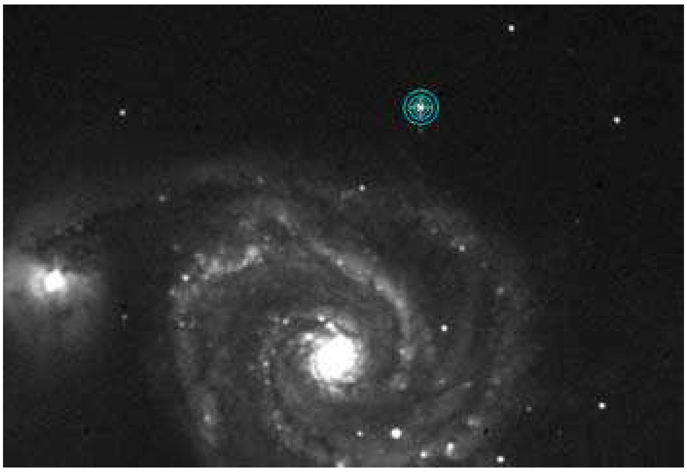
Astronomy is all about seeing as much as possible. That's why astronomers always want bigger scopes and more sensitive CCD chips. After the 100" telescope was built on Mount Wilson, astronomers wanted a 200" for Palomar. Today's biggest telescopes are 8-10 meters in diameter, and already plans are being made for gigantic 30-meter and larger telescopes! Fainter is better. The fainter you can reach, the more detail will be visible in your image.

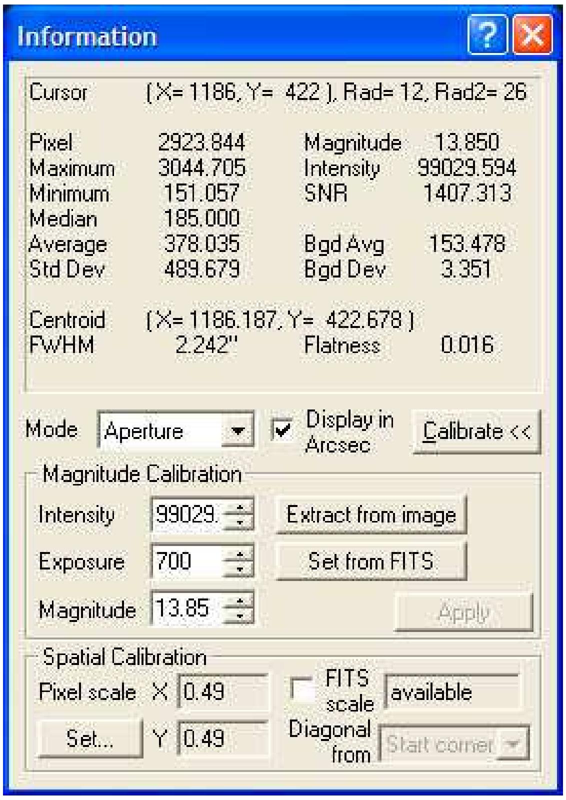
How faint can amateur astronomers go? Visually there are so many factors -- eyesight, transparency, magnification -- that it is almost impossible to correlate observations. Figure with good eyesight from a very dark location it is possible to see a 15th or possibly 16th magnitude star in an 8" telescope. With a CCD camera on the same 8" telescope it is possible to reach the same 16th magnitude limit with only a few seconds exposure. In 60 seconds, magnitude 18 can be reached -- approximately the visual limit on a 30" scope! Longer exposures will reach fainter magnitudes, but there are limitations -- and ways around them!

