# Of Pixel Size & Focal Reducers

### By Dennis di Cicco

THE SCENE PLAYED with the predictability of a well-rehearsed script. On a half dozen occasions last summer visitors stopped by while I was testing two high-end digital cameras. Each knew about the Kodak KAF-1600 and KAF-1000 CCDs in these cameras, but none had seen them firsthand. Handing each person the first camera, I would click the computer's mouse to snap open the shutter and reveal the Chiclet-size KAF-1600. With almost 20 times the imaging area of chips in early cameras marketed to amateur astronomers, this CCD impressed everyone.

Nevertheless, when the shutter clicked open on the KAF-1000 camera, jaws dropped. "Now *that's* a CCD!" exclaimed one guest. Measuring 1 inch square, this chip offers only slightly less imaging area than a frame of 35-millimeter film. While everyone was predictably fascinated by this expensive bit of silicon real estate, blank stares followed my comment that, at a given resolution, I could capture more sky with the KAF-1600 despite its substantially smaller size.

How can this be? Even a quick glance reveals the KAF-1000 to be considerably larger — 4.65 times, to be precise — than the KAF-1600. The key to this paradox, however, was my qualifying statement that *at a given resolution* the KAF-1600 covers more sky.

Most of us photographers never think much about resolution. Today's emulsions have relatively fine grain, and we use the same film with telescopes big and small. As such, the larger the piece of film, the more sky will be captured up to the point where optical or mechanical considerations limit the field of view.

CCDs, however, are a different story. Pixels — the individual, light-sensitive picture elements that make up the checkerboard array of a chip's imaging area — come in many sizes. The detectors found in today's popular cameras have square or slightly rectangular pixels ranging from about 7 to almost 30 microns (thousandths of a millimeter) across. The best results occur when a pixel's size is matched to a telescope's resolution under a given set of observing conditions. For example, conventional wisdom suggests that the astronomical seeing conditions experienced by a typical backyard observer will produce excellent deep-sky images with pixels that cover about 2 arcseconds (2") of sky.

With this criterion established, the paradox is quickly resolved. If you adopt a given pixel scale such as 2" for deep-sky imaging, then you need only remember that the more pixels a chip has the more sky it will cover regardless of the chip's physical size.

Consider the CCDs mentioned above. The KAF-1000 has 1 million 24-micron pixels arranged in an array measuring 1,024 pixels on a side. At 2" per pixel, the

**Even a glance reveals the dramatic difference in physical size between the Kodak KAF-1600 (left) and KAF-1000 chips. But, as explained in the text, at a given resolution the KAF-1600's 1.6 million pixels can cover 60 percent more sky despite having only about one-fifth the area of the KAF-1000.**

