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Evaluation of the Nikon Coolscan 9000 ED Film Scanner for Astronomical Research

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Abstract. Photographic glass plates can be digitized using scanners designed primarily for photographic film. The relatively inexpensive Nikon Coolscan 9000 ED consumer-level medium-format film scanner was found to have better than 1 μm positional accuracy along its translational axis, and a near linear response for a density range of over 3.0. With its ability to completely digitize a 57 x 84 mm region at 4000 dpi (6.35 μm/pixel) in just 3 minutes, this scanner appears to be a viable substitute for our ailing PDS 1010A microdensitometer and should be of interest to others with plate materials no larger than 190 x 57 mm.

1 Introduction

As pointed out in the survey by Robbins & Osborn (see Chapter III), over two million astronomical photographic images and spectra gathered in North America during the past 120 years remain in storage at dozens of observatories and universities. Though much of this material has been studied over the years for its intended purposes, the application of new analysis techniques and new understandings about astronomical phenomena has shown that there is still more that can be discovered using these plates and films. They form a valuable record of events extending back over one hundred years that needs to be preserved and made accessible to the current research community.

The plate collection from the David Dunlap Observatory (DDO) and the University of Toronto Southern Observatory (UTSO) contains over 65,000 glass plates (see Figure 1). During the past 75 years, a steady progression of technological advances has improved the quality and ease with which this photographic material was measured and analyzed. The last major advances at the DDO were the acquisition of a Perkin & Elmers PDS 1010A microdensitometer in 1975 and a major upgrade to its electronics and computer interface in the 1990s. This machine has been used to scan both spectroscopic and direct images of the sky in all the various plate formats the Observatory has generated and has also measured externally generated plates up to a maximum size of 10 x 10 inches. The company that manufactured the PDS no longer exists, and maintaining and repairing this venerable machine is proving both difficult and expensive. Consideration has been given to replacing the PDS with a more recently manufactured research-grade scanner, but the cost of these machines is considerable. Growing out of an initiative begun in 2007 by the author to accurately and quickly digitize the 10,000 modest-sized (to 1-5/8 x 4 inch) MK spectroscopic plates of R.F. Garrison, it was soon realized that the relatively inexpensive film scanner chosen for that project could prove valuable for digitizing the full DDO-UTSO plate collection.

Figure 1. Sample of the various plate formats found within the DDO and UTSO plate collection.

The photographic process has now been almost completely replaced by digital imaging technology. Most photographic film manufacturers have either greatly scaled back the number of emulsions they provide or have completely left the marketplace. Similarly, the number of companies providing professional-quality film scanners has significantly diminished over the last few years, and we are likely going to see the remaining manufacturers exchange some of the current precision and flexibility of top-end units for greater convenience and affordability as professionals and advanced amateurs move completely to digital photography. It is the author's opinion that modestly priced ($500 – $3000) professional-quality film scanners may have now reached their pinnacle in terms of performance and value, and will soon disappear from the marketplace. Therefore, now may be the pivotal moment to identify potentially suitable scanners, to critically evaluate these for their ability to do science-grade digitization of astronomical photographic plates and to make a purchase before market pressures cause them to disappear altogether.

Herein, we report our initial assessment of the relatively inexpensive ($1800 US) Nikon CoolScan 9000 ED film scanner. Intended by its manufacturer to scan medium-format (6 cm wide) negatives, 35-mm format negatives and slides and glass microscope slides, this unit was found able to completely and accurately measure astronomical glass plates dimensioned up to 2-1/4 x 7 inches (6 x 18 cm) at a fixed resolution of 4000 dpi (6.35 μm/pixel).

2 The Photographic Process

A discussion of underlying theory for the photographic process is given by Mees (1942) and an overview of the photographic process as it pertained to astronomy is given by Hoag & Miller (1969). The measurement of incident light via the photographic process differs substantially from the way it is measured using modern linear-response two-dimensional electronic light detectors like Charge-Coupled Devices (CCDs). The light detector in most photographic plates and films designed for astronomy consists of a thin "emulsion" of gelatin holding many micron-size light-sensitive crystals of silver halide (AgBr+AgI) in suspension. Without exposure to light, most of the crystals will remain unchanged when the emulsion is immersed in an aqueous solution of some suitable chemical developing agent. But when the individual crystals are struck by as few as a few photons of light, each transparent crystal will react with the developer to form an opaque clump of metallic silver threads. Note that when a crystal in the emulsion is rendered developable by having absorbed the minimum number of photons, the whole crystal will be converted into metallic silver. That is, either the whole crystal will be converted or none of the crystal will be converted.

