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Laboratory and Telescope Use of the NICMOS2 128x128 HgCdTe Array

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I. Overview

The second generation of Hubble Space Telescope instruments will include a near-infrared instrument. This choice has driven the development of near-infrared arrays to larger sizes and lower read noises. Rockwell International has delivered an array for use in the NICMOS instrument; this array has been dubbed "NICMOS2". NICMOS2 is 128x128 array of HgCdTe diodes In-bonded to a switched MOSFET readout (see Blessinger, *et al.*,this volume). The readout was specifically designed for astronomical use with the HST requirement of low read noise a prime goal. These arrays use detector material which is similar to that used by Rockwell in previous arrays (eg. HgCdTe produced on a sapphire substrate), but the NICMOS2 devices differ substantially from other 128x128 arrays produced by Rockwell in having a read noise of only 30 electrons when read out using appropriate correlated sampling. NICMOS2 has now been characterized in the laboratory, and it has been used on groundbased telescopes.

Table 1 summarizes the properties of the NICMOS2 array.

Table 1: NICMOS2 Characteristics

Detector type	PV HgCdTe
Cutoff wavelength	2.5μm
Readout type	switched MOSFET
Unit cell size	60μx60μ
Nominal operating temperature	60-77°K
Read noise	30 electrons
Dark current @ 60°K	1.5 e/sec

II. Laboratory Tests

Arizona has measured the quantum efficiency, linearity, read noise, uniformity, and response to gamma radiation. In tests which duplicated Rockwell data, similar results were obtained. Dark current data were not acquired using a NICMOS2 array but rather were taken using JFET integrators (see G. Rieke, *et al.* in this volume for a description of the technique); Table 2 summarizes results for a variety of individual diodes with different cutoff wavelengths. In the case of the 2.5-μm cutoff material, Arizona measurements of individual diodes are comparable to the rates measured at Rockwell of 4.5 electron/sec at 77°K and 1.5 electrons/sec at 60°K for NICMOS2 with the output amplifier turned off. Note that the individual diodes have a larger area than the diodes in the array so the lack of a significant drop between the individual diode and array data suggests that a regime is being entered where the dark current is not proportional to diode area. The relatively small drop in dark current between 77°K and 60°K is inconsistent with the dark current being due to generation-recombination and suggests that tunneling may be responsible.

Table 2: Dark Currents for a selection of HgCdTe Diodes

Type	Size	T°K	I_{Dk}(e/sec)
λ_c=1.4μm	160μx160μ	77	6.5
λ_c=2.5μm	130μx130μ	77	9.0
λ_c=2.5μm	130μx130μ	63	2.0
λ_c=3.0μm	50μx50μ	60	6.0
λ_c=4.2μm	60μx60μ	63	200

Of particular interest for NICMOS is the relatively small increase in dark current seen for the 3.0-μm cutoff material as compared to the 2.5-μm cutoff material. This result implies that the NICMOS spectrometer extension to 3.0μm will not exact any large performance penalties.

All of the data reported here were taken using a modified form of correlated sampling. Figure 1 shows this technique where two samples per pixel are taken per readout. One sample is taken at the end of the integration and the second is taken immediately after with the reset enabled. This method also requires that some images (bias frames) with extremely short integration times be taken to calibrate the change in level seen when the reset is released. Bias frames have proven to be very stable over periods of days. The read noise achieved with this sampling technique is 91 electrons; Rockwell saw 80 electrons using a similar method. The 80 electron noise level is what is expected for this technique which is subject to the full kTC noise of the integrating node. A better method which avoids kTC noise and compensates for low frequency drifts is also shown in Figure 1 and is labelled "triple-correlated" sampling. Rockwell has used this method to achieve a readnoise of 30 electrons which is independent of integration time.

