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CCD Detector Performance for NOAO's Wide Field MOSAIC Cameras

Thomas Wolfe[a], Taft Armandroff[a], Morley Blouke[c] Travis Rector[a], Rich Reed[a], Abhijit Saha[a], Robert Schommer[b], Chris Smith[b], Roger Smith[b] and Alistair Walker[b]

[a] National Optical Astronomy Observatories, 950 North Cherry Avenue, Tucson, Arizona 85726
[b] Cerro Tololo Inter-American Observatory , Casilla 603, La Serena, Chile [c] Scientific Imaging Technologies Incorporated, Beaverton, Oregon 97075

ABSTRACT

In July of 1998 the National Optical Astronomy Observatories (NOAO[1]) successfully upgraded MOSAIC I, an 8192 by 8192 pixel array using eight Scientific Imaging Technologies, Inc. (SITe) ST-002A thinned backside 2k by 4k charge coupled devices (CCDs). In July of 1999 MOSAIC II, a clone of MOSAIC I was commissioned also using eight SITe ST-002A CCDs. Additionally in December of 1998 NOAO implemented Mini-MOSAIC a 4096 by 4096 pixel array using two SITe ST-002A thinned CCDs. This report will discuss the performance, characterization and capabilities of the three wide field imagers now in operation at NOAO's Kitt Peak National Observatory (KPNO), Cerro Tololo Inter-American Observatory (CTIO) and at the WIYN Consortium 3.5-Meter telescope on Kitt Peak.

Keywords: CCD, CTIO, KPNO, MOSAIC, NOAO, SITe, ST002A, WIYN

1. INTRODUCTION

A decade ago NOAO started the design and development of CCD cameras to utilize the large field of view of their Astronomical Telescopes. Cameras using a MOSAIC of CCDs (Figure 1.) were designed and built for the Mayall 4-meter telescope at KPNO, the Blanco 4-meter telescope at CTIO and the 3.5-meter WIYN telescope on Kitt Peak. All of these cameras use the SITe 2k by 4k back illuminated three side buttable ST002A CCD as their detector. NOAO has tested and optimized the performance of twenty-one SITe ST002A CCDs. This paper will report on the performance of the ST002As that are in use in NOAO's two MOSAIC large field imagers and the WIYN Mini MOSAIC Camera. The characteristics reported on are the gain, read noise, charge transfer efficiency (CTE), full well, quantum efficiency (QE), dark current and measurements of the surface of the CCDs to verify a maximally flat imaging surface.

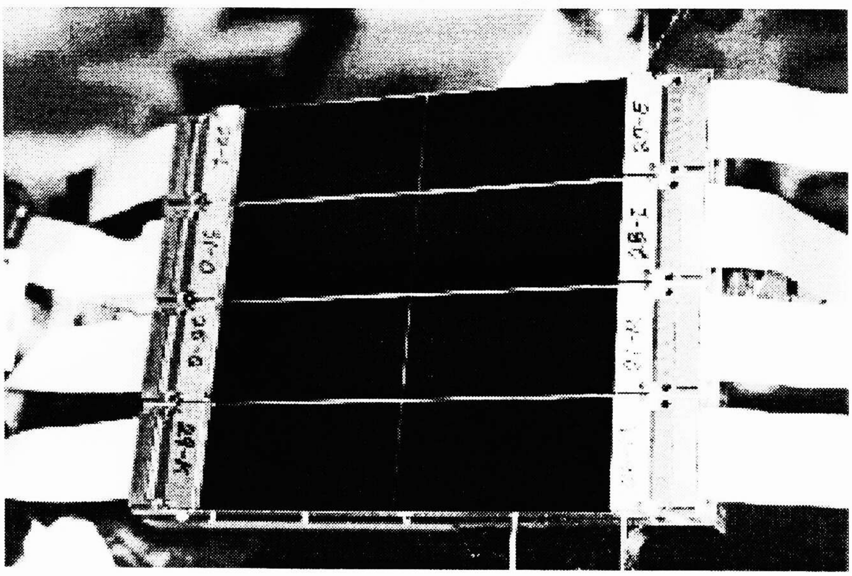

Figure 1 MOSAIC II Base Plate Mounted With Eight SITe ST002A CCDs

[1]National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy, Inc. (AURA) under cooperative agreement with the National Science Foundation.

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2. CCD PERFORMANCE

At NOAO initial test were performed on all the ST002A CCD. These tests characterized the performance of the CCDs and insure the CCD device meet specifications for NOAOs science grade cameras. The testing is done using a standard series of test at NOAO and the same set of test was performed on all the ST002A received. The CCDs are tested and specifications for gain, read noise, charge transfer efficiency, full well, quantum efficiency, and dark current are recorded. The testing is done and the same sets of test were performed on all the ST002A received for the large field imagers at NOAO. Voltages for all biases and clocks were initially set to the nominal voltages given to NOAO bye SITe (Table 1). These voltages are then adjusted if needed to optimize the performance of the CCDs for application in the wide field imagers. In the test system NOAO uses a video amplifier with a dual slope integrator and a 16 bit Analog to digital converter (ADC). For a detailed description of testing methods for NOAO's MOSAIC CCD cameras please read article number two listed in the references of this paper.

Table 1 Nominal CCD Clock Voltages for ST002A CCDs

Gate	Voltage	Gate	Voltage
Voltage Diffusion Drain (VDD)	+25.0 Volts	RESET GATES	0 to +12 Volts
Voltage Reset Drain (VRD) & Voltage Overflow Drain (OFD)	+14.0 Volts	SERIAL GATES	-6.0 to + 5.0 Volts
Last Gate	-4.0 Volts	SUMMING WELL	-5.0 to +5.0 Volts
Substraight	0.0 Volts	Parallel Gates 1,2	-10.0 to +2.0 Volts
Package & Amplifier Ground	0.0 Volts	Parallel 3 Multi-Phased Pin (MPP)	-7.5 to +6.0 Volts

To determine the gain and noise characteristics of the ST002As both the photon transfer technique and a technique that uses the radiation from an Iron-55 source were used. Iraf was used extensively for reduction of the DATA during the CCD testing phase of the MOSAIC projects. Test results for the SITe ST002As tested at NOAO are compiled in Table 2. Parameters for this table include amplifier sensitivity, system gain, read noise, full well, dark current, parallel charge transfer efficiency and serial charge transfer efficiency. Quantum efficiency (QE) testing is reported in Table 3, and shown graphically in figure 2. For additional information on NOAOs, CCDs and MOSAIC imagers refer to the articles listed in the references of this paper.