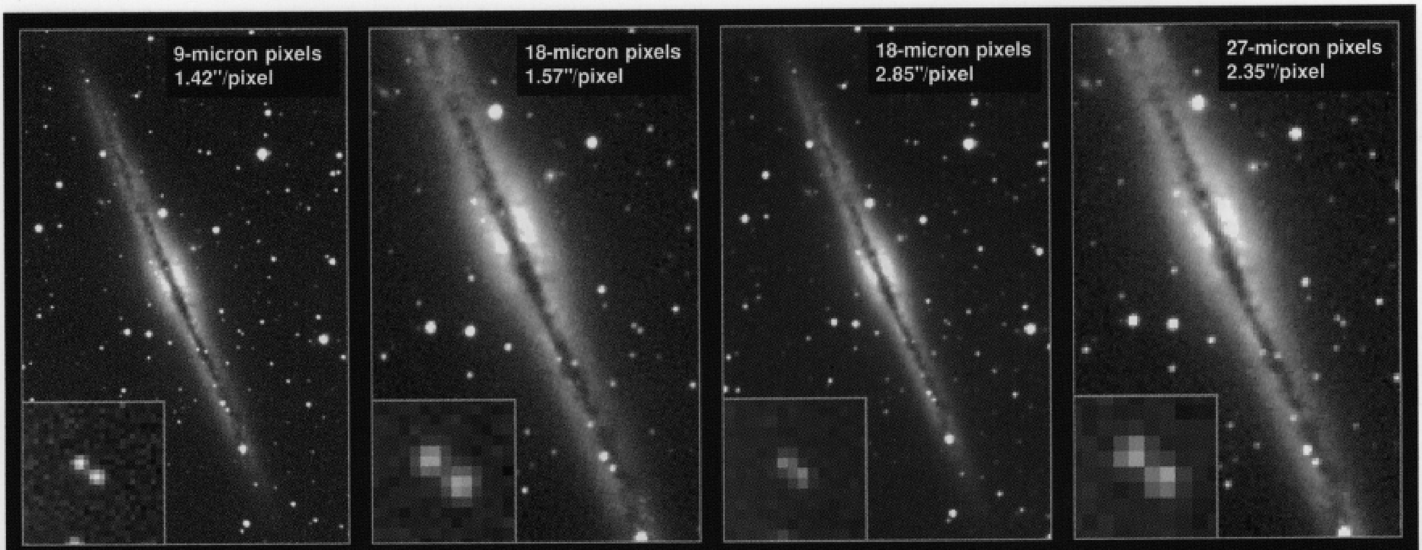


**Image scale, not pixel size, controls the resolution of digital images. To illustrate this point, the author made these pairs of 3-minute exposures of the edge-on spiral galaxy NGC 981 in Andromeda with a Meade 16-inch LX200 Schmidt-Cassegrain telescope and SBIG ST-7 camera equipped with a KAF-0400 CCD. By changing focal reducers and binning pixels, roughly similar pixel scales were obtained at focal lengths of 1,303 and 2,365 millimeters (f/3.21 and f/5.85, respectively). Note that the resolution at a given scale is independent of pixel size. The shorter focal length covered about four times more sky than the longer one. *Insets:* A 5× enlargement of the double star to the lower right (southwest) of the galaxy's nucleus. The magnitude-16½ components are separated by 5.8".**

detector covers a field 2,048" (about 34') square. The KAF-1600, on the other hand, has 1.6 million 9-micron pixels assembled in a 1,552-by-1,032-pixel array. At the same scale, this chip covers a field measuring 3,104" by 2,064" (about 52' by 34'). The KAF-1600 has 60 percent more pixels than the KAF-1000 and should therefore cover 60 percent more sky.

There is a catch, however. Obtaining the same 2"-per-pixel scale for these detectors necessitates very different effective focal lengths. Indeed, the KAF-1000's larger pixels require an effective focal length of 2,475 mm (about 97 inches), while the smaller KAF-1600 pixels need only 928 mm (about 37 inches). The nomogram on this page makes simple work of determining the relationships between pixel size, focal length, and a pixel's image scale.

## PIXEL BINNING

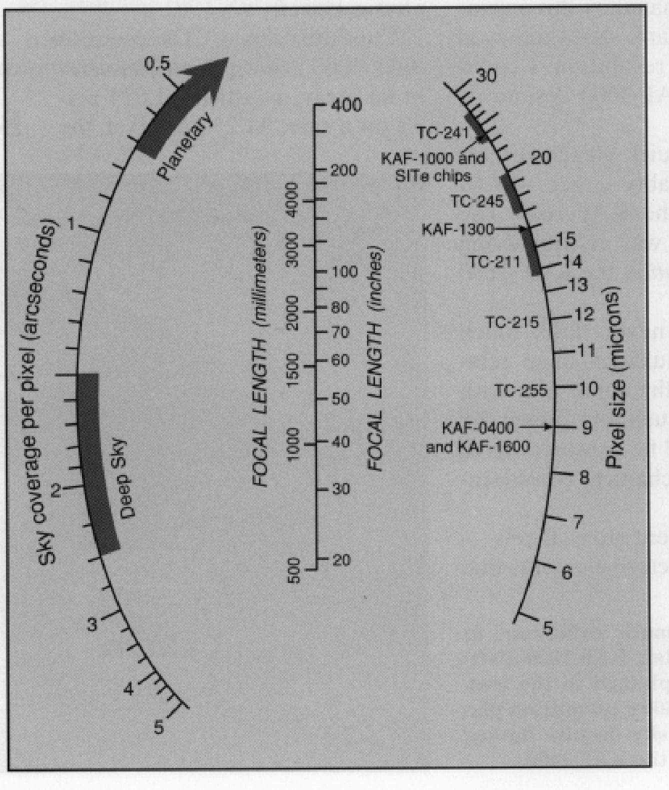
You might think that these parameters would be fixed for a given telescope and CCD camera. However, it is usually possible to vary both the focal length and pixel size within some limits.

