombrero (M 104)	284						32 Mly	130 kly?
M 110	60	M 31						
Silver Coin (NGC 253)[a]	306-7	β Ceti						
NGC 891	62	γ Andromedae						
NGC 2903	143	ϵ Leonis						
NGC 7331	123						48 Mly	

Table E.12: Table of galaxies. kly = thousands of light years, Mly = millions of light years

[a]Sometimes called the Sculptor Filament.