How Faint Can You See?

LIKE MANY AMATEURS, you have probably tested the limit of your telescope. Maybe you've even checked your results against numerous tables and formulas describing how faint you *should* see. The question is: did you see as faint as the published values, or did you go deeper? In this article I'll try to convince you that limiting magnitude is a fuzzy concept and that your threshold can vary by three or more magnitudes — even under superbly dark skies!

The argument is not new. In the December 1950 issue of *Sky & Telescope* (page 46), David W. Rosebrugh of Waterbury, Connecticut, published a table of the faintest stars visible through telescopes of various apertures. He stated that while the theoretical limit of a 6-inch was magnitude 13.1, observers actually saw 14.0 through refractors and 13.5 through reflectors. Another study with similar results was published here in June 1973 (page 401).

Probably the most extensive, recent survey was presented by Bradley E. Schaefer of the NASA-Goddard Space Flight Center in the November 1989 issue of this magazine (page 522). Schaefer demonstrated through computer modeling that limiting magnitude is primarily a function of aperture, magnification, and sky brightness; higher magnifications simply diminish the sky background, allowing you to see fainter stars. But his study also revealed an "unexplained" scatter of about 0.5 magnitude. And while Schaefer's model gave a limit of around magnitude 14.3 for a 6-inch, some observers have claimed to reach 15.2.

In almost every study, a few observers consistently saw much fainter than the theoretical limit. We have also read of fantastic observations. Perhaps the most famous is that of Stephen O'Meara's visual recovery of Halley's Comet (*S&T*: April 1985, page 376). Observing with a 24-inch telescope atop Mauna Kea in Hawaii, O'Meara recovered the 19.6-magnitude comet and saw a 20.4 field star! It is equivalent to seeing a 17th-magnitude star in a 6-inch. Many have criticized such a limit as impossible (I was one for a while) or simply allowed

Stephen James O'Meara breathes oxygen at the 24-inch telescope he used to recover Comet Halley in January 1985. © Jonathan Blair / Woodfin Camp & Associates.

that O'Meara has extraordinary eyesight. But has he?

In May 1991 a group at the Texas Star Party successfully detected a faint gravitational lens (*S&T*: October 1991, page 433). Shortly after that observation I received a call from Texas amateur Barbara Wilson, one of the observers. In explaining her feat, Wilson related another example involving an 18.7-magnitude star seen through her 20-inch. At the time she was with veteran observer John Bortle of Stormville, New York, and O'Meara. All observed the same field independently and recorded the same faint star.

To see it, Wilson says, she had to concentrate very carefully, and even then the star would "flash" into view for only a second or so every minute. After seeing the flash in the same position three times, she knew that it was a real detection of a faint star. At the time she had no idea how faint it actually was.

O'Meara uses a similar method. For example, he will often spend 30 minutes to detect a single faint star. (He spent 1 to 2 *hours* to detect Halley!) He will see the star blink into view occasionally; only a small fraction of the time does he actually see it. By increasing the "integration time" — the time spent trying to make a detection — a few blinks detected at the same location can build up to the positive identification of stars or faint objects normally considered beyond reach.

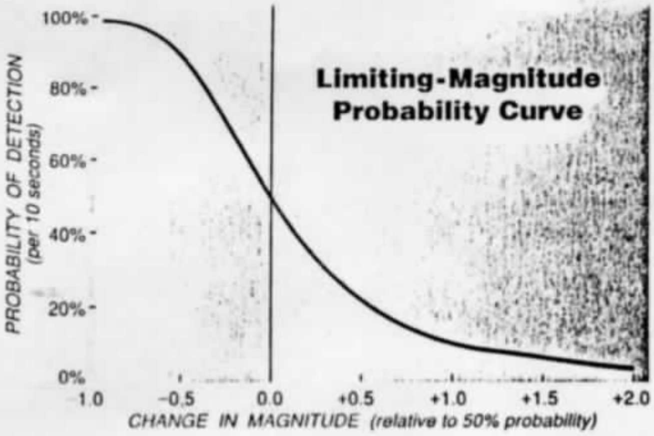
In principle, this is the same method as a time exposure in astrophotography; the longer the exposure the fainter the magnitude limit. Thus, the longer you look, the fainter you should see.

Laboratory research on the eye's response to faint light shows that detection limits can be likened to a probability curve. Using data from an elaborate study conducted by H. R. Blackwell in 1946, I based the curves and tables in my book *Visual Astronomy of the Deep Sky* on a 50 percent probability of detection. Thus, during a given time interval, a star at the limit of detection should be seen by a trained observer using averted vision about half the time. But what if we work at a different probability level?

