RCA2: 0.12 FF PER PIXEL

The UV-enhanced "double-density" RCA CCD (RCA2), associated electronics and universal dewar were ordered by CFHT in August 1985. The format of the detector, 640 x 1024 - 15 micron square pixels, is of interest for spectroscopy, but also for imagery at a finer scale than the RCA1 CCD. According to tests performed at the University of Arizona (U of A), RCA CCDs that had received UV enhancement, i.e., those with the support glass etched from the light-sensitive area and treated with an anti-reflection coating, showed significant response improvement from 300 nm to 450 nm.

The fabrication and UV-enhancement procedures were completed by RCA in October. The CCD was socket-mounted in a universal-type dewar at Photometrics LTD (Tucson, Arizona). The dewar exterior is reminiscent of the UBC dewars currently in use at CFHT (RCA1, 1872 Reticon) to facilitate interfacing RCA2 to existing CFHT instrumentation. The interior of the cryostat is a modified Frank Low design by Infrared Laboratories. The design allows a LN$_2$ hold time in excess of 15 hours, accomplished by lengthening the dewar because the diameter of the cryostat is constrained to 5.5 inches. The dewar holds approximately 0.9 liters of LN$_2$.

The CCD control electronics and interface, designed by Photometrics, can be linked either to the astronomical data acquisition computers via CAMAC or to an engineering 68010 MULTIBUS computer and display system. The CCD system was assembled and tested in November and received at CFH in December. The engineering data system was received from Photometrics in January 1986.

From the very first tests it was clear that the cosmetic quality of the chip is excellent (Figure 1). The one blooming column visible at room temperature near the chip center disappears as the device cools to -130 C. At -130 C the dark current of the device is 1 electron/minute/pixel.

Preliminary quantum efficiency tests conducted in November suggested that the UV enhancement resulted in only a marginal (if any) improvement in the CCD response. This result agrees with similar tests of other double-density and normal-density CCDs. The discrepancy between the CFHT tests and the U of A tests are not completely understood, but it is somewhat reassuring that the CFHT CCD was measured with the same test equipment as the U of A devices.

The read noise of RCA2 upon delivery was 75 to 80 electrons with departure from linearity occurring at approximately 110,000 electrons per pixel. After some minimal tuning of the electronics, RCA2 was used at the telescope in January (P/6) and February (PF). The following results were obtained.

(1) Approximate zero points:
ADCU/sec ~ 14 electrons/sec determined from measurements of Landolt equatorial and CCD standard stars are very approximately:
U ~ 20
B ~ 23.2 [(B-V) = 0]
V,R,I ~ 23.1 [color = 0]

(2) Approximate color terms are
(U-B) ~ 0.9 (u-b) + C1
(B-V) ~ 1.3 (b-v) + C2
(V-R) ~ 1.0 (v-r) + C3
(V-I) ~ 0.95 (v-i) + C4
where u,b,v,r, and i are instrumental magnitudes corrected for extinction, and C1-C4 are constants.

(3) Photometric parameters are preserved when subraster readout and/or moderate binning is used. Operation of
the device in these modes will be useful in a variety of circumstances, especially for imagery of standard stars. It is essential that calibration frames including bias, dark and flat field exposures be obtained with the same binning factor as for astronomical exposures.

(4) Fringing is less than a few percent in all filters. This is an advantage due to the removal of the support glass. In the reddest wavelengths or in narrow band filters, fringing is not severe (<5%).

(5) Considering that the RCA2 chip has had the support glass removed it was of interest to investigate the flatness of the chip for astronomical use. To visual inspection, the chip appears slightly "wrinkled". Measurements of the gate structure of the CCD suggest that these wrinkles can be as large as 80 µm peak to peak or 35 µm (rms), assuming the light-sensitive area follows the gate structure closely. Full-frame exposures of a stellar field were examined using an image shape parameter algorithm. There was no dramatic change in the shape of the stellar images across the field. Images also were fit with a point-spread function calculated from one uncrowded image in the field. When the fitted profiles were subtracted from the frame, the residual images were similar across the field, i.e. to first order, there is no significant variation of the PSF across the face of the chip. Note that the peak-to-peak de-blur in an F/4 beam is expected to be 0.65 arcsec. The rms de-blur is predicted to be 0.25 arcsec.