The manufacture's choice (mixture) of halide crystal size, shape and composition in the emulsion plus silver halide's inherent response threshold gives a film/plate its inherent detection and recording characteristics. Using larger crystals in an emulsion allows each crystal to sample a larger amount of the incident flux and so increases the film's light-sensitivity; but this comes at the expense of lowering the film's physical resolution and lowering the number of silver clumps per unit area that will represent the incident flux, limiting the film's maximum signal-to-noise (S/N) ratio and dynamic range. But also note that the crystals are distributed within a 3-dimensional region, generally separated from each other within any one plane but with many planes of randomly distributed crystals within the thickness of the film to provide a 100% fill-factor when seen in projection. This improves the dynamic range and signal-to-noise ratio by increasing the number of quantized (binary) light-sensing and recording units within the emulsion.

The quantized behavior of the crystals in a photographic emulsion with respect to both exposure and recording of incident light is what distinguishes the photographic process from the linear electronic detectors of today. During an exposure with film, each successive photon in an incident beam of light is less likely to strike an unexposed crystal within the emulsion and be recorded, giving rise to the photographic process' logarithmic response to increasing levels of illumination in terms of the opacity of the emulsion after it has been developed. And although the size of the individual crystals ultimately sets the resolution limit for an emulsion, one generally must expose and later measure the processed film at a substantially lower resolution to sample regions of the emulsion large enough to contain many of the individual light-sensing and recording units (i.e., the crystals and silver clumps) in order to accurately describe the profile and intensity of individual stars and spectral lines.

3 Scanner Requirements

In general, images on glass plates can be successfully scanned using a *film* scanner, including scanners that transport the film using a tray. However, there are several requirements if the scanned images are to be used for scientific research.

For flatbed-style scanners that have their optics and detector sealed below a top window, one needs to arrange that the emulsion of the plate is located at the same distance above the window as required when scanning a sheet of film. Scanners designed primarily for scanning paper documents may require that the image plane be directly on the glass window, but this should be avoided to protect the emulsion.[1] One way to assess if proper focus is achieved is to place two pieces of equal-thickness shim material along only one edge of a plate so that the opposite ends are above and below the mid-point. The plate is then scanned and the scanned image carefully examined to see where the image grain is in best focus. A rescan of the plate with a single thickness of shim material all around is then used to confirm that the grain looks equally sharp everywhere and that it is as sharp as it looked in the best-focused region of the previous scan.

For scanners that use a tray, it is important that the plate be firmly anchored to the tray so that it cannot come loose inside the scanner. In general, the plate should be held at the same distance or in contact with the tray surface that's used to support the film. One should be sure that the plate does not protrude above or below the tray walls and should visually assess how much clearance there is within the scanner to ensure that the plate cannot catch on any internal structures. One should be aware that lenses, transfer mirrors, etc. may change position when the scanner is in operation.

A scanner suitable for scientific research should generally have a positioning accuracy on the same order as the size of the emulsion's silver clumps ("film grain"), typically a few μm or better; but the actual pixel size should generally be considerably larger for reasons explained above. Older electronic scanners like the DDO PDS were generally single-pixel devices, measuring the density (= $\log_{10}$[1/transmission]) at just one position on the photograph at a time. Although slow compared to modern two-dimensional electronic detectors like CCDs, these single-channel scanners typically had better than 1 μm positional accuracy over distances of many inches in both X and Y directions, and generally allowed their entrance aperture to be changed in both size and shape to optimally match the way the plate was illuminated (e.g., selecting a suitable round aperture to closely match the size of the sharpest stars within an image or selecting a narrow rectangular aperture to match the projected slit-size for a spectrograph

[1] Try raising the plate with a very thin shim of paper, plastic or metal, assuming that the scanner can be manually or auto-focused as needed or that it has sufficient focus depth to accommodate the spacer.

plate). Ideally, this would allow measuring the least number of pixels to recover all the information stored on a plate using an aperture that maximizes the S/N ratio for each pixel.