Because the read noise as expressed in electrons depends on knowing the integrating node capacitance, this must be measured, and is one of the keys to the good performance of the NICMOS2 array. Rockwell measured the capacitance by measuring the total current flow

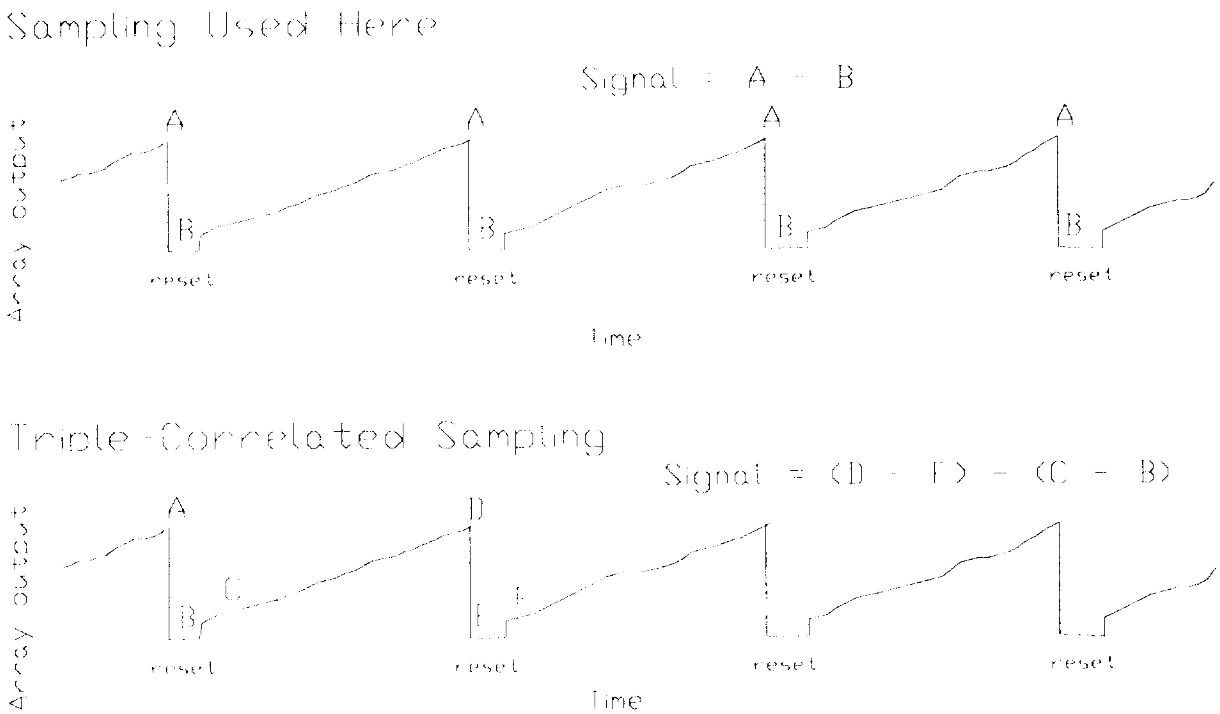

Figure 1: Sampling methods used in reading NICMOS2 arrays.

through the array and obtained a value of 0.10pF with over 80% of the capacitance estimated to be attributable to the HgCdTe diodes. The Arizona measurement took advantage of the fact that signal strength and noise have different dependencies on the capacitance:

$$V_{signal} = ei/C$$
$$V_{noise} = e\sqrt{i}/C$$
$$V^2_{noise} = e^2 i/C^2$$
$$\frac{V_{signal}}{V^2_{noise}} = C/e$$

$C = capacitance,\quad e = electron\ charge,\quad i = photoelectrons/\sec$

The capacitance of 0.127±.035pF measured at Arizona agrees well with the Rockwell data. For the read noises reported in this paper, a value of 0.10pF has been used.

The quantum efficiency was measured for a central region on the array by imaging a spot onto the array. This spot was illuminated by a blackbody source and a combination of cold and warm filters were used to define the bandpass. Figure 2 shows results from a NICMOS2 array at 77°K and an older 64x64 array (Rieke *et al.* 1987). The newer array does not exhibit as sharp a drop in QE towards 1μm as did the older array. The quantum efficiency of the NICMOS2 array was also measured at 63°K and did not change significantly at the lower temperature.