Most cameras sold today offer what are called binning modes — the ability to electronically combine the signal collected by several adjacent pixels such that it appears to come from a single, larger pixel. There are several advantages of binning, including faster image readout, smaller file sizes, and greater CCD sensitivity for a given optical system. This technique is often used with long-focal-length systems, which deliver generous images scales. Unfortunately, binning also reduces a CCD's effective number of pixels.

Consider the example of 3×3 binning with the KAF-1600. The resulting 27-micron-square pixels are similar in size to those of the KAF-1000, and both chips will provide similar resolution when coupled to the same telescope. This binning, however, reduces the KAF-1600's effective number of pixels from 1.6 million to about 178,000, which is roughly one-fifth the number available with the KAF-1000 chip. In this situation the sky coverage of the KAF-1600 will be about one-fifth that of the KAF-1000, which is exactly what common sense tells us. When placed on the same telescope, the KAF-1000 covers about five times more sky than the KAF-1600 since physically it has about five times more area. Changing the binning mode of the KAF-1600 will change the resolution but not the total sky coverage.

If we want the greatest sky coverage from a given CCD, we should operate the chip in its full-resolution (unbinned)

**Roger W. Sinnott developed this nomogram to show the relationship between image scale, effective focal length, and pixel size. A straight line connecting any two values passes through the third. For example, in order to have a 9-micron pixel cover 1½" of sky requires a focal length of about 50 inches. While experience ultimately dictates the best image scale for given conditions, conventional wisdom suggests that scales of 1½" to 2" are good for general deep-sky imaging, while lunar and planetary work can benefit from scales as small as ½" with apertures large enough to allow short exposures that "freeze" the astronomical seeing.**



mode and select a focal length to produce the desired image scale. As mentioned earlier, for 9-micron pixels, a scale of 2" requires an effective focal length of about 37 inches. Traditionally such short focal lengths have been the domain of small apertures. While CCDs can deliver remarkably big performance with small telescopes, it's still desirable to use large apertures for deep-sky imaging. Besides, you probably want to work with your existing telescope. So from a practical standpoint the question becomes, what can be done to adjust its focal length? Fortunately, you can do a lot.

**Focal reducers come in all shapes and sizes. The author feels they are one of the most important accessories for digital imaging since they are ideal for adjusting a telescope's effective focal length to a CCD's pixel size.**

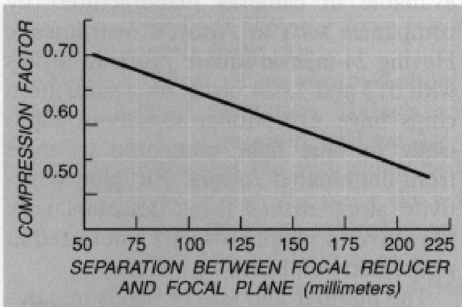
## FOCAL REDUCERS

During the past 20 years numerous focal reducers have appeared on the market. Most observers think of these in terms of decreasing a telescope's f/number to make it "faster" photographically. But, as the name implies, these accessories work by reducing a telescope's effective focal length. They are excellent for helping match image scale and pixel size. This is especially useful for Schmidt-Cassegrain telescopes.

In the past the challenge was to design a system with high-quality images across a large field. But since CCDs are relatively small this tolerance can be relaxed, and many focal reducers suitable for digital imaging can be made from simple achromatic lenses such as those scavenged from a old pair of binoculars. (An excellent source of information about the design and function of focal reducers is an article by the late Alan Gee on page 367 of this magazine's April 1984 issue.)