A limiting-magnitude probability curve based on the Blackwell study appears above. It shows how long a trained observer will detect a faint star relative to a standard 50 percent probability. With my 6-inch, for example, I've found that I have a 50 percent chance of detecting a 14.6-magnitude star. If I glimpse a star 90 percent of the time, the limit would be a half magnitude brighter, or 14.1. But if we reduce the probability of success to 10 percent, the limit goes one magnitude *fainter,* or an amazing 15.6. Similarly, with a 2-inch telescope, a skilled observer who detects a 12.2-magnitude star when working at the 50 percent probability level should see to 13.2 at the 10 percent level.

Clearly, then, there is no single limiting magnitude for a given telescope aperture. Using the Blackwell curve and the faintest-star formula from *Visual Astronomy of the Deep Sky,* I have derived a table (see above) of telescopic limiting magnitude based on probability of detection.

The question is, then, does O'Meara have extraordinary eyes, or has he learned to observe at slimmer probabilities than the rest of us ever considered possible? Tests do show that he has better-than-average acuity, but this does not necessarily affect photon-detection ability.



The author's calculations for limiting magnitude use a "50% probability" standard (vertical line) — that is, the brightness of a star seen through a given telescope half the time by an experienced observer. But as this curve shows, the probability of detection is higher for brighter stars (left side) and lower for fainter ones (right side).

TELESCOPE LIMITING MAGNITUDE

Aperture	Probability of Detection						
(inches)	98%	90%	50%	20%	10%	5%	2%
1	9.7	10.2	10.7	11.2	11.7	12.4	13.2
2	11.2	11.7	12.2	12.7	13.2	13.9	14.7
3	12.1	12.6	13.1	13.6	14.1	14.8	15.6
4	12.7	13.2	13.7	14.2	14.7	15.4	16.2
5	13.2	13.7	14.2	14.7	15.2	15.9	16.7
6	13.6	14.1	14.6	15.1	15.6	16.3	17.1
7	13.9	14.4	14.9	15.4	15.9	16.6	17.4
8	14.2	14.7	15.2	15.7	16.2	16.9	17.7
10	14.7	15.2	15.7	16.2	16.7	17.4	18.2
12½	15.2	15.7	16.2	16.7	17.2	17.9	18.7
14	15.5	16.0	16.5	17.0	17.5	18.2	19.0
16	15.7	16.2	16.7	17.2	17.7	18.4	19.2
18	16.0	16.5	17.0	17.5	18.0	18.7	19.5
20	16.2	16.7	17.2	17.7	18.2	18.9	19.7
22	16.4	16.9	17.4	17.9	18.4	19.1	19.9
24	16.6	17.1	17.6	18.1	18.6	19.3	20.1
30	17.1	17.6	18.1	18.6	19.1	19.8	20.6
36	17.5	18.0	18.5	19.0	19.5	20.2	21.0

Use this table to determine the limiting magnitude of your telescope. The table is based on the probability of detection, which tells you the fraction of total observing time a star of given brightness is seen under ideal conditions.

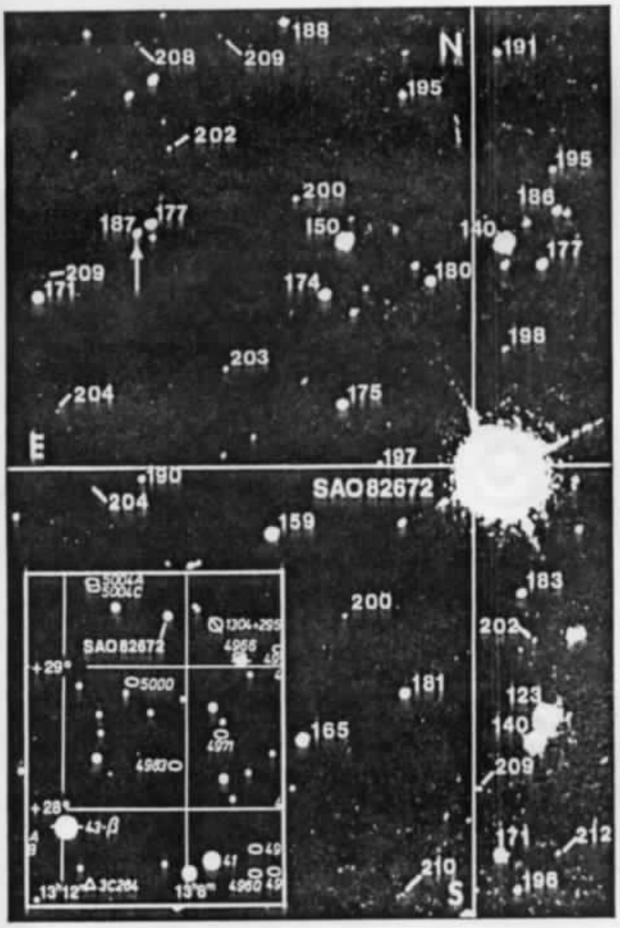
I now believe that O'Meara has detected amazingly faint objects using an acquired observing skill unmatched for detecting faint objects. It is truly amazing that a few observers have discovered such difficult methods empirically. But I also believe that the rest of us "mere mortals" might be able to achieve such limits too!