Measuring Magnitudes

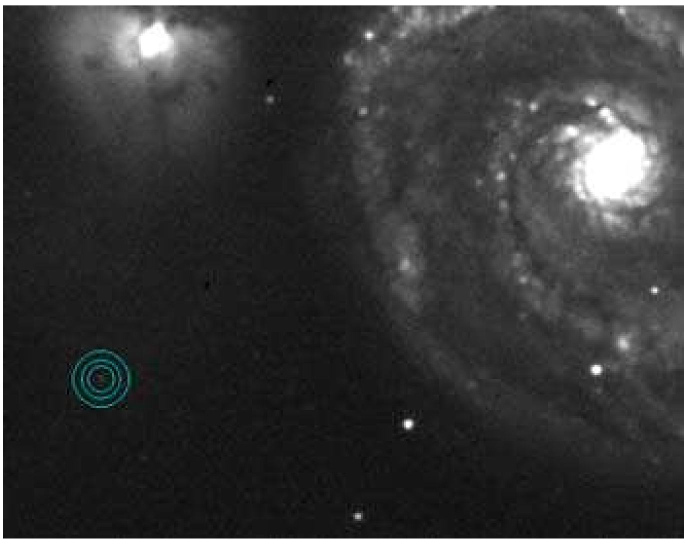
Let's say we'd like to determine how faint this exposure of the Whirlpool Galaxy goes. You can use a program such as MaxIm DL to measure the magnitudes of stars in a CCD image. First, though, you need to calibrate the measurement on a known star. MaxIm DL allows you to extract data from the image and enter the magnitude of your calibration star.



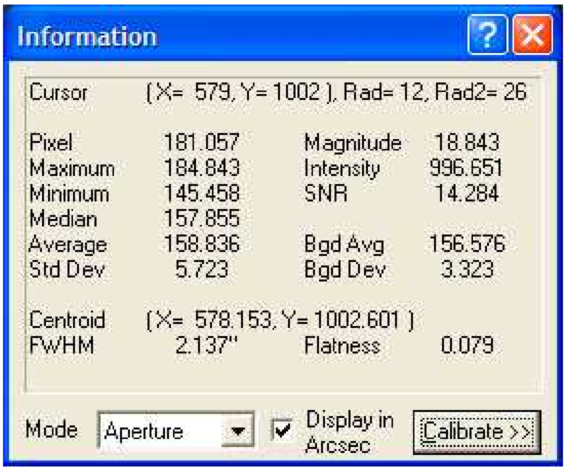
In the image above we have selected the bright star above the galaxy for calibrating the measurements. Checking a planetarium program such as TheSky or Starry Night will give the magnitude of this star. It turns out to be 13.85, so this is the value to enter into the calibration window in MaxIm DL.



Above is he Information window in MaxIm DL. The magnitude has been calibrated on the 13.85 magnitude star above the galaxy. Exposure time (700 seconds) and star intensity were automatically extracted from the image. Now moving the cursor over another star will give the magnitude of that star. Note also that the FWHM (full width at half max) value of the star is also given in arcseconds. This is calibrated by entering the pixel size of the CCD and focal length of the telescope. The FWHM of the measured star is 2.2 arcseconds, indicating average seeing conditions.



Now the cursor is placed over a fainter star, such as this one below the galaxy.



The measured magnitude for this star is 18.8. Note also the SNR, or signal to noise ratio, reading for this object. A SNR of 3 is usually considered the cutoff for the faintest reliable magnitude measurement. So there should be stars in this image fainter than magnitude 18.8 since the SNR of this star is still 14.3. In fact, stars giving a SNR of 3 in this image were measured at magnitude 20.4. This is about 4 times fainter than magnitude 18.8, corresponding well with SNR 3 being about one-quarter of SNR 14.

How Faint Can You Go?

Magnitude 20.4 is about fifty times fainter than you could see visually in the same 12.5" scope that captured the image above, but it is not exceptionally faint. In 2007, amateur astrophotographers Johannes Schedler and Ken Crawford combing more than 12 hours of exposures through 16" and 20" telescopes to image a high-redshift quasar. The magnitude of the quasar was measured at 24.8. Its redshift is 6, meaning light left the quasar nearly 13 billion years ago! Magnitude 24.8 is over 30 million times fainter than you can see with the unaided eye, and 50 times fainter than the above image of the Whirlpool Galaxy reached. With extremely sensitive cameras, large aperture telescopes, and automated imaging software, ultra-deep exposures will become more common.

Project Ideas

Capture the Deepest Amateur CCD Image

Limiting magnitude is largely a function of aperture. Reaching below 25th magnitude will likely require a 20" or larger instrument. The higher the quantum efficiency of the CCD camera, the shorter the necessary exposures will be, and it may be best to combine many shorter exposures. The factor to keep in mind is signal-to-noise ratio (SNR). As mentioned above, the dimmest reliable magnitude in an image will have a SNR of 3:1. (See also the section on Imaging Faint Detail.) Summing images increases the SNR, so combining dozens of images may be necessary. Also, special processing techniques may need to be employed to remove sky noise, camera noise, and other artifacts such as cosmic rays. Ideally, the individual exposures will be as long as possible without wasting exposure by simply imaging background skyglow. See the section on Optimum Exposures to determine the best subframe exposure time for your setup.