Consumer-level film scanners like the Nikon C9000 replace the one-pixel detector with a linear array consisting of typically three or six closely spaced rows of several thousand light sensors each (see the associated paper in this volume by Bob Simcoe). The array or film is mechanically "stepped" in the direction perpendicular to the array's long axis and all the pixels along the array are read out near-simultaneously at each subsequent pixel-size step of the film. Some scanners offer some control over the pixel size by changing (the focal length of) their transfer lens, and most scanners allow the pixel size to be changed by re-binning the full-resolution pixels either during readout or after the scan is completed.

A suitable scanner must also have the ability to accurately illuminate and precisely measure the transmission of the emulsion over a dynamic range somewhat larger than the highest value expected for the features recorded on the plate. For the DDO plate collection, properly exposed plates generally don't exceed a D_{max} of 2.0, except for IIIa-J plates which can be considerably denser.

As noted in Simcoe's preceding paper, the mechanical and electrical design of the detector, quality of the transfer lens and other issues involving scanner hardware and supporting software can strongly influence the performance actually realized by any scanner and its usefulness as a tool for scientific research. Modern film scanners like the Nikon C9000 or Epson V750 should have a huge throughput advantage over older single-pixel scanners like the PDS due to their thousands-of-pixels detector arrays. But if a scanner lacks sufficient positional accuracy and stability, has poor optical quality or lacks photometric precision and dynamic range, then the multiplexing advantage is of little consequence. As will be discussed below, even the venerable PDS has its own set of problems and limitations that need to be considered.

The discussions herein focus mostly on suitability for measuring spectroscopic plate material, but most of the same arguments and recommendations should be applicable to direct image plate work as well.

4 Hardware and Software

We have evaluated the positional and photometric performance of two top-end film scanners: the Nikon Coolscan 9000 ED ("C9000") introduced in 2002; and the Epson V750 available since 2003. Both of these units are intended for the advanced amateur photography market and are priced accordingly (currently ~ $2000 and $700, respectively). Our hope was that one or both of these units would perform well enough to replace the PDS microdensitometer used at the David Dunlap Observatory (DDO) over the past thirty years.

The plate collection from the DDO and University of Toronto Southern Observatory (UTSO) contains about 55,000 spectrographic and 10,000 direct imaging glass photographic plates ranging in size from 1/2 x 2 inches to 5/8 x 7 inches for spectroscopy and up to 4 x 5 inches for imaging. The emulsions are predominantly Kodak IIa-O for the spectrographic plates and Kodak 103a-series for the direct-imaging plates. The IIa emulsions are often claimed to deliver about 90 lines/mm resolution and 103a- emulsions about 60 lines/mm.

Almost all of the DDO and UTSO spectrographic and imaging material can physically be fit within and measured with the Nikon C9000 scanner. The manufacturer includes several trays with their scanner: FH-869S holds one 6 cm wide film strip up to 19 cm long; FH-835S holds two 35 mm wide film strips each up to 23 cm long; and FH-835M holds five 35-mm slides (2 inches square, 1-3 mm thick). Other trays can be purchased as accessories, including ones to hold 16-mm film strips, microscope slides and medium-format slides. An insert was created to hold single glass plates (either 1-3/4 inches square, 1-5/8 x 4 inches or 5/8 x 7 inches) within the manufacturer's FH-869S 120/220-format film strip tray (see Figure 2). The insert is held firmly in place using the tray's two film strip clamps to hold four thin steel "ears" at each corner of the insert. The ears are the same nominal thickness as 120-format film (0.102 mm) to avoid damaging or needing to modify the manufacturer-supplied tray. When the glass plate is loaded emulsion-side down, the emulsion is located at exactly the same position as film emulsion would be in the tray. This is not critical, as the C9000 can autofocus over a substantial range and can easily accommodate glass plates mounted emulsion-side up. To scan the 4 x 5 inch glass plates in our collection, the manufacturer's FH-835M slide tray would have to be heavily modified to serve the purpose; but only a 56.9 mm wide swath within the full 89 mm sq image area can be measured using the Nikon C9000.

