Astrophotography and Digital Imaging: Matching Camera to Telescope

by Chris Patel

Last month I covered camera types. This month I will cover how to match the scope to the camera or vice-a-versa. This section seems technical but it is important to understand if you're going to be successful in getting the results you expect. For any combination of optical and camera system, you can establish the system's image scale, which is expressed as "arc seconds per pixel". The goal is to optimize your combination to yield the best balance between resolution and sensitivity. The current school of thought is that, for most imagers, an image scale of 1 to 3 pixels per arc second is desirable, based on seeing conditions. I will give you the formula, define some of the terms—like pixel size, resolution, arc second, seeing, and sampling—and point you to a fantastic free calculator which will do the grunt work for you and show the visual results in a field-of-view box to help you achieve the goal!

The formula:

Sampling in arc seconds = (206.265 / focal length in mm)*(pixel size in microns) - OR -

Sampling in arc seconds = (8.12 / focal length in inches)*(pixel size in microns)

The Downloadable Calculator:

I encourage you to download the CCD Calculator from Ron Wodaski's "The New CCD Astronomy" site. The web address is:
http://www.newastro.com/downloads/ccdcalc/ccdcalcfull.exe

The calculator has built in data for a variety of scopes and cameras, solves for image scale in arc seconds per pixel and also allows you to input a variety of parameters so you can see how focal ratio, aperture, adding Barlow's or reducers, will affect image scale. Do this now!

Pixel - A CCD consists of a group of pixels arranged into an "array." Each pixel can be thought of as a well that captures photons and reads them out into a digital image. Take my camera's chip, a Kodak KAI-2001M as an example. The chip is rectangular as is common with most chips, but some can be square. It is 11.8MM x 8.9MM in size; draw that on a piece of paper and compare that to a full frame from a 35MM film which is 34MM x 22.7MM. The chip has pixels that are 7.4 by 7.4 microns square. (To give you an idea of how big a micron is, a grain of table salt is 70 micron!) These pixels are arrayed in a series that is 1600 x 1200 or 1600 pixels in a row with 1200 rows. This yields 1,920,000 pixels, so it is considered a 2 million pixel chip or 2 mega-pixels.

Resolution - in a simple way can be defined as a measure of how close together two identical stars could be and you could still see that there are two stars. A telescope with 11 arc seconds resolution would be able to distinguish equal binary stars 11 arc seconds apart. A telescope with 2.3 arc second resolution would be able to distinguish stars only 2.3 arc seconds apart.

Arc second is a unit of angular measurement. There are 360 degrees in a circle, and 3600 arc seconds in a degree. The full moon is 1800 arc seconds across. So an arc second itself is a fairly small measure that lends itself well as a measure of how much sky a pixel can see.

Seeing is a term that we use to quantify the turbulence in the atmosphere and how it affects our viewing. The stars appear to twinkle because of this turbulence. In conditions of bad seeing, the stars twinkle strongly, and the images that you take with your telescope are blurry. In conditions of good seeing, the stars appear more stable, and you can take very sharp images. Seeing is also defined in arc seconds. Typically, the atmosphere is what limits telescopes. Even on clear and steady nights, the atmosphere moves around enough that the resolution of a telescope is seldom more than about 2 or 3 arc seconds. In the rare extremely good seeing conditions, seeing is 0.5 arc seconds, indicating that a telescope whose resolution limit was at least 0.5 arc seconds could actually be used to see stars that close together under those sky conditions.

Sampling is basically how many pixels are used to produce details. We know a CCD image is made up of tiny square-shaped pixels and each pixel will have a brightness value based on the number of photons that fill it that corresponds to a shade of gray. Because the pixels are square, the edges of features in the image will have a stair-step appearance. The more pixels and shades of gray that are used, the smoother the edges will be. If your image has blocky or square stars, you are under-sampled and there aren't enough pixels being used for each star's image. When you are over-sampled, you loose sensitivity because light is spread out over several pixels. Your CCD's ability to record faint stars is reduced and this reduction of light forces you to take longer exposures. Over sampled images may have very nice round stars but the image may take 16 times the exposure of a normal image to get this effect due to reduced light per pixel! With the longer exposures you also risk recording atmosphere fluctuations, similar to blurring when a regular camera is moved.