Flatness of the focal plane was important with these large field arrays of CCDs. At NOAO measurements of the surface of the CCDs were done to verify a flat imaging surface. The flatness of the CCDs as delivered from SITe did not meet the specifications required for the imagers so a shim with a complex and compound angle was fabricated uniquely for each CCD. Several iterations of measurements of the CCD plus shim and subsequent grinding of the shim were needed. This process was used to insure the desired specifications for the array focal plane flatness was achieved. Listed in Table 4 and Table 5 are the final measured surfaces of MOSAIC I and MOSAIC II respectively. For MOSAIC I the maximum height is 11,203 microns and the minimum height is 11,180 microns for a delta of 23 microns peak to valley. For MOSAIC II the maximum height is 11,203 microns and minimum height of 11,185 microns for a delta of 18 microns peak to valley. These values for flatness meet the scientific specification for flatness needed for NOAOs large field imagers.

	Parameter	MOSAIC I								MOSAIC II								Mini		Other		
	SITe ST002A Serial Numbers and Camera	7061FBR03-02	7233FBR08-02	7223FBR10-02	7294FBR05-01	7298FBR03-02	7298FBR06-01	8014FCR06-02	7465FBR01-02	98164FACR10-02	98202FABR03-02	98173FABR10-02	98173FABR14-02	98261FABR18-02	98261FACR06-02	98261FACR09-01	98241FABR07-02	8061FBR07-02	8061FBR05-02	8061FBR07-01	98261FACR12-02	7061FBR03-01
A-Amplifier	Amplifier Sensitivity µV/e⁻	1.48	1.32	1.36	1.17	1.08	1.28	1.58	1.38	1.36	1.13	1.52	1.48	1.57	1.55	1.64	1.44	1.15	1.01	1.38	1.64	1.57
A-Amplifier	System Gain 15µs Dwell (e⁻/DN)	0.95	1.07	1.04	1.20	1.31	1.10	0.89	1.02	1.04	1.25	0.93	0.95	0.90	0.91	0.86	0.98	1.23	1.39	1.02	0.86	0.90
A-Amplifier	System Noise 15µs Dwell (e⁻ RMS)	3.0	3.9	3.6	4.3	4.7	3.8	2.8	4.0	4.1	4.1	2.8	2.9	3.2	3.4	3.6	3.4	4.5	4.6	3.2	2.9	2.4
A-Amplifier	System Gain 8µs Dwell (e⁻/DN)	1.78	2.04	1.97	2.26	2.46	2.06	1.78	1.92	2.18	2.34	1.72	1.78	1.70	1.70	1.63	1.85	2.30	2.60	1.90	1.63	1.70
A-Amplifier	System Noise 8µs Dwell (e⁻ RMS)	4.4	4.9	4.5	5.3	6.1	4.8	4.3	4.9	5.4	5.4	3.8	4.0	4.0	4.1	3.4	4.4	4.9	5.9	4.2	3.4	3.7
A-Amplifier	System Gain 5µs Dwell (e⁻/DN)	2.87	3.25	3.16	3.63	3.97	3.31	2.86	3.06	3.48	3.82	2.79	2.82	2.71	2.73	2.60	2.93	3.70	4.20	3.05	2.60	2.70
A-Amplifier	System Noise 5µs Dwell (e⁻ RMS)	5.6	6.6	5.8	6.8	7.3	6.4	5.5	5.7	6.6	6.6	5.2	4.7	5.1	5.1	5.0	5.2	6.3	8.0	4.5	5.0	5.0
B-Amplifier	Amplifier Sensitivity mV/e⁻	1.64	1.32	1.34	1.22	1.26	1.18	1.47	1.38	1.68	1.17	1.45	1.53	1.57	1.62	1.58	1.53	1.13	1.10	1.31	1.58	1.41
B-Amplifier	System Gain 15µs Dwell (e⁻/DN)	0.86	1.07	1.05	1.16	1.12	1.19	0.96	1.02	0.84	1.20	0.97	0.92	0.90	0.87	0.89	0.92	1.25	1.28	1.08	0.89	1.00
B-Amplifier	System Noise 15µs Dwell (e⁻ RMS)	4.0	3.5	3.8	4.0	3.6	4.3	3.7	4.1	2.5	3.9	3.4	3.3	3.5	3.1	3.4	2.8	4.9	4.7	3.7	3.4	3.4
B-Amplifier	System Gain 8µs Dwell (e⁻/DN)	1.64	2.01	1.96	2.18	2.10	2.23	1.80	1.92	1.78	2.23	1.78	1.73	1.69	1.64	1.68	1.73	2.50	2.40	2.03	1.68	1.90
B-Amplifier	System Noise 8µs Dwell (e⁻ RMS)	3.5	5.0	4.5	5.2	5.4	5.2	4.2	5.0	4.8	5.7	4.7	4.6	4.4	4.0	4.2	3.5	5.6	5.5	4.9	4.2	4.7
B-Amplifier	System Gain 5µs Dwell (e⁻/DN)	2.65	3.24	3.17	3.47	3.38	3.60	2.89	3.07	2.85	3.59	2.90	2.79	2.68	2.62	2.66	2.78	3.90	3.90	3.24	2.66	3.00
B-Amplifier	System Noise 5µs Dwell (e⁻ RMS)	5.4	7.2	6.1	6.3	6.5	6.7	5.8	6.8	6.2	7.3	6.6	5.8	5.6	5.0	4.7	4.9	6.8	6.8	6.5	4.7	5.0
	Fullwell @ 1% Linearity (Ke⁻)	73	79	74	82	98	92	70	62	90	69	82	80	63	64	63	83	80	70	69	63	72
	Dark Current @ -90°C (e⁻/pixel/hour)	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	1	1	1
	CTE Parallel @ 1620 e⁻	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998
	CTE Serial @ 1620 e⁻	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998	0.999998