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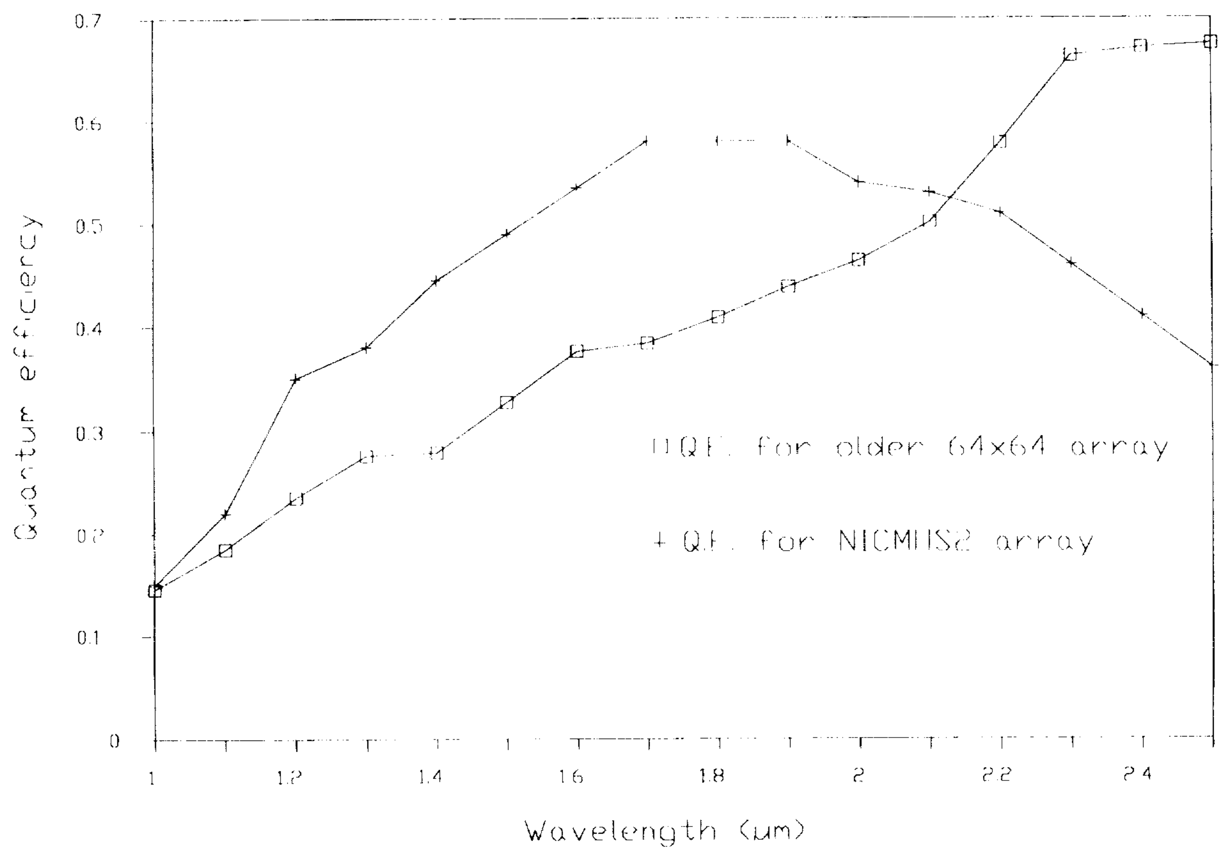

Figure 2: The quantum efficiencies of a NICMOS2 array and an older 64x64 HgCdTe array measured at 77°K.

One problem with the NICMOS2 array which has been used most extensively is its gradient in quantum efficiency from one corner to the diagonally opposite corner. The image in Figure 3 was obtained looking at sky at 2.2μm; no correction procedures of any sort including bias correction have been applied to this image. The gradient in quantum efficiency and "striping" due to column to column variations are apparent. The quantum efficiency ranges from over 70% to about 25% in the worst areas. This gradient is much smaller at 1.6μm and essentially gone at 1.25μm. The "striping" is seen in bare NICMOS2 multiplexers, and is very stable. Flatfielding removes all traces of this column to column structure in the image.

