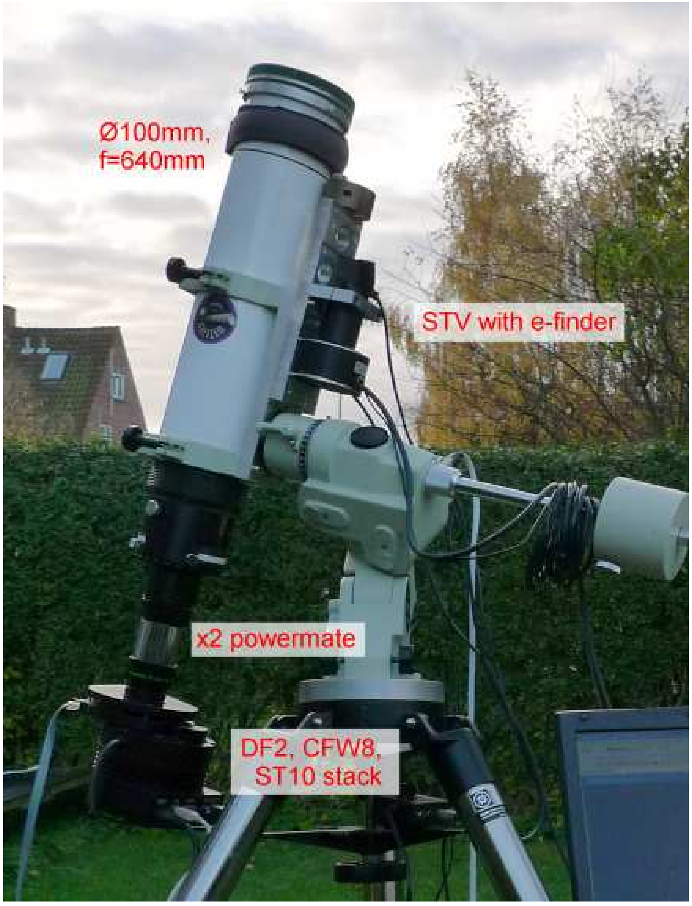
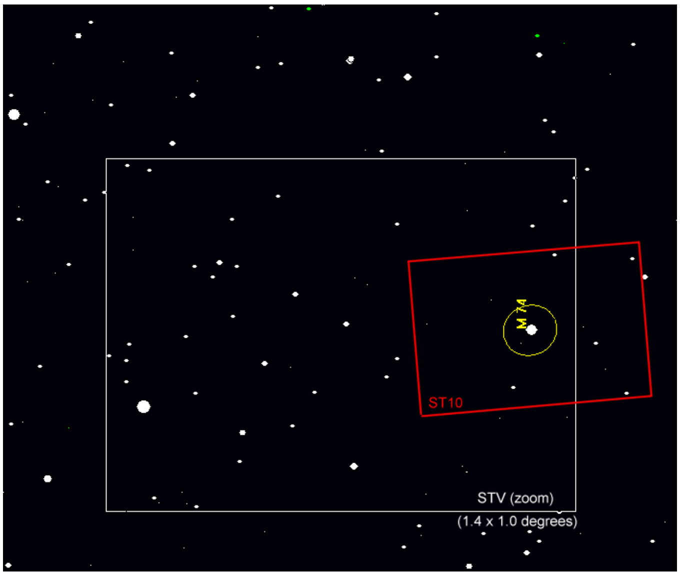
Introduction: I have long suspected that deep sky imaging with fast refractors is resolution limited by sampling effects rather than by seeing conditions. Take my setup as an example: 100mm objective with f=640mm and a ST10 camera yields 2.2 "/pixel which, for average seeing conditions of 4-5 arcseconds should be just fine according to the Nyquist sampling theorem. On typical images with this setup I get stellar FWHMs of 3.5pixels=8", which is worse than you would expect from seeing. Increasing the focal length by, say, a factor two would only lead to severe oversampling; i.e. an expected FWHM of ~7pixels, right? Wrong! Read more below.