Table 2 CCD Test Results

SITe ST002A Serial Numbers and Camera		Wave Length: 300 nm	320 nm	334 nm	365 nm	380 nm	405 nm	450 nm	500 nm	550 nm	600 nm	650 nm	700 nm	750 nm	800 nm	850 nm	900 nm	950 nm	1000 nm
MOSAIC I	7061FBR03-02	8.9	18.0	22.7	49.8	62.8	67.5	74.0	77.9	83.2	86.8	87.8	84.7	78.2	68.4	54.0	39.3	24.5	10.9
	7233FBR08-02	7.6	15.8	22.4	42.1	56.2	57.9	63.6	69.9	75.3	80.3	82.7	82.8	76.4	67.0	54.7	40.2	25.4	11.8
	7223FBR10-02	7.8	16.1	23.0	43.5	57.1	60.9	65.6	73.6	77.7	84.4	86.6	84.5	77.0	68.0	55.3	44.1	25.5	12.2
	7294FBR05-01	9.5	18.5	26.4	53.0	62.1	63.9	70.7	76.1	81.6	88.3	89.7	88.4	81.5	71.9	57.6	41.9	26.2	12.0
	7298FBR03-02	9.4	18.5	27.1	52.7	61.9	66.9	72.5	77.8	81.4	87.7	89.2	86.3	80.5	68.1	54.0	39.2	24.5	10.6
	7298FBR06-01	8.4	18.5	25.4	49.2	58.2	63.4	70.2	75.0	80.3	85.1	87.1	85.7	79.0	69.5	56.5	41.3	26.2	11.8
	8014FCR06-02	9.6	19.3	27.6	54.0	65.8	72.1	78.3	81.4	86.5	89.7	90.6	88.1	80.3	70.1	56.1	40.8	26.0	11.7
	7465FBR01-02	9.7	18.9	27.9	52.6	56.1	68.8	74.4	79.4	83.9	87.0	88.7	86.2	78.3	68.8	54.5	40.3	25.4	11.6
MOSAIC II	98164FACR10-02	8.4	18.3	25.4	48.1	55.3	64.5	70.2	74.1	79.2	82.4	81.8	80.3	72.3	61.1	50.0	36.6	23.2	11.7
	98202FABR03-02	9.0	18.4	26.2	50.8	63.2	68.7	71.8	76.3	80.5	84.8	88.7	87.9	80.1	70.1	57.2	41.7	27.2	12.8
	98173FABR10-02	8.7	17.3	24.7	46.7	61.0	68.4	75.5	77.6	82.6	86.3	87.8	82.8	76.8	67.5	54.1	39.7	25.8	12.1
	98173FABR14-02	8.2	18.1	25.5	49.0	61.8	68.5	75.0	78.5	83.5	88.4	88.6	87.3	80.4	70.2	56.4	72.2	25.7	11.4
	98261FABR18-02	8.4	16.7	23.8	46.1	58.9	65.1	70.8	75.4	79.5	84.0	86.2	86.0	79.9	69.2	56.3	41.2	26.0	11.2
	98261FACR06-02	8.6	17.5	24.6	48.2	60.7	68.5	72.6	77.3	82.7	87.7	87.3	86.3	78.8	67.5	55.0	38.8	24.5	10.5
	98261FACR09-01	8.7	17.5	24.4	47.6	59.6	66.5	76.9	77.6	82.6	86.3	87.3	85.7	76.8	68.7	54.3	39.4	24.7	10.7
	98241FABR07-02	8.3	16.5	23.6	46.0	56.8	68.8	70.4	77.0	80.7	85.4	87.8	85.8	77.0	69.5	56.0	41.4	25.8	12.0
Mini	8061FBR07-02		18.5		48.5	59.6	69.4	73.2	78.5	81.7	85.9	86.9	84.8	77.8	68.4	54.8	40.3	24.5	
	8061FBR05-02		18.3		48.1	59.4	62.0	68.7	73.4	77.4	81.6	83.4	80.7	77.4	68.8	54.4	40.3	24.9	
Other	8061FBR07-01	9.6	18.7	27.6	52.1	55.5	68.1	73.7	78.6	83.1	86.1	87.8	85.3	77.5	68.1	54.0	39.9	25.1	11.5
	98261FACR12-02	8.7	17.6	24.8	47.0	59.8	68.9	74.4	74.7	82.9	87.6	88.3	86.4	78.1	68.6	54.2	39.1	24.8	10.6
	7061FBR03-01	9.9	19.4	25.4	51.0	60.7	65.7	73.2	77.2	81.4	87.0	88.2	85.4	80.7	68.9	54.8	39.8	25.0	11.1