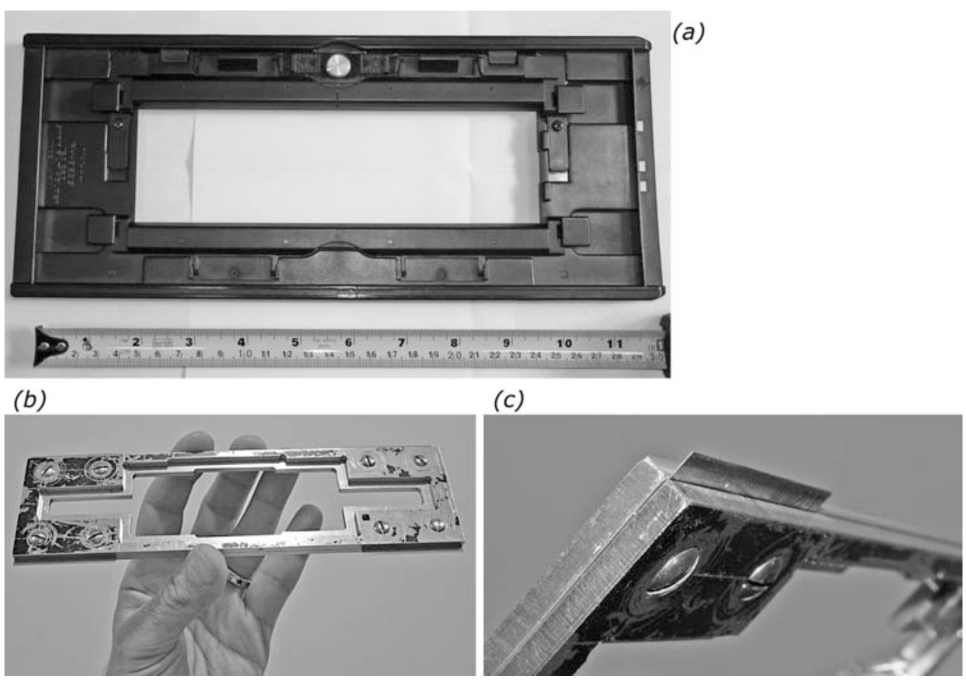

Figure 2. (a) Manufacturer supplied FH-869S film tray for the Nikon Coolscan 9000 ED; (b) custom-made glass plate holder that inserts into film tray; (c) close-up showing one of the mounting "ears."

The Epson scanner has no such restrictions and can accommodate all of the DDO plate material. But custom plate holders would still be needed to hold the glass plates at the correct distance above the scanner's window, and this distance changes depending on which of the scanner's two lenses is being used (and they are selected automatically depending on the width of the scan region requested). The Epson scanner can't autofocus like the Nikon C9000, so it is very important that the correct elevation for the different plate materials be precisely determined and maintained in order to minimize the time consumed in obtaining proper focus when using the Epson V750 scanner.

The Nikon C9000 has a fixed-magnification transfer lens delivering 4000 dpi (6.35 μm per pixel, non-interpolated) at the film plane using a monochrome CCD array composed of 3 rows with 10,000 pixels each. The unit can read from the three rows simultaneously to triple the scan speed or it can read from just one row to reduce pixel-to-pixel sensitivity variations. Different standard film and slide formats can be accommodated using one of the manufacturer's various removable trays. The scanner moves the tray holding the film between a stationary camera and illuminator using a stepping motor. The film is illuminated by firing in rapid succession red, green and blue channels of a long linear tricolor LED array after each advance of the film tray. The Nikon scanner only provides a IEEE 1394 "Firewire" port to connect it to the host computer, but a PCI-slot Firewire board is included with the scanner in case the computer doesn't have one of these ports. The scanner also came with the program Nikon Scan 4.0, which provides excellent control over the many features of the scanner. This software runs under Windows or MacOS, and a fast ($\geq$ 2 GHz CPU) computer with plenty of RAM ($\geq$ 2 GB) and a large hard disk ($\geq$ 500 GB) is strongly recommended. The scanner makes its output available in Nikon-RAW or TIFF format with either 8 or 16 bits per pixel for each red, green and blue channel in color mode, and 8 or 16 bits per pixel in monochrome (gray-scale) mode.

For the evaluation reported here, the glass plates were scanned as black and white negatives at 16-bits per pixel and the output saved as 16-bit monochrome TIFF files using Nikon Scan. The files were then translated into 16-bit FITS format using the program MaxIm-DL (version 4.51) by Diffraction Limited.[2].