The linearity of the NICMOS2 array has been assessed in two regimes shown in Figures 4 and 5. The array should be subject to an inherent non-linearity because the photocurrent is collected on the combined capacitance of the diode and MOSFET, and the diode capacitance is a function of the bias across the detector and hence depends on how much charge has already been collected (see Hoffman 1987). The degree to which this non-linearity poses a problem depends on how rapidly the diode capacitance varies with bias and on how much effort can be expended on calibrating it and removing it from the data in the image processing steps. HgCdTe diodes have the excellent characteristic that they change in capacitance relatively slowly; from a bias voltage of -0.2 to -0.5 volts, they exhibit a change of only 4% in their capacitance. This voltage range is a typical operating regime for NICMOS2 arrays. Data taken by varying the integration time while viewing a constant source of

Figure 3: An unprocessed image taken of the sky at 2.2μm.

illumination have been used to study the linearity. In the low signal case plotted in Figure 4, NICMOS2 appears very linear with no small signal collection problems seen. In Figure 5, the large signal linearity is examined with no problems apparent until the bias level is approached. The bias used in taking these data was 0.5 volts which yields an effective well-depth of about 300,000 electrons. No linearity corrections are needed if NICMOS2 is operated at less than 85% capacity, and no corrections have been applied to the telescope data reported below.

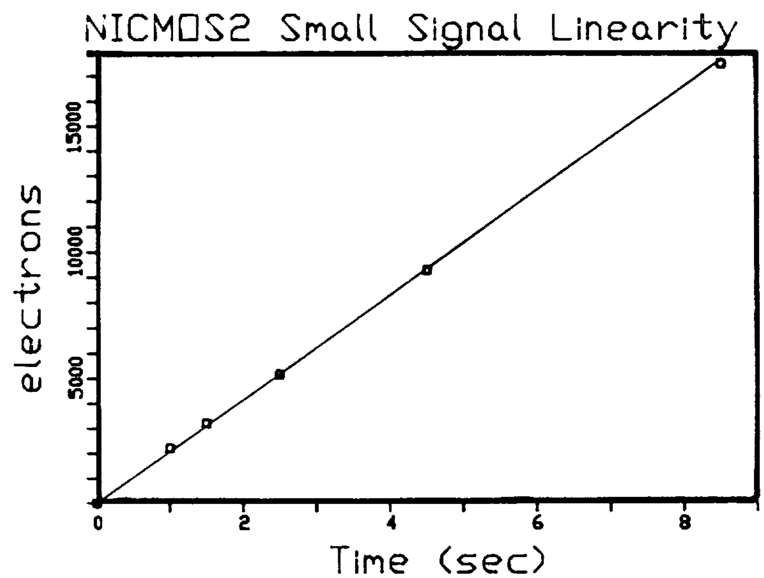

Figure 4: Small signal linearity for a NICMOS2 array.

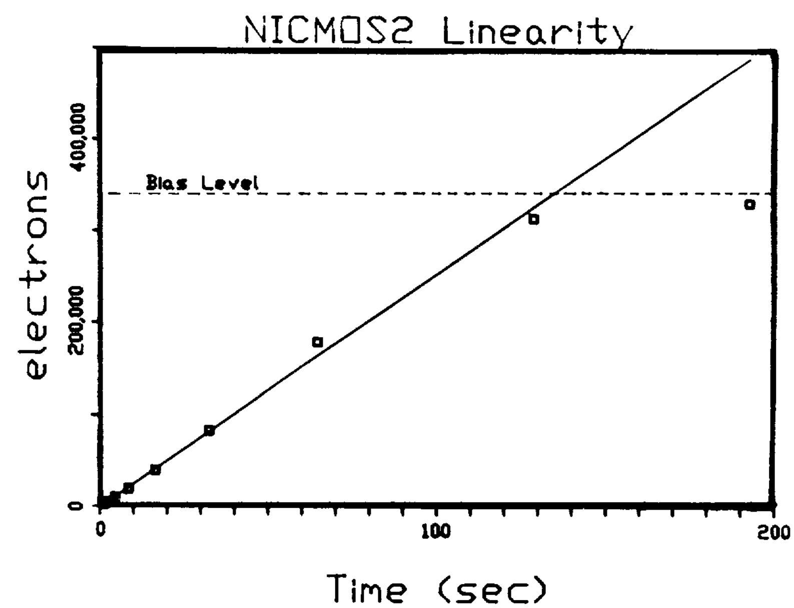

Figure 5: Large signal linearity for a NICMOS2 array. The bias level corresponds to 0.5 volts.