Table 3 CCD Quantum Efficiency

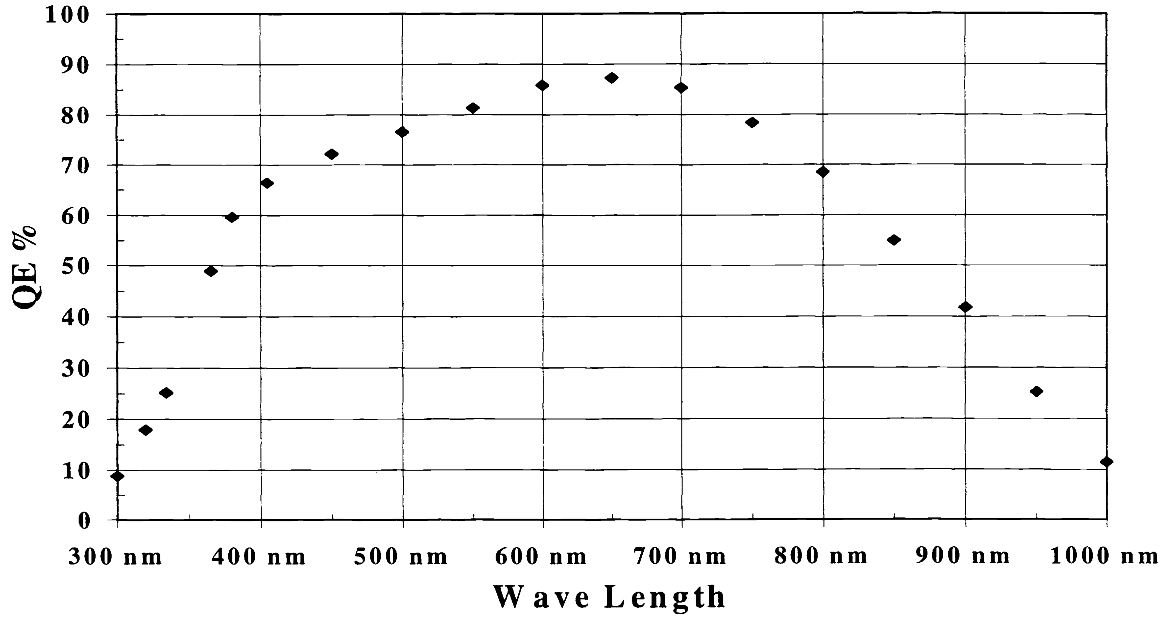

Figure 2 Average Quantum Efficiency NOAO's ST002A CCDs

CCD Serial Number	Minimum Height	Maximum Height	Average Height	Delta
7061FBR03-02	11,188 μ	11,203 μ	11,195 μ	15 μ
7233FBR08-02	11,191 μ	11,197 μ	11,195 μ	6 μ
7223FBR10-02	11,193 μ	11,197 μ	11,195 μ	4 μ
7294FBR05-01	11,188 μ	11,200 μ	11,196 μ	12 μ
7298FBR03-02	11,194 μ	11,203 μ	11,200 μ	9 μ
7298FBR06-01	11,194 μ	11,203 μ	11,199 μ	9 μ
8014FCR06-02	11,194 μ	11,200 μ	11,197 μ	6 μ
7465FBR01-02	11,180 μ	11,189 μ	11,186 μ	9 μ

Table 4 Final Surface Measurements of CCD and Shim for MOSAIC I

CCD Serial Number	Minimum Height	Maximum Height	Average Height	Delta
98164FACR10-02	11,188 μ	11,193 μ	11,191 μ	5 μ
98202FABR03-02	11,185 μ	11,199 μ	11,193 μ	14 μ
98173FABR10-02	11,194 μ	11,203 μ	11,199 μ	9 μ
98173FABR14-02	11,187 μ	11,198 μ	11,194 μ	11 μ
98261FABR18-02	11,191 μ	11,199 μ	11,195 μ	8 μ
98261FACR06-02	11,192 μ	11,202 μ	11,197 μ	10 μ
98261FACR09-01	11,193 μ	11,202 μ	11,197 μ	9 μ
98241FABR07-02	11,186 μ	11,197 μ	11,193 μ	11 μ

Table 5 Final Surface Measurements of CCD and Shim for MOSAIC II

3. NOAO'S MOSAIC I AND MOSAIC II PERFORMANCE

NOAO's two 8192 by 8192 large field cameras are world class instruments. MOSAIC I, located at KPNO near Tucson, Arizona, is used at the 4-meter Mayall and 0.9-meter telescopes. MOSAIC II, located at CTIO in Chile, is used at the 4-meter Blanco telescope. The MOSAIC Imagers accommodate 8 SITe ST002A CCDs separated by a small gap. The CCDs have excellent cosmetic qualities and very high quantum efficiency. The sampling for the 4-meter class telescopes is 0.26 arc seconds per pixel and a field of view of 36 arc minutes. At the 0.9-meter telescope the sampling is 0.43 arc seconds per pixel and a field of view of 59 arc minutes. Typical seeing is 0.6-0.7 arc seconds full width half max. The read out take approximately 150 seconds for the full 8k by 8k array and the read out is accomplished via four Arcon controllers. At the present time each Arcon reads out two CCDs through one amplifier on each CCD. Plans are underway to upgrade the Arcons to read the CCDs through two amplifiers per CCD and the read out time will be reduced to 100 seconds for the 8k by 8k array. The MOSAIC camera/dewar mounts inside the MOSAIC Instrument assembly. Raw images from the 8k by 8k MOSAIC are 135 Mbytes each and a typical night of approximately 70 images produces about 10 giga bytes of data. CCD characteristics can be found in Tables 4,5,and 6. For more information on NOAO's MOSAIC please refer to the articles listed in the reference of this paper.

Sample pictures from both MOSAIC I and MOSAIC II are displayed in Figure 3, Figure 4 and Figure 5. Figure 3 is image of a raw, unprocessed Hydrogen alpha image of the Rosette taken with MOSAIC I 0.9m telescope on Kitt Peak. Notice the distinct eight CCD outlined with a narrow gap. An overscan correction to bring each CCD bias down to the same level has been applied otherwise the image is unprocessed. Figure 4 is the same image of the Rosette Nebula (NGC 2237) but has been processed with false color. Five 10-minute exposures were made with Ha, O[III], and S[II] filters and assigned to the red, green, and blue color channels, respectively, to create this false color image. Figure 5 is a black and white image of the Sculptor Group galaxy NGC 247. The image was taken with the MOSAIC II camera and CTIO Blanco 4-m telescope on the night of Nov. 27, 1999. The large format of MOSAIC II combined with the large aperture of the Blanco telescope produced deep images and captured the entire galaxies and their surroundings in a single frame. Most of the fuzzy objects outside the main body of NGC 247 are distant background galaxies; some, however, are globular clusters native to NGC 247.

