The MDM/Ohio State/ALADDIN Infrared Camera (MOSAIC)

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ABSTRACT

The MDM/Ohio State/ALADDIN Infrared Camera (MOSAIC) is a general purpose near infrared (0.9-2.5 micron) imaging camera and medium-resolution (R=1300) long-slit spectrometer in use on the MDM 1.3-m and 2.4-m telescopes and the Kitt Peak 2.1-m and 4-m telescopes. In cooperation with NOAO and USNO, MOSAIC is one of the first general-purpose near-IR instruments available to the astronomical community that uses a first-generation 1024×512 ALADDIN InSb array, with the capability to use a full 1024×1024 array once one becomes available. MOSAIC provides two imaging plate scales (narrow- and wide-field), and a variety of long-slit grism spectroscopic modes. This paper describes the general instrument design and capabilities, and presents representative scientific results.

Keywords: Infrared, Imagers, Spectrometers, Astronomical Instruments

1 INTRODUCTION & HISTORY

The MDM/Ohio State/ALADDIN Infrared Camera (MOSAIC) is a joint project of the Ohio State University (OSU) and the Michigan-Dartmouth-MIT (MDM) observatory to provide a state-of-the-art facility IR imager and spectrometer for the 2.4-meter Hiltner Telescope. MOSAIC was built by the OSU Imaging Sciences Laboratory (ISL). The first phase instrument was begun in late 1994 (using OSU and later MDM funds) and was deployed with a 256 NICMOS-3 HgCdTe array in late 1995.

In early 1996, OSU and MDM entered into an agreement with the United States Naval Observatory (USNO) and the National Optical Astronomy Observatories[1] (NOAO) to obtain a loan of one of the first of the new-generation ALADDIN InSb arrays being produced by Santa Barbara Research Corporation (SBRC). In exchange, OSU and MDM have made MOSAIC available to the general KPNO user community. The present ALADDIN array has two adjacent working quadrants giving an overall 1024×512 pixel imaging area. This format is ideal for the spectroscopic capability described below. Since October 1997, MOSAIC has been in regular use as a facility instrument at MDM on the 2.4-m and 1.3-m telescopes, and at KPNO on the 2.1-m and 4-m telescopes.

In building MOSAIC we have drawn extensively upon our experience with the construction of OSIRIS[2]; copying many of the successful OSIRIS sub-systems. Although we use an updated version of the IR array controller currently used in OSIRIS, many of the mechanisms follow the same general mechanical design (e.g., filter and slit wheels with indented positions and rim-driven by cryogenic stepping motors), and the dewar design is very similar.

The name of this instrument has changed a number of times. As originally conceived, the design included a tip-tilt correction system for use with the 2.4-m Hiltner telescope, and so was it was dubbed the "MDM/Ohio State *Active* Infrared Camera" or MOSAIC. When funding was not secured for this feature, the name changed to the "MDM/Ohio State *Array* Infrared Camera," preserving the MOSAIC acronym. After the agreement with USNO and NOAO for an ALADDIN InSb array, *Array* was changed to *ALADDIN*. While this is acceptable for use at MDM, at NOAO this name conflicts with that of the 8K×8K CCD-mosaic camera, and we were asked to change the name, at least for use at NOAO. We settled upon the alternative name TIFKAM ("The Instrument Formerly Known As MOSAIC"), whereupon NOAO dubbed the instrument ONIS ("Ohio-State Near-Infrared Spectrometer"). We shall refer to it as MOSAIC throughout this paper.

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* Operated by the Association of Universities for Research in Astronomy, Inc. under cooperative agreement with the National Science Foundation.

2 INSTRUMENT OVERVIEW

A plan view of the instrument is shown in Figure 1. All optics are mounted on a cold optical bench that is kept at 77K by an internal LN_2 reservoir (a "wet" optical bench). Internal heat shields further isolate the inner cold bench from the dewar's vacuum shell.