Another important attribute of an array intended for use in space is the ability to withstand charged particle hits. NICMOS2 arrays have not themselves been subjected to radiation testing. A similar readout has been, and limited testing of HgCdTe diodes has been carried out. In both cases, the testing consisted of exposing the device to a 10 mCurie Am^{241} gamma-radiation source mounted within a few centimeters of the device being tested. In other situations the deposition of energy by gamma rays induces effects similar to those induced by other types of radiation; more extensive testing of NICMOS2 arrays and HgCdTe diodes should be done to verify this assumption. A TCM-1000B switched FET readout with 2.5-μm HgCdTe diodes showed no sensitivity changes when exposed to the Am^{241} source. This test was conducted with the array viewing a relatively high background. The other test consisted of exposing a 3.0-μm diode being read out with a JFET integrator to the radiation source. This diode showed complete recovery to its normal dark current 5 minutes after being irradiated at 20% of an HST South Atlantic Anomaly passage. Recovery may have been faster, but a few minutes are required for an accurate dark current measurement at these levels. Other testing at Rockwell has not revealed any problems, but more radiation testing is needed before certifying the NICMOS2 array for space use.

III. Telescope Use

The NICMOS instrument will operate at wavelengths where observations can be done from groundbased sites. A camera for such use has been built, and the performance of the NICMOS2 in an actual astronomical situation has been characterized. The camera is shown schematically in Figure 6. Note the use of a cold pupil and cold filters to limit the radiation reaching the detector array. The background levels at 2μm from a groundbased telescope are not very different from those expected at this wavelength on HST because the larger pixel scale used on the ground is compensated by the fact that HST is warmed to temperature of 76°F, much warmer than is typical for a groundbased site. At shorter wavelengths the groundbased backgrounds are much higher than will be seen from HST because of the OH-airglow.

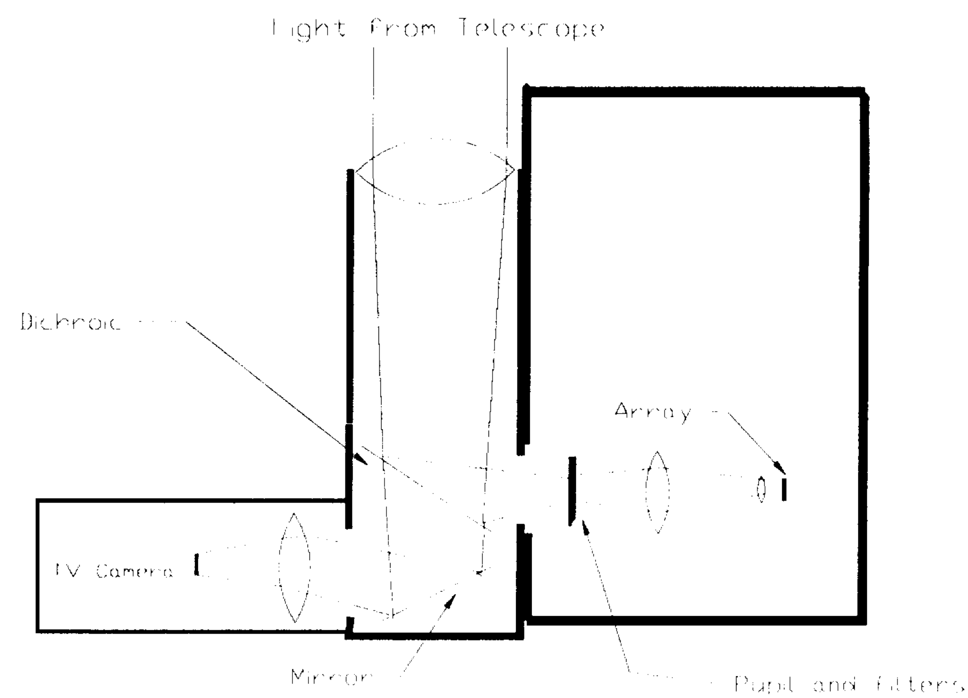

Figure 6: Camera optics schematic

The equipment used to read out the array at the telescope is very compact and is based on clock waveforms being generated using EPROMs. The hardware does not do any of the differencing required by the readout sampling; all differencing is done in the computer controlling the array readout (a 80386-based computer in this case). The readout electronics themselves are very compact and occupy a volume of only .009 cubic meters. These electronics digitize to 16-bits and when used with the NICMOS2 array provide a gain such that one unit of the digitizer corresponds to 19 electrons. The system noise without an array is 40 electrons, and with the array, yielded a read noise of 91 electrons. The electronics also include protection circuits for all lines controlling the array and a real-time video display which is very useful for focussing and alignment.