Both MOSAICs are very popular at NOAO and in the science community. This is demonstrated in the number of request for use of these instruments. The request statistics for observing semester 2000A (February 2000- July 2000) will be given. For this semester 146 nights requested to use MOSAIC I at the 4-meter at KPNO, 158 nights requested to use MOSAIC I at the 0.9-meter at KPNO and 98 nights were requested to use MOSAIC II at CTIO. The quality of the CCDs and the outstanding performance of the MOSAIC instruments make this a popular choice in the scientific community for large field imaging.

4. MINI MOSAIC PERFORMANCE

The Mini MOSAIC imager consists of two SITe ST002A 2k by 4k CCDs. It is configured into a 4096 by 4096 array with a small gap between the two CCDs. The CCDs have high quantum efficiency and have excellent cosmetic qualities. The imager has a resolution of 0.14 arc seconds per pixel and a large field of view at 9.6 arc minutes per side. Mini MOSAIC is used at the WIYN 3.5-meter telescope. Each of the two CCDs is read out via a Harcon controller and the four video outputs of the two CCDs is multiplexed through a single analog to digital converter. The read out time for this camera is approximately 182 seconds. CCD characteristics can be found in Tables 4,5,and 6 of this report

A sample image Figure 3 is included in the paper. This image of the globular cluster M3 (NGC 5272) was obtained with the Mini-MOSAIC camera on a Nasmyth focus of the WIYN 3.5m telescope on Kitt Peak. The white stripe down the middle of the image shows the gap between the active area of the two CCDs of the Mini MOSAIC camera. In this configuration, the pixel size is 0.14 arc seconds on the sky, and the field of view is 9.6 arc-minutes on a side. The image is shown with a logarithmic gray-scale. It is a 120-second exposure in the `B' passband, and images have full width at half maximum of better than 0.5 arc-seconds. Note the uniform image quality across the entire array. The inset shows how the superb seeing is very well sampled. The instrument thus exploits the superb seeing achieved by the WIYN telescope while also delivering uniform image quality over a moderately large field of view.

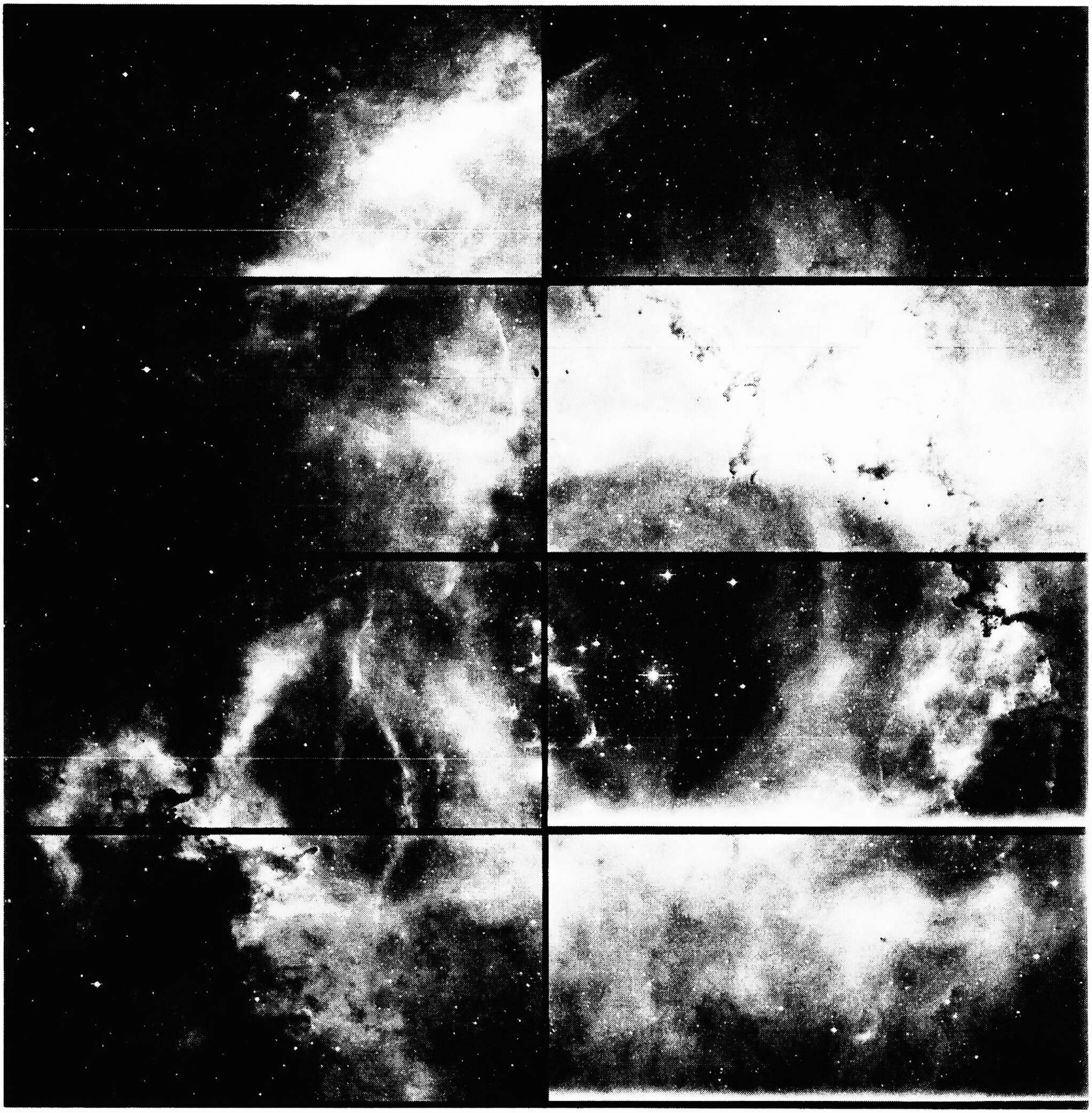

Figure 3 Image of a raw, unprocessed Hydrogen alpha image of the Rosette taken with MOSAIC I an array of eight SITe ST002A 2kx4k CCDs at the National Science Foundation's 0.9m telescope on Kitt Peak. An overscan correction to bring each CCD down to the same level has been applied otherwise the image is unprocessed.

