Instruments and Imaging Section
Technical Tips No. 11
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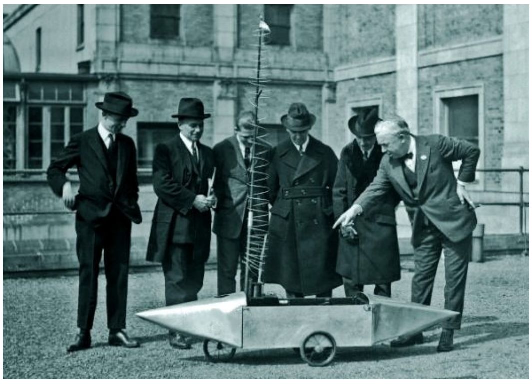


... and the floggle-toggle box will reach magnitude 37

There recently appeared, on the BAA website forum, a discussion by Eliot Hall, Martin Mobberley, Grant Privett, and Richard Miles on imaging very faint objects and the various factors and techniques involved in achieving reliable and successful results. Such information is worth disseminating directly and more widely, and is therefore presented here. I have also appended my own note on visual limiting magnitudes.

The mystery object in the previous *Technical Tips* is a pair of spectacles fitted with two $^1/_6$-inch aperture Galilean telescopes, providing a small central field at higher magnification. Such devices have long been available, either as tiny telescopes in spectacles or as binoculars that can be worn like spectacles. The next mystery object (above) is ...? Clue: there are several variants of this instrument, which was installed in 1900.

1924

2014

Limiting magnitude

Eliot Hall

Having decided recently to hunt for some faint asteroids, I consulted Cartes du Ciel, which stated that there would be three twentieth-magnitude asteroids in the field of view of a galaxy that I was imaging. I double checked the ephemeris on the Minor Planets Center website, but none of the asteroids required further observation, and I assumed that they had stable orbits. I imaged the target area with my 10-inch f/4.7 Newtonian with a Starlight Xpress MX916 and UV/IR cut filter. I took 10 x 60s and 10 x 120s exposures with darks and flats. The telescope was pointing above 50° elevation. Using Astrometrica and Cartes Du Ciel I scanned the regions of the image where the asteroids should be. However, I could not find any trace of them. Using the object selection tool in Astrometrica I measured the V magnitudes of the faintest stars in the image. The faintest I could make out were eighteenth to nineteenth magnitude. Therefore:

1 Am I being unrealistic in expecting to find twentieth-magnitude asteroids using the equipment that I have?
2 Have I hit the sky's magnitude limit? I live on the edge of a village, and the seeing was acceptable but not brilliant. I also tried analysing a few 300s subs from the same night, but could not see any extra stars.
3 Do I need to stack the images to obtain a better signal-to-noise ratio? If so, how can the images be aligned on something that cannot be seen?

Martin Mobberley

I think you have answered your own question, as you are detecting stars of eighteenth to nineteenth magnitude near the limit, and so any twentieth-magnitude asteroids will be just beyond the limit. Over the years I have imaged quite a few faint objects with my Celestron 14 and other telescopes, and while I have reached as faint as magnitude 22 under exceptional skies, with long exposures, it becomes much harder to extract objects from the noise beyond magnitude 19, when the signal is only a few percent above the noisy sky background. Even with an unfiltered exposure and a 14-inch aperture, reaching fainter than magnitude 19 or so becomes a problem unless the sky is really dark and crystal clear and the tracking and focusing are spot on. It may be worth your having a look at Peter Birtwhistle's website:

http://www.birtwhistle.org

Peter is the undisputed master at tracking down faint asteroids, and his website shows what can be achieved with a large aperture in the UK. Of course, any kind of filter will restrict the limiting magnitude: a V filter can reduce the limit by a magnitude and a half quite easily. Also, while an ephemeris might state that an object is magnitude 20, there is often considerable error in the values given by planetarium packages, and the phase of an asteroid plays quite a role too. Many of the keenest imagers of faint objects use Guide 9.0 to determine where asteroids and comets are and how bright they are. It is not a flashy graphics package, but it is accurate and very modestly priced.

So, I would say you are close to the limit of your equipment on an average UK night, but magnitude 20 is certainly possible if the night is crystal clear and focusing is perfect and tracking excellent, with good seeing. An image scale of around 2 arcsec per pixel is often quoted as the optimum sampling value for recording faint stars without the sky background swamping them.

You ask how images can be aligned on something you cannot see. The Help section of Astrometrica includes a Tutorial which explains how to track and stack images allowing for the object's predicted motion. In my version it is Tutorial number III.

Eliot Hall

Thanks, Martin, for such a comprehensive reply. You have given me a few things to muse over and research further. I will certainly have a look at the Astrometrica Tutorial and stack the subs again. I thought that I might have hit the sky's limit. It is very interesting to know what others have found possible in the UK.

Grant Privett

I have a few comments, as my telescope is the same size as yours. A year or two back I tried going deep from a fairly dark UK site (blue on Philip's Dark Skies Map). I took a couple of hundred 45-sec images using a 10-inch f/4.3 Newtonian and a Starlight Xpress MX7. By median stacking the images (though sigma clipping would have worked as well) in bunches of ten (to eliminate artefacts and cosmic rays or satellites) and then stack-adding the resultant twenty or so frames, I managed to detect stars at the magnitude 21 level with a signal-to-noise ratio of about 5. So, not spectacular, but real.

Personally, I would not use a UV/IR filter, as many modern CCDs are surprisingly sensitive in the 650–950 nm range, and you are disposing of signal for no gain. If it were a refractor it would be another matter altogether. With my current set-up, a good clear night, no Moon, clean mirrors, exposures of 600 sec plus and a newer CCD, such as the 694, I might just hit magnitude 22.5. This is similar to the photographic limit of the UK Schmidt survey, so is respectable.