Setup: Using a 2x powermate for deep sky imaging is usually not advisable since the exposure time increases by a factor of four to achieve the same signal. Patient people could ignore this, expect for the fact that autoguiding through such a system will be impractical, especially with narrow band filters.



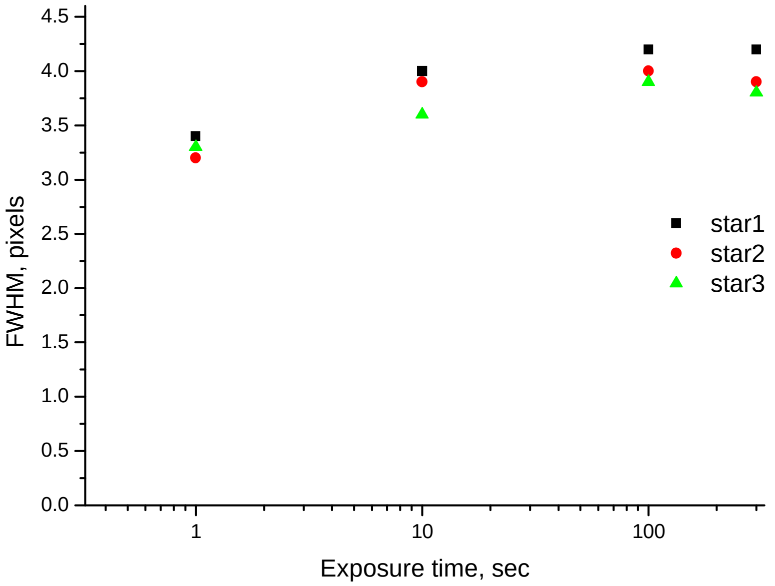
I therefore added an STV with the e-finder assembly to the setup for autoguiding. This has three advantages: 1) the slow f-ratio of the main OTA is avoided, 2) the narrowband filters are likewise, and 3) the main camera does not need to be rotated carefully to find a good guidestar. The complete setup is shown the the right.

Although this setup might work patience is still required, more precisely four times as much of it! Fortunately, I am a patient person and I don't really care if it takes four nights or one to get a good image. I care more about whether my images are limited by my observing conditions rather than my choice of equipment.



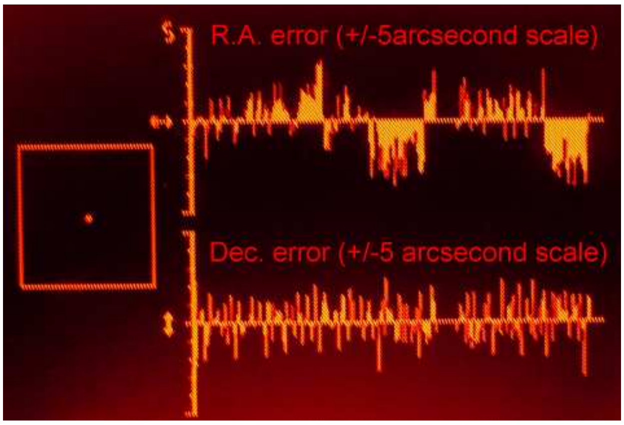
First night results: On my first night I fiddled around a lot trying to master the combination of setting circles, planetarium software, and two CCD camera fields of view to navigate the sky. To the right is shown the fields of view and how they overlap. The ST10 field can rotate freely to permit the best framing. For some reason there is an offset in pointing direction of the two cameras, but it doesn't matter much as long as you take the time to measure it once and for all.

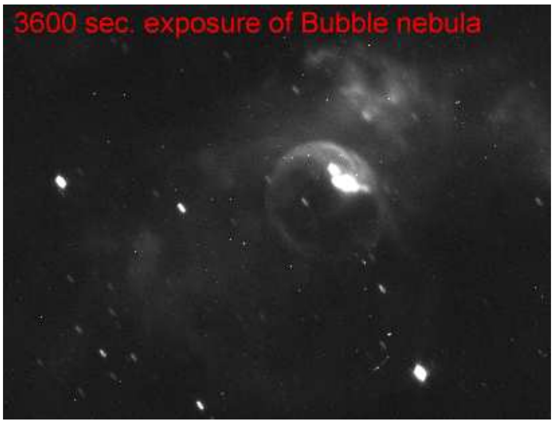
I finally managed to get some images of M74 through an IRreject filter while the STV was guiding. First I tried various exposure times to see how the tracking worked:



The stars appeared nice and round for all exposure times. The FWHM increased during the first minute, then levels off. Note that the FWHM values measured in pixels are similar to that seen when no powermate is used, i.e. I am getting roughly a factor two improvement in resolution when measured in arcseconds!