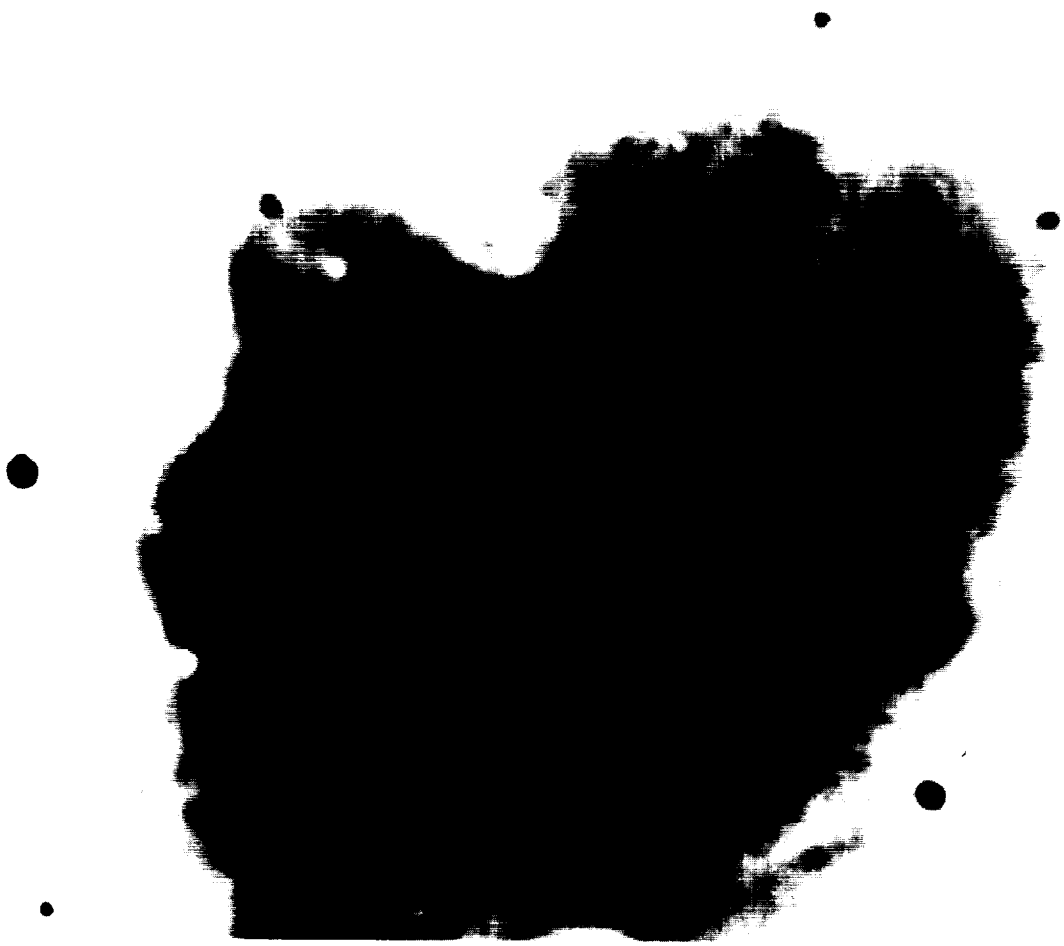

Figure 7: The Crab Nebula at 2.2μm.

