Limiting Magnitude and Angular Resolution vs. Aperture

The 6“ doghouse telescope is ideal for experimenting with the effects of varying telescope aperture since the objective is readily accessible and can easily be “stopped down” from its native 6“ diameter. The equipment in the doghouse includes aperture stops for the 6“ telescope that provide 4”, 2”, 1” and 1/2” apertures that you will use in this lab. Your pre-lab preparation assignment has prepared you with a magnitude-labeled finder chart for the open cluster M35 which you will use for evaluating limiting magnitude. You have also assembled coordinates, found separations, and developed airmass curves for the binary stars Castor, and Xi Ursa Majoris which will be your primary targets for examining the effects of telescope aperture on spatial resolution and Airy patterns.

Some preliminaries:

Moon awareness: Before going any further it is important to recall the role of moonlight in compromising astronomical observations. As described in class, just like artificial light pollution, the moon adds unwanted background to an observation and that background compromises sensitivity. The Moon is full on February 22, so it will just be reaching first quarter early in the first week of this lab. You will either need to get the limiting magnitude observations done early in the lab period (before the Moon becomes a problem) or work around the Moon, for example working after moonset later in the first week. Moonlight will not affect the double-star observations in part two. Splitting this lab into two observing sessions, one devoted to limiting magnitude in the dark of the moon and the other focusing (no pun intended) on the effects of diffraction vs. aperture size may help you avoid the complications of severe frostbite.

Seeing awareness: The results of this lab, both for limiting magnitude and for observing the effects of diffraction and resolving binary stars, are dependent on the seeing. In bad seeing the blurry star images are spread out over a larger area and fainter stars become difficult to detect (Going in the other direction, one benefit of using adaptive optics to beat the seeing is to concentrate a star's light in a small area, making the star easier to detect. In addition to improving resolution to the diffraction limit of the telescope adaptive optics maximizes sensitivity to faint objects). For this lab you should be selective about trying to find a night with good seeing, particularly for the double-star portion of the lab. At the very least be sure to note as quantitatively as possible, the quality of the seeing during your observations.

Physiology awareness: Without getting too deeply into the physiological details, there are two characteristics of vision that are of importance for this lab.

Dark adaptation: The eye is an adaptive organ. It has a remarkable dynamic range. That is, the range between the smallest detectable light level and the brightest light the eye can handle (something we'll learn about in detail in the context of CCD detectors a bit later). To achieve this range the eye is capable of changing (both via pupil dilation and from chemistry and neuronal adaptation) from bright light to low-light mode, but only over a period of 10-20 minutes. This dark adaptation is lost almost instantaneously upon exposure to bright light and another 10-20 minutes is required to recover. The evaluations of limiting magnitude need to be made when your eye is largely dark adapted. To maintain dark adaptation avoid exposure to bright light. Lighting up your notebook with a normal flashlight will cause the loss of your dark adaptation. Traditionally red filters have been used to cut down on flashlight intensity although there is much discussion about the optimal color for low light illumination that
preserves dark adaptation. Dim is good regardless of color. You also might be interested in experimenting with limiting magnitude vs. time since your loss of dark adaptation is part of this lab. More than you ever wanted to know about night vision can be found [at this link].

Averted vision: The center of your visual field is devoid of the most sensitive light detectors in your eye (known as "rods"). This adaptation is one that sacrifices light sensitivity for visual acuity. If you stare directly at a faint star it will disappear. You are most sensitive to starlight about 10-20 degrees from the center of your visual field. Looking off to the side of your target to increase visual sensitivity is called using “averted vision”. You should use this technique to find the faintest stars in the field in order to evaluate limiting magnitude for your eye.

Limiting Magnitude

Limiting magnitude refers to the faintest detectable star in an observation and is dependent on observing conditions such as sky brightness and seeing. Limiting magnitude also depends on the detector whether it be the human eye with its sensitivity and integration time limitations or a sophisticated high quantum efficiency CCD capable of integrating for minutes at a time. For this experiment you will be using your own eyes. You may even be able to explore the variation in sensitivity (or observing ability) amongst the people in your group.

Star clusters provide particularly useful fields for evaluating limiting magnitude since clusters concentrate a large number of stars of varying brightness within a field of view of a few arcminutes. Messier 35, near the foot of the constellation of Gemini, is particularly well placed for February observing. If you are executing this lab then you have already produced a magnitude-labeled finder chart and have coordinates for M35 from your pre-lab work. If interested, see [this paper] for more than you ever wanted to know about M35. Also don't forget to take a peak at NGC 2158 while you are in the neighborhood of M35.

Each member of your group should make the limiting magnitude assessment using M35 for the various telescope aperture stops (specifically 6” (unstopped), 4”, 2”, 1”, and 0.5”) using the lowest power eyepiece. For the unstopped aperture also make an assessment as to whether limiting magnitude changes as you change eyepieces. You should compare the consistency of these results between observers and speculate on reasons for any differences. Most importantly your lab write-up should approach these observations as an experiment to demonstrate (or not) that limiting magnitude scales with aperture as expected.

Be sure to consult the North Polar Limiting Magnitude chart in Norton's Sky Atlas and assess the limiting magnitude for the unaided eye at the time of your observations. Before, after, or during your measurements in M35 use the handheld light meter to measure the sky brightness in magnitudes per square arcsecond. Are your north polar measurements consistent with the measured sky brightness?