Today, however, designing a custom focal reducer is necessary only in unusual situations. Commercial units, particularly those for Schmidt-Cassegrain telescopes, offer many options — especially when the resulting focal length is tweaked by adjusting the spacing between the reducer and CCD.

Popular f/6.3 reducers sold by Celestron and Meade for their f/10 Schmidt-Cassegrains are designed to be used with a 105-mm separation between the back surface of the reducer and the detector (be it film, CCD, or whatever). As the accompanying graph indicates, altering this spacing changes the compression factor — great for fine-tuning a CCD system. Increasing the separation increases the amount of compression and thus reduces the effective focal length. Ideally we could increase the separation enough to accommodate small pixels. In practice, however, either image quality or, more likely, mechanical restrictions imposed by the telescope's focusing system will limit the amount of compression that can be obtained.



**The compression factor of popular focal reducers can be varied somewhat by adjusting the spacing between the reducer's back mounting surface and the CCD. The author derived this graph using Celestron and Meade f/6.3 reducers, which are designed for a spacing of 105 mm.**

**SCHMIDT-CASSEGRAIN FOCAL LENGTHS**

| Instrument | Focal length (millimeters) | | |
|---|---|---|---|
| | Nominal | f/3.3 reducer | f/6.3 reducer |
| 8" f/10 | 2,032 | 670 | 1,050–1,400 |
| 8" f/6.3 | 1,280 | — | 800 |
| 9¼ f/10 | 2,350 | 775 | 1,200–1,650 |
| 10" f/10 | 2,540 | 838 | 1,350–1,800 |
| 10" f/6.3 | 1,600 | — | 1000 |
| 11" f/10 | 2,800 | 924 | 1,500–1,950 |
| 12" f/10 | 3,050 | 1,005 | 1,600–2,100 |
| 14" f/11 | 3,910 | 1,290 | 2,050–2,700 |
| 16" f/10 | 4,060 | 1,340 | 2,100–2,850 |

There is one notable exception. Optec's MAXfield unit is specifically designed to compress the field of an f/10 Schmidt-Cassegrain to a remarkable f/3.3 for CCD work. The spacing between the reducer and chip is critical, however, and changing it by even a millimeter degrades images. Also, the reducer has a maximum usable field about 11 mm across, too small for large chips.

There are also a few caveats for observers planning to use focal reducers with Meade's 8- and 10-inch f/6.3 Schmidt-Cassegrain telescopes. I have found that the MAXfield focal reducer, while in theory yielding an f/2 system when attached to these instruments, will not give satisfactory star images — it works only with f/10 telescopes. The f/6.3 focal reducers, on the other hand, will compress the f/6.3 telescopes to about f/4 with very acceptable results. But experience suggests that changing the spacing to obtain other compression ratios is not recommended and is the reason for the single focal-length entries in the table at left.

Of the many comments I've heard about focal reducers, no one has ever

**Small telescopes can deliver big performance when properly coupled to today's CCDs with small pixels. This 10-minute exposure of the spiral galaxy NGC 2903 in Leo was made with a Celestron 5-inch Schmidt-Cassegrain and a focal reducer, yielding a effective focal length of 898 mm (about 35 inches). The camera's 9-micron pixels each covered 2.1" of sky, and the field is nearly $^1/_2$° wide with north up.**

mentioned their cost-saving benefit. Consider this example. I do much of my deep-sky imaging with a Meade 16-inch LX200 Schmidt-Cassegrain. The telescope's nominal f/10 (4,000-mm) focal length is long even for large pixels. Adding a f/6.3 focal reducer drops the effective focal length to about 2,500 mm — a good match for the 18-micron pixels available with a KAF-1600 chip binned 2×2. Such a setup would yield an image scale of 1.49" per pixel and a field of view measuring roughly 19 by 13 arcminutes.