The maximum region that can be covered by the Nikon scanner in a single scan is 56.9 x 83.7 mm (8,964 x 13,176 pixels); this can be located anywhere within a region 56.9 x 190 mm. It takes about 3 minutes to produce one maximum-size scan at 16 bits per pixel (the same time whether color or monochrome) with all three CCD rows active. It takes about three times longer using the one-row scan mode and the improvement to image quality was found to be small; the three-row mode was therefore used for this study.

The Epson V750 scanner has two built-in lenses to cover a maximum scan-width of either 216 mm or 150 mm (8.5 or 5.9 inches) at either 4800 or 6400 dpi (interpolated) using a 6 row x 20,400 pixel tricolor CCD array. The appropriate lens is automatically selected depending on the size of the region being scanned.

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[2] `http://www.cyanogen.com`

5 Scanner Resolution and MTF Results

Quantitative assessment of each scanner's ability to faithfully record fine image details was made using the software program Imatest and standard USAF test targets containing a very high contrast pattern of precisely spaced bars on a clear glass substrate. The target was scanned and the output assessed to see how rapidly the signal rises as the bar edges are crossed. Tests for the Nikon scanner indicated that the optics are excellent and well matched to the scanner's CCD array pixel size, delivering a resolution of 48 line-pairs/mm in the direction of tray motion with 50% contrast. This is about half the scanner's Nyquist limit of 79. The Epson scanner delivers only 13 line-pairs/mm in either direction at the 50% contrast point, far from the detector's expected Nyquist limit of 47 in 2400 dpi mode. Harvard's custom-made high-performance DASCH scanner delivers 31 line-pairs/mm at 50% contrast compared to its Nyquist limit of 45.

Our tests indicated that both commercial scanners use CCD arrays with non-square pixels, as shown by the difference in resolution depending on whether we are going along or orthogonal to the CCD array's line of pixels. This is not an unusual practice, and is done to improve the dynamic range and noise characteristics of the array (by making each pixel bigger) while still being able to claim no degradation in resolution (along one axis). The scanner manufacturer then recreates the "missing" pixels by stepping the array (or film) as if it had square pixels. The Nikon scanner pixels are estimated to be elongated by $\sim$20%, and the Epson scanner's pixels are believed to have a 2:1 aspect ratio. The Epson V750 was found to deliver poorer resolution compared to the Nikon C9000 even though the manufacturer claims their scanner has the higher resolution. Note that when analyzing scans of direct images (stars) obtained with either the Nikon or the Epson scanner, the point-spread function (psf) along one plate axis may be significantly degraded by the elongated pixels. This is less of a concern for spectroscopic data, but can still cause problems if one isn't paying attention. For spectroscopy, one will generally want the lower-resolution scanner axis aligned with the direction that the spectra are broadened. Unfortunately, because of their 7-inch length, the highest dispersion plates from the DDO 74-inch telescope's grating spectrograph (in its "G16" = 16 Å/mm, "G12" = 12 Å/mm and "G8" = 8 Å/mm configurations) must be scanned with their dispersion axis running along the axis of tray motion, which is the lower-resolution axis for the Nikon scanner. The DDO and UTSO MK spectrographic plates (120 and 66 Å/mm) have their dispersion axis along the short axis of the plate and can be scanned in the Nikon scanner using the preferred direction.

6 Mechanical Precision

A scanner's ability to maintain positional accuracy throughout a scan is critically important for spectroscopic observations. Positional accuracy was assessed by looking at the residuals from a low-order polynomial fit to a plot of wavelength versus position of calibration lines on a high-dispersion spectroscopic plate. This was carried out using the spectral analysis routines in the IRAF software suite (available from the NOAO website[3]).