My old Polaris mount was pretty poor, so I often had to recentre the target (I lost about 70% of images to trailing). In effect, this dithered the hot/cold/dodgy pixels around the image and helped to suppress background streaking, which ruins so many attempts to go deep. Dithering long exposures is very tedious, so when I have refurbished my mount I shall be using the dither function of Nebulosity in conjunction with PHD autoguiding to help flatten the background. It is worth a try.

Incidentally, Astroart can stack images aligned with interframe offsets derived from the PA and speed of a candidate. Also, a flat field really will help when looking for very small variations in the sky background.

Richard Miles

As can be seen from Martin's and Grant's responses, you certainly have the capacity to reach twentieth magnitude with a 10-inch aperture. Very good seeing can have a remarkable effect on going faint, provided that the focus is accurate. When carrying out a long time-series of a mover with the aim of tracking and stacking to go as deep as possible, the instrument might have to be refocused several times, especially during the first two or three hours of use (when the temperature is dropping), to ensure that the stars are pinpoints. It is often worth checking the turbulence in the upper atmosphere by consulting, for example, the 300 mbar level pressure chart forecast at:

http://www.wunderground.com/wundermap/

Select 'Model data'; click on the 'Tools' symbol; under 'Map type', select 300 mb; move the 'Forecast' slider to the time and date on which you intend to observe. The chart obtained is colour coded: anything purple indicates good or very good seeing, and anything green or yellow indicates poor seeing. There is no point in trying to go really faint if the weather and seeing are unfavourable despite a clear sky.

Eliot Hall

So ... the limiting magnitude is determined by seeing (turbulence) and transparency (particles, light pollution). Given perfect conditions, magnitude 20–22 may be possible, but magnitude 18–19 is possible with average conditions.

Focus and accurate tracking/guiding is critical for maximising the signal received. Unfiltering the camera will allow more light onto the sensor. (Will this not spread the light over more pixels, degrading the definition?)

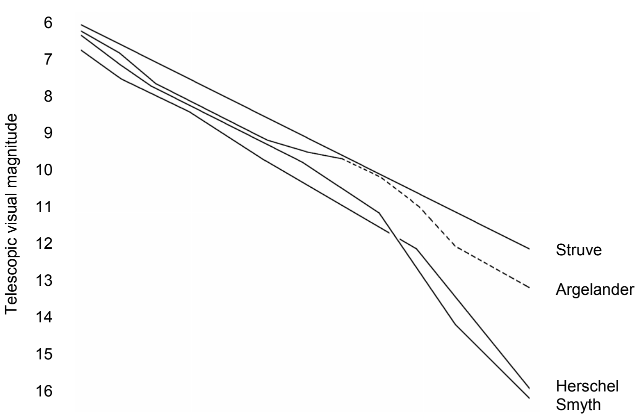
Using a larger aperture or a more sensitive camera will only decrease the time to reach the sky's limiting magnitude, but shorter exposures are useful for faster-moving objects.

Astrometrica will predict the path of the asteroid across the field of view and align the frames accordingly for stacking, thus improving the signal-to-noise ratio. I tried this on some other data I acquired a few days later, and found an asteroid – a case of reading the manual.

Visual limiting magnitudes

Bob Marriott

In the 1850s Norman Pogson established a mathematical formula for defining what was to become the standard magnitude scale. He defined a star of the first magnitude as being 100 times brighter than a star of the sixth magnitude. Thus, a first-magnitude star is about 2.512 times brighter than a second-magnitude star. The fifth root of 100 is known as 'Pogson's ratio': $100^{1/5}$ or $\sqrt[5]{100} \approx 2.511886...$ The formula defining the limiting magnitude (m) of an instrument is



$m = N + 5\log D$, where D is the aperture and N is a constant. This constant was defined by Pogson as 9.2, but others have assigned a different value, and the formula derives a limiting magnitude accurate to only one or even two magnitudes. Other factors influencing magnitude assessment include the colours of stars, sky brightness, magnification, focusing, the sensitivity of the eye, the physiological condition of the observer, and personal judgement.

The accompanying graph compares telescopic magnitude scales based on observations made during the 1820s–50s by F. G. W. Struve with the 9.5-inch f/17.7 Fraunhofer refractor at Dorpat, F. W. Argelander with the 3-inch f/8.4 refractor at Bonn, John Herschel with his 18-inch f/13.3 reflector, and W. H. Smyth with his 5.9-inch f/17.3 Tulley refractor. Up to the naked-eye limit their magnitudes are compatible, but fainter magnitudes are widely disparate. Argelander's observations for the *Bonner Durchmusterung*, first published in 1859, extended to only magnitude 9–10, while Herschel recorded objects of magnitude 20, indicating a scale extending beyond the modern accepted visual limit of his 18-inch reflector. Struve's scale is the best fit with the modern scale.

By 1850, numerous catalogues of stars and nebulae had been produced, but only twenty-two variable stars and thirteen asteroids were known. Recorded magnitudes were often personal, and Pogson's scale was not accepted widely and finally until the 1890s. Anyone researching early records of magnitudes of any object needs to be exceedingly careful in judging and accepting them.

For an extensive and authoritative study, see Bradley E. Schaefer, 'Telescopic limiting magnitudes', *Publications of the Astronomical Society of the Pacific*, 102 (1990), 212–29.

http://articles.adsabs.harvard.edu//full/1990PASP..102..212S/0000212.000.html