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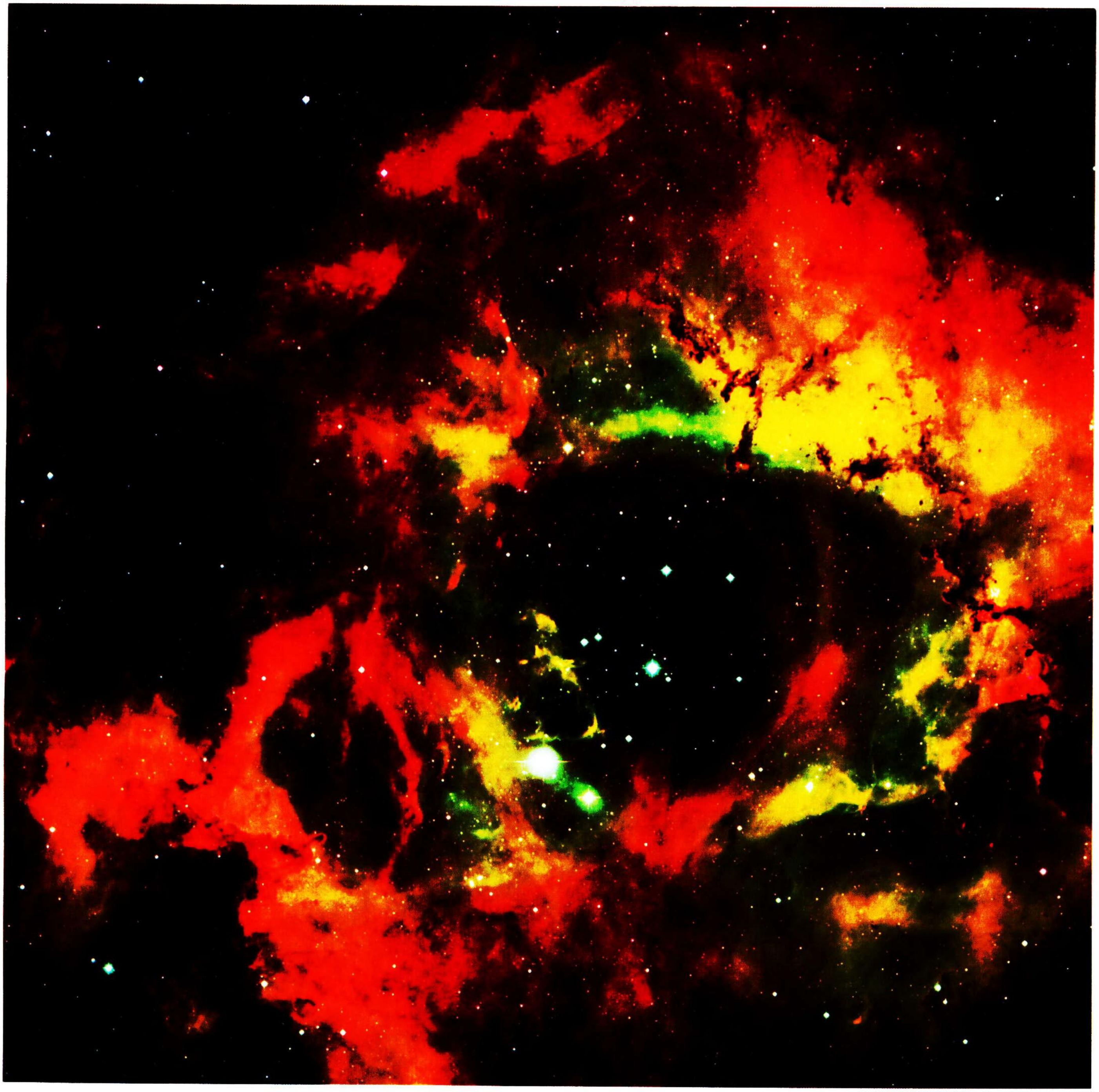

Figure 4 This image of the Rosette Nebula (NGC 2237) was taken with MOSAIC I an array of eight SITe ST002A 2kx4k CCDs at the National Science Foundation's 0.9m telescope on Kitt Peak. Five 10-minute exposures were made with Ha (hydrogen), O[III] (oxygen), and S[II] (sulfur) filters and assigned to the red, green, and blue color channels, respectively, to create this false color image.