A high-quality G8 DDO plate (No. 47527) was scanned with the Nikon scanner at 4000 dpi, 16-bits per monochrome pixel, and a numerical solution was sought that would describe the position of 62 uniformly-spaced, moderately-strong and sharp Fe-arc comparison lines straddling the stellar spectrum over the range of λ 3930 to 4530 Å (see Figure 3). The 62 lines and their wavelengths were taken from the MSc thesis of Gorza (1970). A 2^{nd} order fit reveals the overall curvature to the solution and a 4^{th} order fit using all 62 lines returns residuals of 0.0086 Å; dropping the 4 worst points improves the fit to 0.0065 Å. With a nominal plate-dispersion of 8 Å/mm, the Nikon scanner pixels each span about 0.0508 Å along the dispersion axis of this plate, implying that the Nikon scanner can maintain its step pitch to an accuracy of $\sim$1/6 pixel (about 1 μm) over its full 84 mm scan length along the axis of plate-holder motion. Although that is only about half the accuracy claimed achievable when using the DDO PDS to scan the best high-dispersion DDO plates, this should still be considered an excellent result, especially given the relative ease of use and relatively low cost of the Nikon scanner. With two calibration spectra straddling every stellar spectrum, we have every expectation that the excellent fit demonstrated above for the calibration spectra will be directly transferable to calibrate the stellar spectrum, and that the Nikon scanner can be used to recover precision wavelengths and hence radial velocities from the DDO plate material.

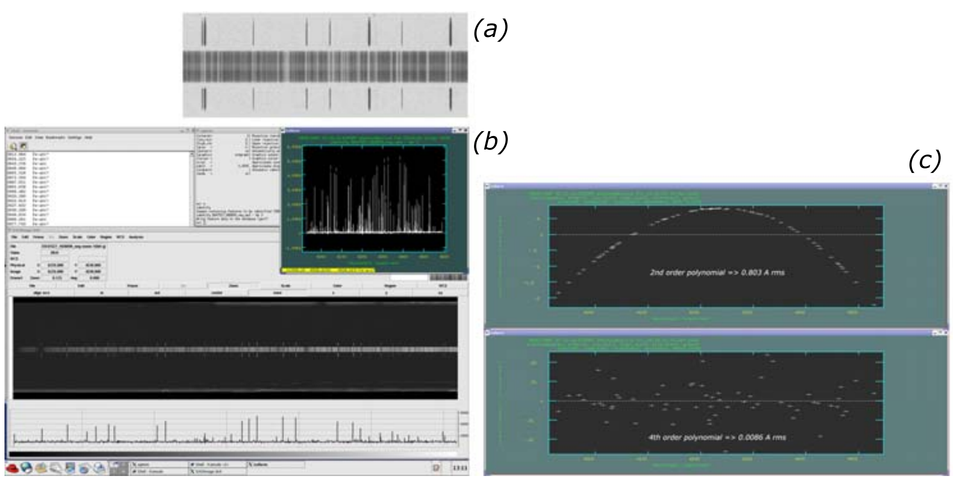

Figure 3. Assessing the positional precision of the Nikon C9000 scanner (a) scan of a typical DDO G8 spectroscopy plate obtained with the Nikon C9000 showing just 10 mm of its full 170 mm length; (b) identifying calibration lines in IRAF; (c) residuals for a 2^{nd} and 4^{th} order polynomial fit.

[3] http://iraf.noao.edu/

7 Photometric Response

It is common practice for manufacturers to quote their scanner's dynamic range based simply on the pixel-depth of the analog-to-digital converter they use. Using the maximum number of converter steps expressed as a density, the Nikon scanner is claimed to be able of measuring density levels up to a $D_{max} = \log_{10}(2^{16}) = 4.8$. The implication is also that the scanner is perfectly linear over this whole range and that there are no issues with scattered light or zero-point. Based on considerations like the maximum number of electrons that can be stored in such small pixels and the level of readout noise published for commonly used arrays, it's likely that the majority of consumer-level scanners can't provide accurate measurements much beyond a density range of 3.0. But based on our initial tests, the Nikon C9000 appears to excel and be capable of measuring much higher densities, likely to at least 3.5 and possibly as high as 4.0.

It should be noted that most of the properly exposed plates in the DDO collection are claimed to have a D_{max} well below 3.0 (Bolton 2007). But some of the exposures, especially those on Kodak IIIa plates can exceed 3.0. These plates are not easily handled with the DDO PDS because of that unit's need to scan very slowly when working at low light-levels (i.e., looking through high density regions on a plate). Here is one application where the Nikon scanner could prove invaluable, using its greater dynamic range to measure plates in the collection that up until now have only been measured poorly or not at all.