By switching to the f/3.3 focal reducer, however, I can get nearly identical sky coverage and imaging performance from an unbinned KAF-0400 detector. This chip has the KAF-1600's same 9-micron pixels but is only one-quarter as large, with a 768-by-512-pixel array. What is really attractive about this arrangement, however, is that cameras equipped with the smaller chip cost about half as much as those with the KAF-1600, amounting to a savings of $2,500 to $3,000 depending on make and model! Similar results are possible with today's 12- and 14-inch Schmidt-Cassegrain telescopes.

**SPECIFICATIONS FOR POPULAR CCDs**

| Manufacturer | CCD | Imaging area (millimeters) | Array format (pixels) | Pixel size (microns) | Total pixels |
|---|---|---|---|---|---|
| Kodak | KAF-0400 | 6.9×4.6 | 768×512 | 9×9 | 390,000 |
| Kodak | KAF-1000 | 24.6×24.6 | 1,024×1,024 | 24×24 | 1,000,000 |
| Kodak | KAF-1300 | 20.5×16.4 | 1,280×1,024 | 16×16 | 1,310,000 |
| Kodak | KAF-1600 | 14.0×9.3 | 1,552×1,032 | 9×9 | 1,600,000 |
| Philips | FT12 | 7.7×7.7 | 512×512 | 15×15 | 260,000 |
| SITe | SI502A | 12.3×12.3 | 512×512 | 24×24 | 260,000 |
| SITe | SI003A | 24.6×24.6 | 1,024×1,024 | 24×24 | 1,000,000 |
| Sony | ICX027BLA* | 6.4×4.3 | 500×256 | 12.7×16.6 | 130,000 |
| Sony | ICX055AL* | 4.9×3.6 | 500×256 | 9.8×12.6 | 145,000 |
| Texas Instruments | TC-211 | 2.5×2.5 | 192×165 | 13.75×16 | 32,000 |
| Texas Instruments | TC-215 | 12.3×12.3 | 1,024×1,024 | 12×12 | 1,000,000 |
| Texas Instruments | TC-241* | 8.6×6.5 | 375×242 | 23×27 | 91,000 |
| Texas Instruments | TC-245* | 6.4×4.8 | 378×242 | 17×19.75 | 91,000 |
| Texas Instruments | TC-255 | 3.2×2.4 | 320×240 | 10×10 | 77,000 |

*An asterisk indicates the size and number of pixels as generally configured for astronomical use, since these chips actually have smaller, highly rectangular pixels originally intended for video applications.

## MORE THOUGHTS

The previous discussion only highlights ways to maximize the field of view for deep-sky imaging with today's popular CCDs. There are many other considerations when it comes to matching telescopes and detectors. First, nowhere is it chiseled into stone that you must have an image scale of 2" per pixel. Anyone doing lunar and planetary imaging will get superior results with scales of $^1/_2$" or less per pixel. Even for deep-sky imaging, any site with good seeing will benefit from scales of less than 2". Some image-processing techniques, especially those involving resolution-enhancing algorithms like maximum-entropy deconvolution, work better with images that have large image scales (so-called oversampled images).

Conversely, excellent deep-sky imaging has also been obtained with pixel scales of 4" or more, especially in the case of large, bright objects. Indeed, many stunning images are produced with conventional camera lenses attached to CCDs. The resulting image scales (tens or even hundreds of arcseconds per pixel) may not yield the best-looking stars, but they can render remarkable views of huge nebulae.

Another consideration is that some desirable features are found only on large-pixel chips. Take, for example, the back-illuminated SITe CCDs that are currently available in cameras manufactured by companies such as Apogee Instruments. Having 24-micron-square pixels in arrays with 512 and 1,024 pixels on a side, these chips have exceptional sensitivity, especially to blue light, compared to their front-illuminated cousins. The blue sensitivity alone makes these detectors very attractive to people who are interested in photometry and tricolor imaging.

The number and size of pixels in a detector are only two considerations when you are planning the purchase of a CCD camera. In the coming months we'll look at other important issues involved with getting the best performance from today's state-of-the art digital-imaging equipment.