Capture the Faintest Deep-Sky Object

While stars and quasars (which as effectively stellar objects) will allow the faintest possible magnitudes to be reached, grabbing dim galaxies and nebulae can provide another type of challenge. Finding a specific object may be difficult as few catalogs exist which go as faint as even an amateur telescope can reach. For stellar objects, aperture is the key, while for extended deep-sky objects such as nebulae another important factor is the focal ratio. A faster focal ratio will capture fainter deep-sky objects with less exposure time. Again, combining a large number of images will be necessary to reach the faintest magnitudes. See how many galaxies you can capture in a distant galaxy cluster. Another recent challenge has been to capture what has been called the Integrated Flux Nebulae, extremely faint clouds of dust illuminated by the collective glow of the Milky Way's stars. See Steve Mandel's website for details on his project to catalog these elusive objects and for details on finding the nebulae and imaging them yourself.

Capture the Most Distant Object

What will it take to top Schedler and Crawford's redshift-6 quasar? A relatively easy target to test your equipment and skills would be quasar PKS 1354-17. At a redshift of 3.14, this active galaxy glows faintly across more than 11 billion light-years of space*. With a magnitude of 18.5 this object should be within reach of most CCD setups. The location of this object is listed below.

A more challenging object is the radio galaxy 4C 41.17 (such catchy names, these distant objects). 4C 41.17 has a redshift of 3.80, equivalent to a light-travel time of 11.9 billion light-years. At magnitude 21.7, this galaxy is not an easy prize, but certainly is worthy of the effort required as the galaxy is one of the most distant known. The galaxy is so far away that it is receding from us as 92% the speed of light. This means its light has been shifted toward the red end of the spectrum, so a red/near-infrared-sensitive CCD would be required, as was used for the faint quasar discussed above. (Most of the light seen in the visible portion of the spectrum from 4C 41.17 was actually originally emitted as extreme ultraviolet radiation. The quoted magnitude is in the red portion of the spectrum, comparable to the peak sensitivity of many amateur CCDs.)

Perhaps the most distant object within easy reach of amateur CCDs, however, is the quasar APM 08279+5255. This object has a redshift of 3.87 yet has a magnitude of 16.6. This is due to the fact that the quasar is being gravitationally lensed by a foreground galaxy causing the light to be amplified. This object is located in Lynx, very near the nose of Ursa Major, making it a prime target for northern-hemisphere observers during much of the year. (Also, at a magnitude brighter than 17, this object is a visual target in a large-aperture telescope.)

To top the redshift of 6 of Schedler and Crawford's CFHQS J1641 +3755 will require going to magnitude 25 or greater. But telescopes of 20" and larger are not uncommon amongst advanced amateur astronomers, and with high-sensitivity cameras and automated software, all-night deep exposures are not that difficult to achieve anymore. A camera with good infrared sensitivity and a few dozen hours of exposures should be able to reach beyond the 13-billion-light-year mark.

Object	**Right Ascension**	**Declination**	**Magnitude**	**Light-Travel Time***
PKS 1354-17	13h 57m 6.07s	-17° 44' 1.9"	18.5	11 billion l.y.
4C 41.17	6h 50m 52.15s	+41° 30' 30.5"	21.7	11.9 billion l.y.
APM 08279+5255	8h 31m 41.6s	+52° 45' 17.0"	16.6	12.0 billion l.y.
CFHQS J1641 +3755	16h 41m 21.6s	+37° 55' 20.5"	24.8	12.7 billion l.y.

* *Actual physical distances at large redshifts depend greatly on factors such as the expansion rate of the universe, the acceleration of the expansion rate, and the actual "shape" of the universe. These numbers are still not precisely determined, so the numbers are approximations. Because of the expansion of the universe it doesn't really make sense to talk about the actual distance to such objects. While the light from a redshift 5 quasar has taken about 12.5 billion years to reach us, the universe has been expanding all the while. The actual current distance to an object of such redshift is more like 26 billion light-years!*

If you succeed in any of these challenges, or any similar projects, please contact us as we would love to post the results in our Image Gallery!