Spatial Resolution vs. Aperture

Barlows and Illuminated Reticle Eyepieces: Evaluating sizes of Airy rings, image widths, and binary star separations requires significant magnification beyond that provided by the shortest focal length eyepiece available at the 6”. In fact we will use a 12.5mm eyepiece for these observations because it is the only one with an illuminated reticle. As discussed in
Resolving Stuff: Center on Castor and find the objective aperture stop for which the two components become marginally resolved. Make your best sketches for this marginally resolved configuration and one other aperture for which the two stars are well resolved. Demonstrate that the observation is consistent with the Rayleigh criterion for that aperture (or not).

Find the Jovian satellite Ganymede, which should be approximately 1” in diameter (consult JPL Horizons for the exact value at your time of observation). Measure Ganymede's diameter with the reticle eyepiece and compare that diameter to that of a nearby star. Are you able to demonstrate to your satisfaction (or not) that you can resolve the 1” disk of Ganymede? Since you are carefully reading this lab before going to the telescope you know that you should consult, in advance, some resource to determine the position of Ganymede on the night of your observation.

As a challenge, finish your 6” night by finding Xi Ursae Majoris. Xi UMa is a fascinating system. Each of the stars that you can see is in fact a spectroscopic binary – so it is a quadruple star system. An extremely cool brown dwarf companion orbits thousands of astronomical units (several arcminutes) away from this tight double-double. The tight double takes about 60 years to complete an orbit, making it a physical separation of order 15 AU. If the separation is 15 AU and the separation is 1.6” arcsec that means the system is only of order 10 parsecs away, right in our backyard. In any case, do your best to split this double with the full 6” aperture and make appropriate sketches.

26 1/2 inch Comparison (optional for the ambitious)

After completing the 6” observations compare the performance of the unstopped 6” with the 26 1/2” for M35 limiting magnitude and for resolving Ganymede and the double-star Castor or/and Xi UMa. You need not be precisely quantitative as you were for the 6” experiment, but make some qualitative observations comparing the two. To do so productively may require having made some good sketches in your notebook at both telescopes.
"You know Orion always comes up sideways. Throwing a leg up over our fence of mountains, And rising on his hands, he looks in on me Busy outdoors by lantern-light with something I should have done by daylight, and indeed, After the ground is frozen, I should have done Before it froze, and a gust flings a handful Of waste leaves at my smoky lantern chimney To make fun of my way of doing things, Or else fun of Orion's having caught me. Has a man, I should like to ask, no rights These forces are obliged to pay respect to?"
So Brad McLaughlin mingled reckless talk Of heavenly stars with hugger-mugger farming, Till having failed at hugger-mugger farming, He burned his house down for the fire insurance And spent the proceeds on a telescope To satisfy a lifelong curiosity About our place among the infinities.

"What do you want with one of those blame things?"
I asked him well beforehand. "Don't you get one!"

"Don't call it blamed; there isn't anything More blameless in the sense of being less A weapon in our human fight," he said. "I'll have one if I sell my farm to buy it."
There where he moved the rocks to plow the ground And plowed between the rocks he couldn't move, Few farms changed hands; so rather than spend years Trying to sell his farm and then not selling, He burned his house down for the fire insurance And bought the telescope with what it came to. He had been heard to say by several: "The best thing that we're put here for's to see; The strongest thing that's given us to see with's A telescope. Someone in every town Seems to me owes it to the town to keep one. In Littleton it may as well be me."
After such loose talk it was no surprise When he did what he did and burned his house down.

Mean laughter went about the town that day To let him know we weren't the least imposed on, And he could wait—we'd see to him tomorrow. But the first thing next morning we reflected If one by one we counted people out For the least sin, it wouldn't take us long To get so we had no one left to live with. For to be social is to be forgiving. Our thief, the one who does our stealing from us, We don't cut off from coming to church suppers,
But what we miss we go to him and ask for.
He promptly gives it back, that is if still
Uneaten, unworn out, or undisposed of.
It wouldn't do to be too hard on Brad
About his telescope. Beyond the age
Of being given one for Christmas gift,
He had to take the best way he knew how
To find himself in one. Well, all we said was
He took a strange thing to be roguish over.
Some sympathy was wasted on the house,
A good old-timer dating back along;
But a house isn't sentient; the house
Didn't feel anything. And if it did,
Why not regard it as a sacrifice,
And an old-fashioned sacrifice by fire,
Instead of a new-fashioned one at auction?

Out of a house and so out of a farm
At one stroke (of a match), Brad had to turn
To earn a living on the Concord railroad,
As under-ticket-agent at a station
Where his job, when he wasn't selling tickets,
Was setting out up track and down, not plants
As on a farm, but planets, evening stars
That varied in their hue from red to green.

He got a good glass for six hundred dollars.
His new job gave him leisure for stargazing.
Often he bid me come and have a look
Up the brass barrel, velvet black inside,
At a star quaking in the other end.
I recollect a night of broken clouds
And underfoot snow melted down to ice,
And melting further in the wind to mud.
Bradford and I had out the telescope.
We spread our two legs as it spread its three,
Pointed our thoughts the way we pointed it,
And standing at our leisure till the day broke,
Said some of the best things we ever said.
That telescope was christened the Star-Splitter,
Because it didn't do a thing but split
A star in two or three the way you split
A globule of quicksilver in your hand
With one stroke of your finger in the middle.
It's a star-splitter if there ever was one,
And ought to do some good if splitting stars
'Sa thing to be compared with splitting wood.

We've looked and looked, but after all where are we?
Do we know any better where we are,
And how it stands between the night tonight
And a man with a smoky lantern chimney?
How different from the way it ever stood?