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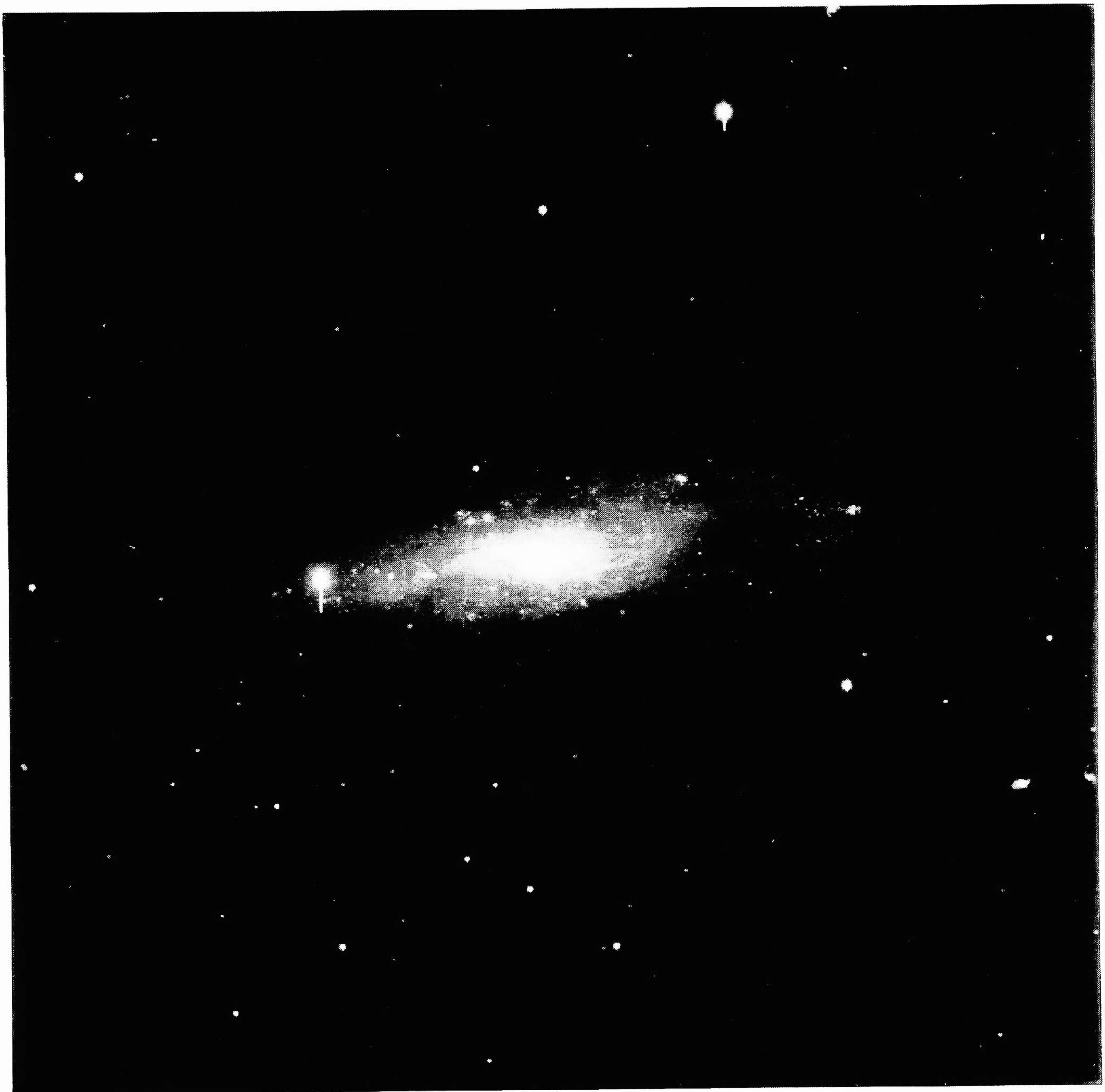

Figure 5 This image of the Sculptor Group galaxy NGC 247 was produced by combining frames taken through three different (blue, green, and red) filters. The images were taken with the MOSAIC II camera and CTIO Blanco 4-m telescope on the night of Nov. 27, 1999. The large format of MOSAIC II combined with the large aperture of the Blanco telescope produced deep images and captured the entire galaxies and their surroundings in a single frame. Most of the fuzzy objects outside the main body of NGC 247 are distant background galaxies; some, however, are globular clusters native to NGC 247. Astronomers Knut Olsen, Robert Schommer, and Nick Suntzeff (CTIO) will use the images to identify and study the candidate globular clusters, the properties of which will provide clues as to how galaxies like NGC 247 formed. PHOTO CREDIT: K. Olsen, R. Schommer, N. Suntzeff,

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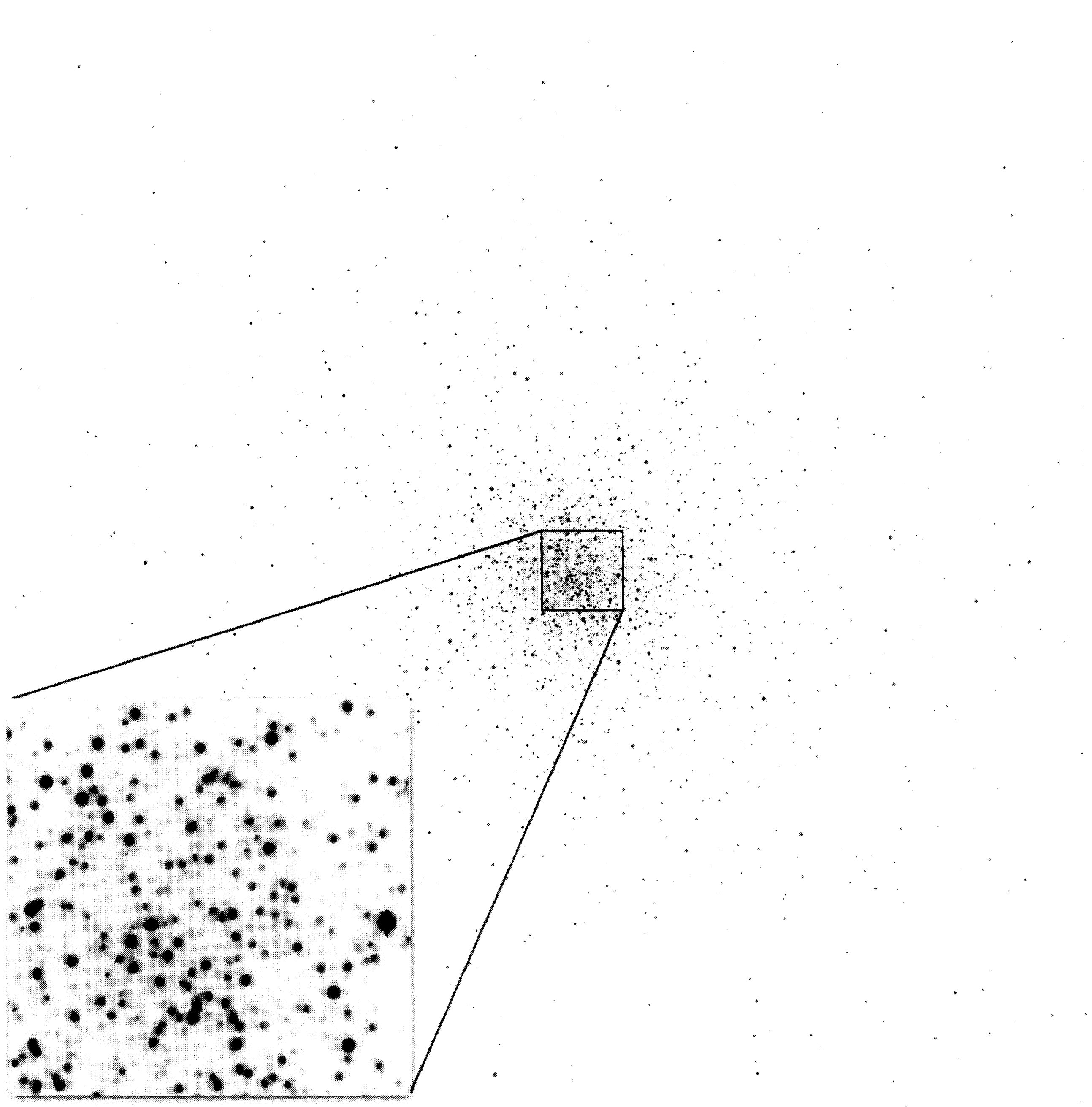