For scientific research purposes, the stability and reproducibility of a scanner and the way it illuminates the photographic emulsion are generally more important concerns than the maximum dynamic range. Illuminating the emulsion with diffuse rather than collimated light is often preferred by photographers, as it reduces the visibility of photographic grain by scattering peripheral light to lower the contrast. But it has been argued that for scientific measurement of photographic density, the illuminator should closely replicate the way the emulsion was illuminated at the telescope (i.e., via collimated light). Research-grade microdensitometers like the venerable PDS adhere to this belief. The Epson V750 uses a semi-diffuse illuminator and the Nikon C9000 uses a semi-collimated solid-state (LED) tri-color illuminator. It's still unclear if either the Epson or the Nikon scanner is handicapped in any way because of the way it illuminates the emulsion.

The photometric responses of the Nikon and Epson scanners were assessed using commercial film density-calibration targets ("stepwedges"). The results for the Nikon C9000 ED scanner indicated it has a nearly linear transfer function and can be used out to a maximum density of at least $D = 3.05$ (see Figure 4). This dynamic range rivals, and likely exceeds, what is possible with the DDO PDS. The Epson scanner tests also showed a linear response up to $D = 2.5$, but a somewhat stronger departure from linearity by $D = 2.9$ (the maximum level on the test target). The Epson V750 should be capable of returning accurate densities for moderately dense (larger-format) plates.

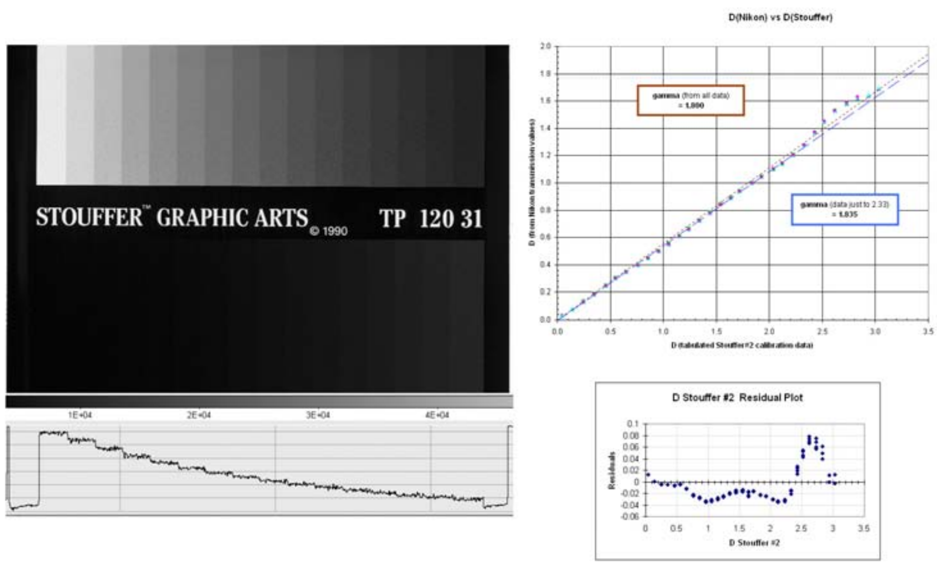

Figure 4. Nikon C9000 photometric response and dynamic range testing.

8 Nikon C9000 Versus PDS 1010

Preliminary tests with the Nikon C9000 showed that its sampling at 4000 dpi (6.35 μm per pixel) produces scans showing effectively an identical background grain pattern to what was obtained with our PDS 1010 using a 5 μm square aperture at the detector and 7.5 μm square aperture at the light source. Given that the PDS creates scans one pixel at a time and the Nikon scans with a 10,000 x 3 pixel detector array, the Nikon can cover the same area of plate thousands of times faster. But with the PDS, you can select from several rectangular apertures to find the one that best matches the size and shape of the slit used to produce the spectrogram, greatly reducing the number of sampling positions needed to extract effectively all the spectral information contained on the plate. Our most detailed plates (obtained with the DDO grating spectrograph at 8 Å/mm) have starlight dispersed over 170 mm with a projected slit-width of about 10 μm. These plates are generally scanned with the PDS using at least 34,000 samples stepped at half an aperture-width (i.e., 5 μm) per pixel. Each plate requires a minimum of four passes to capture: (i) the stellar spectrum; (ii) each of the two regions on either side of the stellar spectrum where comparison lines are imaged; (iii) and the plate background. The time needed per G8 plate using the PDS is only about 4 minutes for the actual scanning and at least 5 minutes to clean, insert, align and remove each plate from the scanner. The Nikon scanner takes at least 6 minutes to scan a full G8 plate (done in two sections), plus 5 minutes of setup time per plate. Throughput may be somewhat improved if the Nikon scanner tray is loaded with three grating spectrograph plates placed side-by-side and scanned simultaneously; but there would be the additional overhead needed to split up the scan file into its three parts afterwards and there is still the time needed to clean and load each of the plates just as before.