Current tracking problems: On later nights I noticed that the tracking performance was poor; both as seen on the STV tracking graphs and on the ST10 image:

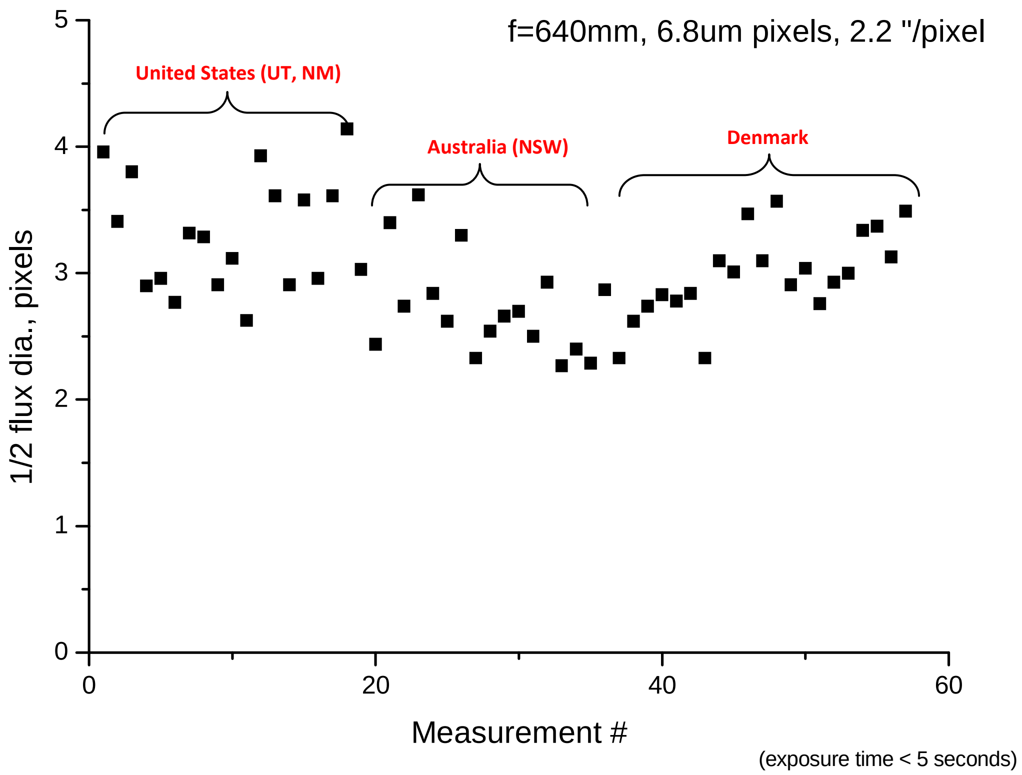




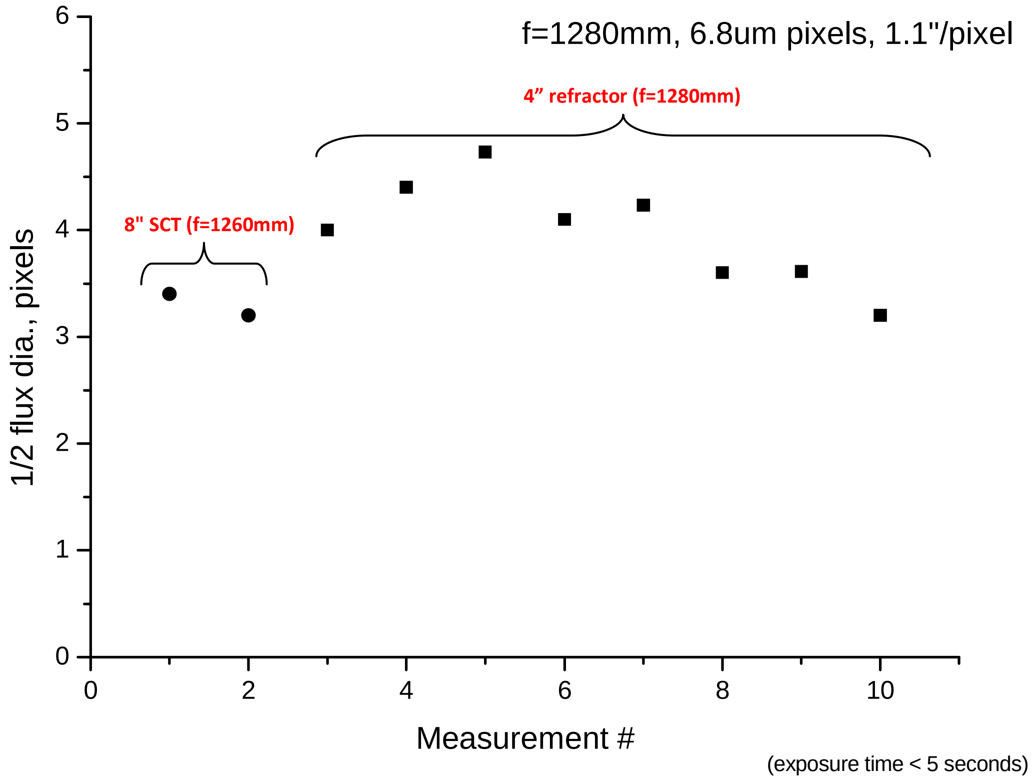
The stellar elongation present in the ST10 image corresponds to the equatorial direction which is also the axis displaying the greatest deviations on the STV tracking graphs. Currently, I have not solved this problem. Why didn't I notice it on the first night? I don't know. I believe it is caused by a combination of balance issues and imprecise polar alignment. I am baffled by this since I have use this setup – sans powermate and STV – for many years and not noticed such problems.

Measurements of stellar diameters:

The Nyquist sampling theorem is commonly quoted when stating that ideal pixel scale for deep sky imaging is half the stellar FWHM. This will ensure a maximal field of view, fastest detection capability and minimal loss of resolution. The image scale is given by (pixel size in microns)*206/(focal length in millimeters). For a seeing of 4-5" my old setup (f=640mm, 6.8 micron pixels ⇒ image scale =2.2"/pixel) should therefore be ideal. Increasing the focal length should not lead to any significant resolution improvment. Measurements of the stellar diameter using this setup are shown below. They span three continents and three years, thus sampling a wide range of local circumstances.