Figures 7 and 8 show fully reduced data taken with the NICMOS2 camera using the Steward Cbservatory 1.5-meter telescope on Mt. Bigelow, AZ. The telescope has an f/45 infrared secondary which was used for these observations. The plate scale of 1.8"/pixel is optimized fc - studying extended sources. This plate scale yields a total field-of-view of 3.8

arc minutes. These images were produced by beam-switching between the object and adjacent sky every 60 seconds. The 60-second exposures which were recorded for analysis consisted of 6 co-added 10-second exposures which were necessary to avoid overfilling the array. The final pictures were produced by subtracting a bias frame from each of the object and sky frames, ratioing the resulting frames on a pairwise basis, and then averaging all of the ratio frames. This is the same technique that has been used with our previous arrays (Rieke *et al.* 1987), and results in flatfielding to 1 part in 20000. The sensitivity achieved using the NICMOS2 array at K(2.2μm) on the 1.5-meter is 21.5 magnitudes per square arc second (one sigma in one hour of integration composed of co-added frames).

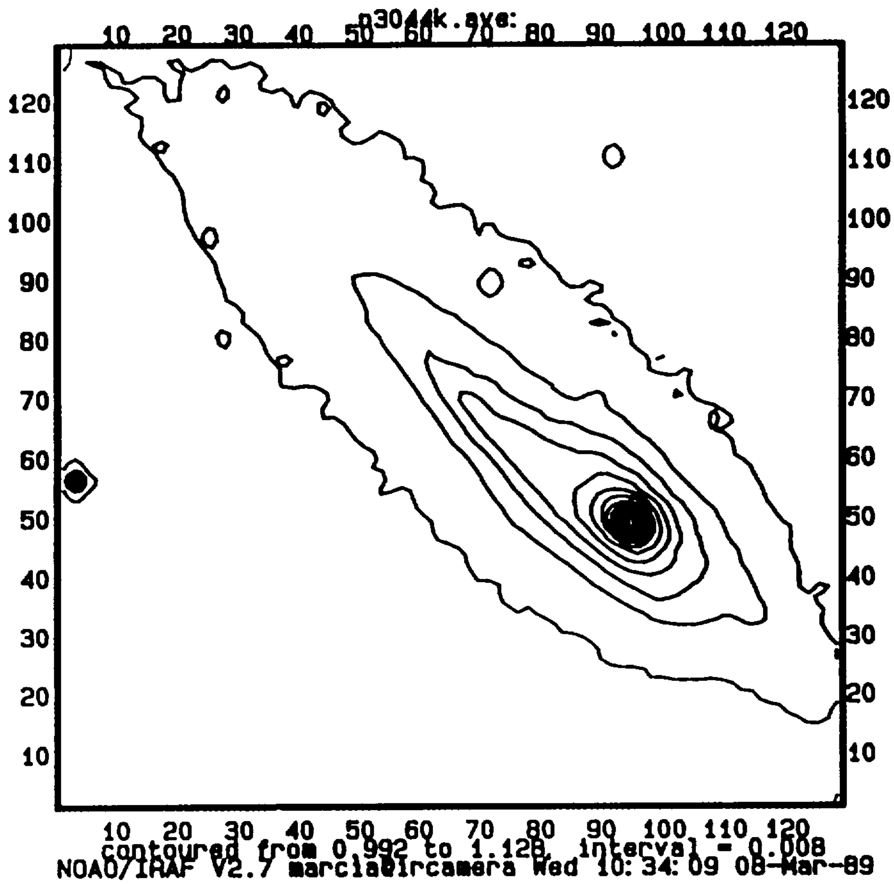

Figure 8: Part of the edge-on galaxy NGC3044 at 2.2μm.

At this point, the full capabilities of the NICMOS2 array have yet to be exploited in groundbased use, but it has already shown that it is capable performer.

IV. Summary

The NICMOS2 128x128 HgCdTe array developed for use on HST is a significant step forward in the technology available to astronomers. Its readout has been designed with astronomical use in mind, and it delivers a level of performance at 30 electrons read noise that will permit full use of HST as well as very interesting investigations from the ground.

V. References

Hoffman, A. W. 1987, in Infrared Astronomy with Arrays, ed. C. G. Wynn-Williams and E. E. Becklin, p. 29.

Rieke, M. J., Rieke. G. H., anf Montgomery, E. F. 1987, in Infrared Astronomy with Arrays, ed. C. G. Wynn-Williams and E. E. Becklin, p. 213.