Throughput using the Nikon scanner is therefore not likely going to be much higher than when using the PDS. But using the Nikon scanner offers the advantage of capturing both the spatial and spectral information on the plate at the same high resolution, allowing for the detection and rejection of dust and plate defects when the data is reduced to a one-dimensional spectrum. Even more important, the Nikon scans are free of the image-smearing (typically several 10 μm pixels wide) seen in PDS scans due to the unit's slow electronics (see Figure 5). Even with improvements like those done at DAO to the PDS detector and logarithmic amplifier as reported by Stilburn, Stetson, & Fisher (1992), scan times would still need to be increased more than 10x to reduce the image smearing to sub-pixel (i.e., < 10 μm) values. Even though the PDS image smearing has been recognized and allowed for when creating, reducing and analyzing PDS scan data, it would be best if no such artifacts were present in scans that are meant to preserve the full information content of the plates, giving the Nikon scanner a real advantage over the PDS.

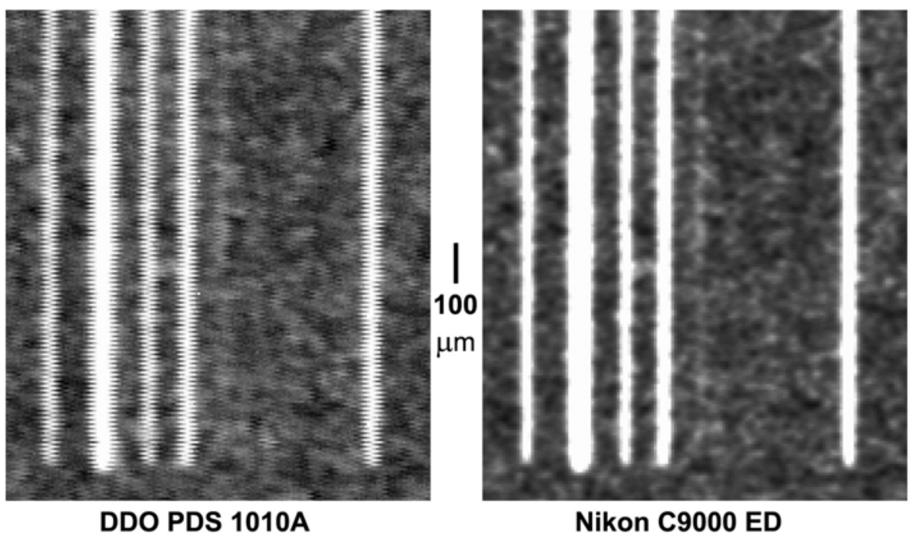

Figure 5. DDO PDS scanner "smearing" (artifacts) in the spectral lines, and even in the much less dense plate background area.

9 Conclusions

There are many small and medium-size collections of astronomic spectra and small-format wide-field plates around the world whose curators would like to have digitized. There is now some movement and support for having these individual collections deposited into a small number of storage and scanning centres where the cost of storage and access to a fast, very capable scanner can be shared among all users of the facility. But it will take time to digitize all of the plates arriving at these facilities and, remembering the lesson learned from the demise of the Great Library in Alexandria, it would be wise insurance if the smaller collections could first be digitized in-house using a carefully chosen, relatively inexpensive scanner like the Nikon C9000ED described herein. The Epson V750 is also worthy of consideration because it can handle images up to 8 x 10 inches; but its inferior resolution, lower contrast and lack of hardware and software support for achieving a critical focus with glass plates are all issues that detract from its value. We are continuing to evaluate the Nikon Coolscan 9000 ED for use in scientific research and as a replacement or substitute for scanners like the venerable but antiquated PDS or the very capable, but very expensive, Harvard DASCH scanner.

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