Image separation, i.e. distortion of the chip, was checked by opening and closing the shutter, offsetting the telescope by 10 to 20 arcsec and opening the shutter. In this way multiple exposures can be obtained in one frame. The relative separations of the stars were calculated and compared. Across the face of the chip the image separation did not vary by more than 0.3 pixel (0.03 arcsec). The scatter is due to a combination of distortion and, more importantly, image centering accuracy.

The CCD was tested both at F/4 and F/8. Tests in an F/2 beam certainly should be conducted to examine the precise effect on imaging and spectroscopic data.

(6) The resolution and imaging capabilities of the CCD in imaging mode were tested. The observation of the triple QSO PG1115+080 at PF showed that in good seeing component A was easily separable into the two components A1 and A2 using an automatic image finding routine (see article this issue). In good

![Figure 1: Fred at the Edge of the Universe](image-url)
to mediocre seeing (0.6 to 1.2 arcsec FWHM) the CCD at PF gives excellent image sampling (0.21 arcsec per pixel). For higher resolution work on small fields the F/8 Cassegrain may be more appropriate. In situations where the seeing degrades, on-chip binning can be used to optimize the sampling and S/N.

From February to May extensive testing and tuning of RCA2 took place; over 4,000 frames were taken. The CCD read noise was minimized at approximately 45 electrons by adjustment of the horizontal clock levels and the double-correlated sampling time. The effect of the horizontal clocks was surprising considering that such adjustments did not significantly improve amplifier performance for the normal density RCA devices. The noise optimization did not influence the chip transfer efficiency or other chip characteristics.

The transfer efficiency of the CCD was measured using the overclocked area of the CCD. The vertical transfer efficiency appears to be "unmeasurable", that is >0.99999 at all signal levels. The horizontal transfer efficiency was measured higher than 0.9995 for signal levels >100 electrons and >0.99990 for signal levels >1000 electrons.

Read noise was checked as a function of the row binning factor. Binning along rows (short axis) can be used advantageously for spectroscopic applications; for example, at the coude focus, binning factors as high as 50 might be used to compress the image produced by the image slicer. The read noise was found to degrade slightly with bin factor, reaching approximately 70 electrons at a binning factor of 50 (Figure 2). The capacity of the horizontal register was also checked in binning mode. It was found that the horizontal register appears to have a full well capacity in excess of 500,000 electrons. In fact the 16 bit ADC of the CCD controller was exceeded well before the horizontal register exhibited departure from linearity.

The most serious characteristics for RCA2 use are (1) the charge skimming at the horizontal register and (2) the flatness of the CCD. The charge skimming is a result of the architecture of the device. When charge is clocked out of the device a certain number of electrons appear to be "lost" or skimmed from each pixel. The amount of charge skimmed is a function of column number and varies randomly from column to column. The problem can be treated in two ways. First, the CCD can be prefetched to insure that all columns can accommodate the charge skimmed during readout. Note that this problem is not related to poor transfer efficiency or deferred charge. Accordingly, prefetch lamps have been installed behind the CCD shutter and can be used to prefash the chip immediately prior to an astronomical exposure. The second method for treating charge skimming is to correct each column for the charge lost prior to preprocessing. However the only columns that can be corrected are those for which the number of photoelectrons collected exceeds the amount lost in charge skimming.

The flatness of the CCD (mentioned above) is of concern for all uses of the CCD, particularly in fast beams. The astronomical tests in January and February showed that image quality of the device is good at F/8 and F/4. For the highest precision work techniques using geometric distortion corrections and partial image reconstruction may be desirable. The results from the laboratory and astronomical tests are more or less qualitative. The detailed performance of the CCD will be established through repeated use of the detector in a variety of applications during the second semester of 1986. There is no doubt however that RCA2 will provide an invaluable tool for many astronomical programs.

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![Figure 2](image)