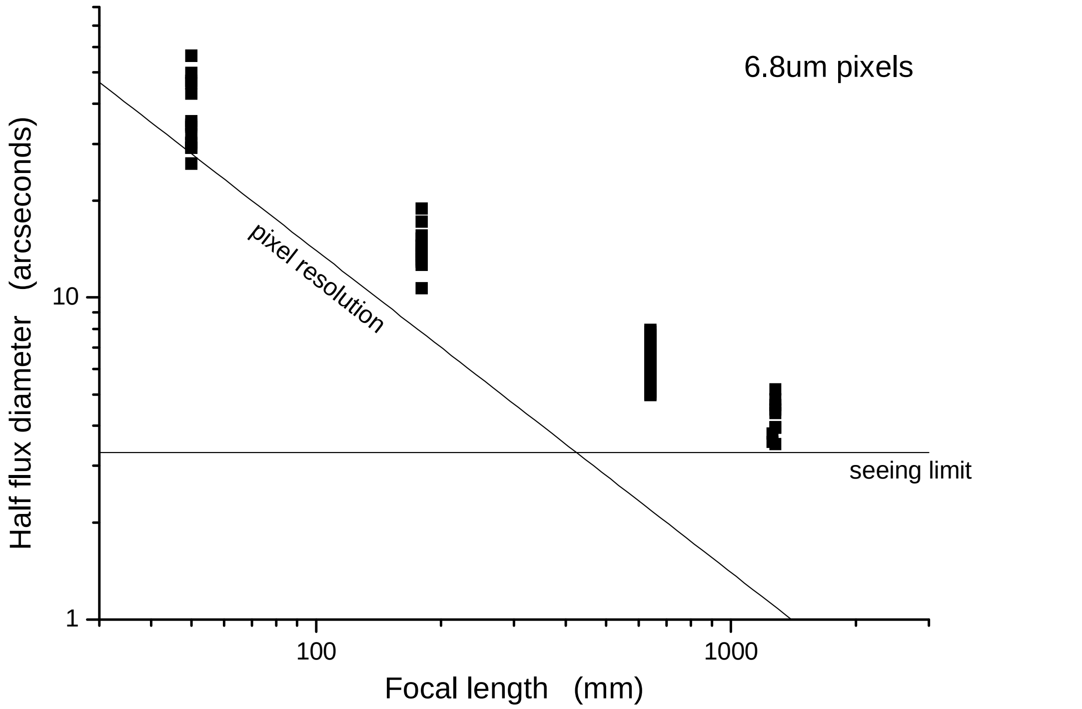


The median diameter is 2.9 pixels, corresponding to 6.4". All measurements were made with less than 5 seconds exposure time, hence the values cannot be influenced by tracking errors. It looks like I have nothing to gain from using a longer focal length for this particular camera. However, I had noticed from the work of others that bigger scopes 'always' seemed to produce a sharper image than mine. The fact that bigger scopes have proportionally larger optical resolution capability is irrelevant because deep sky images are usually limited by seeing. The only other factor I could think of was focal length. Bigger scopes usually have larger focal lengths. I therefore tried using a 2x powermate on my setup, yielding 1.1 "/pixel. Eight measurements are shown below, along with two made with a f=1260mm SCT. If I was actually sampling the seeing properly before the stellar diameter should now be ~6pixels – grossly oversampled. Instead I find that the stellar diameter averages 3.8 pixels = 4.2". This improvement – from 6.4" to 4.2" – is substantial and merits further investigation. Now I just need to get the tracking/balancing problems fixed!



Note: During this work I learned that measuring a stellar diameter using the FWHM value from a Gaussian fit can be subject to significant uncertainties from seeing and noise. A more robust measurement is the half flux diameter (http://www.cyanogen.com/help/maximdl/Half-Flux.htm) which gives very nearly the same value as FWHM for focussed star images.

Analysis of resolution vs. focal length: Inspired by the preliminary results above I went through all my autofocus images for various focal lengths. All data were aquired from Denmark with the ST10XE camera just after automatic focussing with a DF-2 and had exposure times less than 5 seconds. I have used four optical setups: 50mm f/2.8 Nikkor lens, 180mm f/4 Nikkor lens, 640mm f/6.4 objective and finally the same objective with a 2x powermate yielding 1280mm f/13.



Two lines are plotted as well: the seeing limit (chosen arbitrarily to be 3.3") and the pixel scale vs. focal length. The former represents the ultimate resolution limit while the latter represents the resolution limit in the extremely undersampled regime. The data clearly shows how a transition occurs between these two regimes and puts into a broader context my initial powermate vs. no-powermate investigation. The data also hints that going beyond f=1260mm (1.1 "/pixel in my case) may yield slight resolution improvements, however limits in tracking accuracy will quicly prevent much from being gained in practice for long exposures.

I would love to get more data from other users to plot! It doesn't matter what setup you are using as long as I am told what the focal length and pixel size are. Ideally, the ½ flux diameter measurement method should be used (I use CCDware's CCDInspector, available for free evaluation at http://www.ccdware.com/products/ccdinspector/). Exposure times should be kept short so that tracking errors are avoided. If you provide raw images for download I will do the measurements and plot your data.

Note: I am not the first person to state that seeing limited imaging requires ~1"/pixel image scale, see for instance this great online presentation: http://www.ewellobservatory.com/bestpractices/index.cfm by Richard A. Bennion.

Any and all comments are very welcome!! Mikael Svalgaard, www.leif.org/mikael