The Skinny! - Remember we said we are trying to get a combination which gets us an image scale of 1 to 3 arc seconds per pixel. If the combination is below one or over three, you could end up in a situation where most of your images are going to be under or over sampled. You have control over focal length and pixel size. But you do not have as much control over the size of the star image, which depends on the seeing conditions of the observing site. A general rule of thumb to avoid under sampling is to divide your seeing in half and choose a pixel size that provides that amount of sky coverage. For example, if your typical seeing conditions are generally 4 arc seconds, you should try for an image scale of 2 arc seconds per pixel. If the seeing conditions are often 1 arc second, you'll want a pixel size that yields 0.5 arc seconds per pixel. Maybe I am unlucky because I think I have seen a night of 1 arc second seeing just once in my life!

Now if you have downloaded the calculator, its time to play! What I like about the calculator is that it shows you a field of view based on the variables with well known imaging targets. For instance, you can select the Orion Nebula and see how different telescope and camera combinations will frame it. Let's take my camera and one of my scopes to see what happens on the nebula. Select the ST-2000 as the camera and Takahashi TOA 130 at f7.7 as the scope. Notice that the image scale is 1.52 and notice how it will not capture the entire nebula. So let's insert a reducer which makes the focal length 754mm, just change the focal length to 754 and hit the recalculate button next to the focal length field. Notice how the field of view changed and also the image scale jumped to 2.02 arc seconds per pixel. I am still in the recommended image scale range for the scope and camera combination but I really want to image the entire nebula and possibly the Running Man next to it! What should I do?

Well thank god I have another scope, my Takahashi FS-78. Pull up that scope with the same camera and let's see what the calculator tells us. Wow, image scale jumps to 2.41 and the field is almost wide enough to get the whole nebula and if I use the settings menu and select rotate FOV 90 degrees I can probably get the running man…but I would still like to get more! Let's pop in a reducer which changes the focal length to 460mm. Input 460 in the focal length box and hit recalculate. What happens? Looks like the field of view is good and the image scale is 3.31, a bit over sampled but my stars should look good and if I take longer exposures, the result should be fine. Notice a couple of things: for a given pixel size, decreasing the focal length *increases* the image scale; and at any given aperture, increasing the focal length *decreases* the image scale.

I now want to image Saturn with my TOA 130, because it looks so good in the scope naked eye. Go to the calculator and select Saturn as the object with my camera and scope. The image scale is 1.52 but look at the field of view. Do you think I will have any detail in the image when I am done? No, just a speck on the screen! Now let's put in a 5X power mate, in the Barlow/reducer field change the 1 to a 5 and what happens? The field of view drops but it should frame the planet nicely and the image scale is now .3. If it is a night of the best seeing I have ever encountered in my life I should have a nice shot of Saturn. But I can't wait for that night so I sold that power mate! Now if I live to image planets, I sell everything and get an 8 inch SC with a ST-9 camera. Plug that combo in on Saturn and what happens? Wow, nice field of view and look - the image scale is 2.06 which will allow me to image at f10 most nights. This seems to be a great combo for Saturn, but why? For a clue look at the pixel size of the ST-9: they are huge compared to my ST-2000, 20 microns versus 7.4 microns. Change the target back to the Orion nebula and what happens in the field of view? Looks like you can get the bird beak as I call it but you are never going to get the entire nebula even if you reduce it to f5.

If you have a long focal length instrument, go for a camera with large pixels; for shorter focal lengths, go smaller pixels. Want more field of view with a given scope? Go for a larger chip, change my ST-2000 and TOA 130 combo to a SBIG Research Grade 4020M and your field of view grows due to chip size while pixel size and image scale remain the same.

This is a lot of information, but it is very important to understand if you want to select a good camera and scope combo. The thing to avoid is a camera and scope combo that's grossly under or over sampled — not to say they do not have uses but, on most nights, you will not be able to get the results you seek.

Play with the calculator and get Ron Wodaski's book if you're really interested in coming over to the dark side of the force!

So how did the Orion image turn out for me? Here it is -

***

It's our club, let's continue to make it grow and diversify…Chris Patel