TRICKS OF THE TRADE

Whether you have a 24-inch telescope or a 2-inch, you can push your limits by spending more time behind the eyepiece. The best observers achieve results at the 2 percent level, yet they are actually detecting the target star perhaps only 1 percent of the time. The reason is simple: it's difficult to hold your eye steady enough to allow the most sensitive part of your retina to collect photons from a tiny part of the total image. Thus while you might spend 100 seconds trying to detect a faint star, it is challenging to hold your eye steady in the correct position for even 50 seconds. Even the best observers can't do it all the time, and they have practiced the technique long and hard.

How long does it take to detect faint objects at the 5 percent probability level? Assuming you can hold your vision steady for a third of the time, and assuming you need three good sightings (flashes) to have confidence in your detection, you must observe about six times longer than the duration between the flashes. These impulses may occur only once every minute or so. Thus some 5 to 10 minutes are needed. To push the detection level to the 2 percent threshold requires much longer observation time.

You also need to be far away from city lights and have keen averted vision and intense concentration. If you cannot escape all city lights, there are tricks that will help you achieve the faintest possible observation. High on my list is total isolation from extraneous light. Cover your head with a black cloth if you must. Or use higher magnifications, which help reduce the sky background and the interference of bright stars in the field.



How faint can you see? Use this section of a photographic chart prepared by the late Edgar Everhart. The arrow points to the 18.7-magnitude star observed by Barbara Wilson, John Bortle, and Stephen O'Meara at the 1991 Texas Star Party. The bright star at right is 8th-magnitude SAO 82672, arrowed on the inset chart adapted from *Uranometria 2000.0*. That star can also hinder observations, so use high power and keep it out of the field. A different series of test charts also appear in Roger Clark's *Visual Astronomy of the Deep Sky*.

For example, stars 4 or 5 magnitudes brighter than your target limit will tend to "pull" your view toward them. Another aid is to tap the telescope tube lightly when trying to confirm a sighting of a faint star, since our eyes are very sensitive to motion.

Some observers breathe more deeply or frequently than normal, in the hope that doing so will deliver more oxygen to the eye's receptors. Stories abound about observers breathing heavily at high altitude while looking up at the sky and seeing faint stars pop into view (I have never experienced this effect, despite having tried it on numerous observing runs at 14,000 feet on Mauna Kea).

O'Meara agrees. The purpose of heavy breathing at high altitude, he says, is to deliver oxygen to the brain so you can think and concentrate on the observation. It may even work to a degree at sea level. When fatigued, it is difficult to concentrate, especially for long periods through the night. Be careful not to hyperventilate, however, because you may blank out — or the spots you see may end up not being stars!

TEST YOURSELF

To test how faint you can see, use the star chart above. Try pushing your limits. But don't be discouraged if you can't detect a star at the 2-percent-probability level on the first try. You must learn the technique over time. Try for the 50 percent level, and work there for a while. After that seems routine, edge toward 20 percent, then 10 percent, and so on. Each fainter target will be harder than the last and will take longer to achieve.

Naturally, it is difficult to separate all the variables when experimenting with human subjects. Therefore, the limiting-magnitude table on page 107 is only a guide. If you believe your eyes are relatively normal (this does not include the correction you may have with glasses or contact lenses), then the table should be close. Try to determine what probability level you are currently working at and then try to push to lower levels for the times you want to detect something fainter. It doesn't matter if you are near- or farsighted, because you simply compensate by adjusting the focus of the eyepiece. When working at higher powers it also does not matter if you have astigmatism because the beam of light entering your eye is very small in diameter.

But there is more to observing than simply detecting faint stars. The probability principles can apply to contrast in extended objects. You may detect a low-contrast feature on a planet by simply observing it long enough for it to "flash" into view. Planetary observers usually credit seeing changes as being responsible for all fine, low-contrast detail they see. Some of these "moments of good seeing" might well be the eye and brain combination hitting those low probability levels! Perhaps this knowledge can be exploited by observers to see even more detail on planets and deep-sky objects.

Again, to reach the lowest levels, you *must* have excellent skies. You may not achieve the same detection limit at sea level as from a mountain site situated above more of the atmosphere and haze. You must also be far from cities and work on very clear nights. Fortunately, we are currently past solar maximum, so the airglow component will not be bad. High-altitude volcanic haze, like that from Mount Pinatubo the last couple of years, inhibits detection of faint stars. But it appears to be thinning, so let's hope there are no major eruptions soon.

Good luck, and let me know what you are able to achieve. Has anyone seen Pluto in a 2-inch telescope?

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