Figure 6 An image of the globular cluster M3 (NGC 5272) obtained with the Mini-MOSAIC camera on a Nasmyth focus of the WIYN 3.5m telescope on Kitt Peak. The camera uses two 2K X 4K SITE CCDs, mounted side by side for a 4K x 4K field of view. The white stripe down the middle of the image shows the gap between the active area of the two CCDs of the Mini MOSAIC camera. In this configuration, the pixel size is 0.14 arc-seconds on the sky, and the field of view is 9.6 arc-minutes on a side. The image is shown with a logarithmic gray-scale. It is a 120-second exposure in the `B' passband, and images have full width at half maximum of better than 0.5 arc-seconds. Note the uniform image quality across the entire array. The inset shows how the superb seeing is very well sampled. The instrument thus exploits the superb seeing achieved by the WIYN telescope while also delivering uniform image quality over a moderately large field of view.

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5. OTHER LARGE FORMAT DEVICES AT NOAO

Other projects and proposals using large format devices are being developed at NOAO. At the WIYN telescope on Kitt Peak the WIYN Tip Tilt adaptive optics project will use a camera with a ST002A as the detector. NOAO facility in Chile is constructing a camera for the multi-fiber spectrograph HYDRA. This camera will also use a ST002A SITe device as its detector. Also at NOAO there is currently a study to determine the feasibility of a large survey telescope for KPNO. The instrument proposed for this telescope would include a camera that would have approximately 1000 CCDs.

6. SUMMARY

NOAO has developed Wide Field Imagers using detectors from Scientific Imaging Technologies, Inc. (SITe). The science grade ST-002A thinned backside illuminated 2k by 4k, three side buttable charge coupled device (CCD) is the backbone of NOAO's large field cameras. The delivered performance in all of NOAOs wide field imagers is excellent. The outstanding qualities of these devices are the low read noise, the high quantum efficiency and low number of cosmetic defects. With these device a read noise of approximately 6 electrons RMS is attainable using double correlated sampling with 3-microsecond dwell. A quantum efficiency of 86% peeks at 6000Å and these devices have response from 4,000Å to 10,000Å. (This data based on an average for SITe ST-002A CCDs tested.) A comparative summary of the parameters of the three wide field imagers now in operation at NOAO is listed below in Table 6. With these wide field instruments NOAO will continue to provide outstanding science.

Table 6 Parameter Summary of NOAO's Large Field Imagers

	MOSAIC I	MOSAIC II	Mini- MOSAIC
Location	KPNO 4-Meter Mayall Telescope; KPNO 0.9-Meter Telescope	CTIO 4-Meter Blanco Telescope	WIYN Telescope Kitt Peak
Arrays	8 SITe ST002A 2048x4096 CCDs; thinned science grade	8 SITe ST002A 2048x4096 CCDs; thinned science grade	2 SITe ST002A 2048x4096 CCDs; thinned science grade
Image Size	(8192 x 8192) + overscan + header @ 16 bits: ~135 Mbytes of Data	(8192 x 8192) + overscan + header @ 16 bits: ~135 Mbytes of Data	(4096 x 4096) + overscan + header @ 16 bits: ~34 Mbytes of Data
Pixel Size	15 μm (0.26"/picel @ 4-m; 0.43"/pixel @ 0.9-m)	15 μm (0.26"/picel)	15 μm (0.14"/picel)
Gain	~3 e-/dn @ 3μs Dwell	~2 e-/dn @ 3μs Dwell	~1.4 e-/dn @ 3μs Dwell
Read Noise	~6 e- RMS	~6 e- RMS	~6 e- RMS
Read out Time	150 Seconds in 8-channel mode; (expected ~ 100 seconds in 16-channel mode)	150 Seconds in 8-channel mode; (expected ~ 100 seconds in 16-channel mode)	182 Seconds (4 video-amplifiers multiplexed through one ADC)
Saturation	Typically, linear to 0.1% to 70,000 e-	Typically, linear to 0.1% to 70,000 e-	Typically, linear to 0.1% to 70,000 e-
Quantum Efficiency	87% peak @ 6000Å	87% peak @ 6000Å	84% peak @ 6000Å
Dark Current	~2e-/pixel/hour	~2e-/pixel/hour	~2e-/pixel/hour
Field of View	36'x36' @ 4-m; 59'x59' @ 0.9-m	36'x36'	9.6' x 9.6'

7. ACKNOWLEDGEMENTS

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