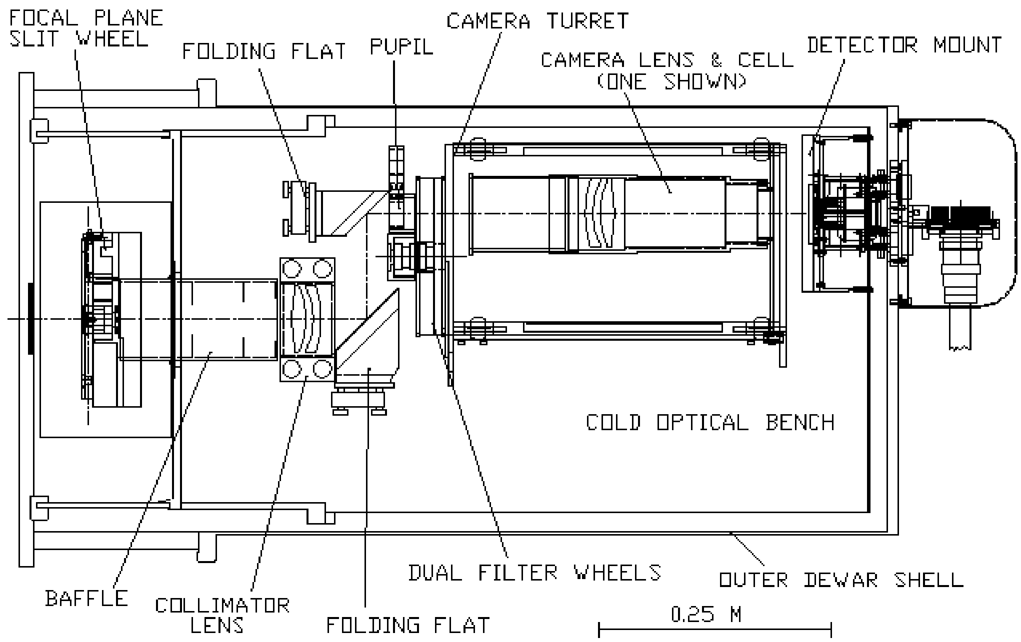

Figure 1: Plan view of MOSAIC, showing major components.

Light enters from the telescope through a dewar window and is focussed onto a focal plane slit wheel that provides both cold masks for imaging and the spectroscopic slits, as well as a cold dark mask. At the end of a cold baffle, a doublet *f*/7.5 collimates the beam. The doublet is made of BaFl and Schott IRG-2 components. This combination of glasses makes an excellent near-infrared achromat, although the Schott IRG-2 glass is expensive and difficult to obtain. The performance of the collimator is essentially diffraction limited. After collimation a pair of gold-coated folding flats create an image of the primary pupil at a cold Lyot mask. This mask mounted on a remotely-operated 2-axis adjustment system, and has been optimized for use with the 2.4-m Hiltner and 4-m Mayall telescopes. Behind the Lyot stop is a pair of 9-position filter wheels that can accommodate a total of 16 filters and grisms (including positions reserved as "open"). Up to four re-imaging cameras can be mounted in a rotating turret that provides both camera select and focus. At present, MOSAIC has three cameras: an *f*/7.5 wide-field camera (another BaFl/Schott IRG-2 doublet), an *f*/16 narrow-field camera (a telephoto comprised of a BaF/Schott IRG-2 doublet and a BaF singlet), and a Silicon lens pupil viewing camera. This latter allows the observer to view an image of the pupil, providing a means to precisely align the cold Lyot stop with the secondary mirror spider of the telescope, ensuring optimal rejection of much of the thermal background from the telescope.

The detector is mounted in a separate detector mount that can be removed from the instrument without removal of the outer dewar shell or internal heat shields. For the ALADDIN InSb array (see below), this detector mount includes an integral cryocooler to keep the detector at its operating temperature of 35K. The detector is further mounted behind a piece of polished, AR-coated BK7 to provide further rejection of long-wavelength IR radiation from the relative warm (77K) optical bench and internal heat shields. A discussion of the residual thermal background is given in the next section.

There are 7 mechanisms in MOSAIC. These include a focal plane mask wheel, x and y pupil mask motions, the two filter wheels, and camera select and focus. As in OSIRIS, all mechanisms are driven by stepping motors mounted direcly to the cryogenic worksurface. There are no mechanical breaks in the dewar; only electrical connections are passed through the dewar shell. Along with the modular detector mount, this makes assembly of the instrument straightforward. The motors and mechanisms have proven very reliable and robust. Including those in OSIRIS, these designs have survived more than 100,000 revolutions with no failures.

MOSAIC is under complete computer control using the OSU Instrument Control and Image Acquisition System (ICIMACS, see Mason et al. in these proceedings), a set of custom PC hardware and software that ties together the instrument control electronics, the array controller, and (at KPNO) the telescope control interface. The observers use the *Prospero* package on a Sun workstation. *Prospero* is an interactive instrument control and data acquisition environment that serves as a user-friendly front-end for the ICIMACS system. It is documented online at http://www.astronomy.ohio-state.edu/~prospero/.

3 IMAGING MODE

MOSAIC has three imaging cameras: two science cameras (*f*/7 and *f*/17) provide wide- and narrow-field imaging, and a third pupil viewing lens used to align the cold Lyot stop with the telescope secondary mirror and support structure. Cold masks in the focal plane wheel are used to block stray light outside of the field of view of the detector and camera from entering the system. The pixel scale depends on the telescope used, and is summarized in Table 1.

Table 1: MOSAIC Imaging Modes

	Telescope			
Camera	MDM 2.4m	MDM 1.3m	KPNO 2.1m	KPNO 4m
f/7	0.30"/pixel	0.55"/pixel	0.34"/pixel	0.18"/pixel
f/17	0.14"/pixel	0.26"/pixel	0.16"/pixel	0.08"/pixel

Figure 2 shows a typical image obtained with MOSAIC. The internal optics perform very well and do not degrade the best seeing we have experienced (~0.5") and maintain a very constant point-spread-function over the entire field-of-view of the 1024×512 detector array.

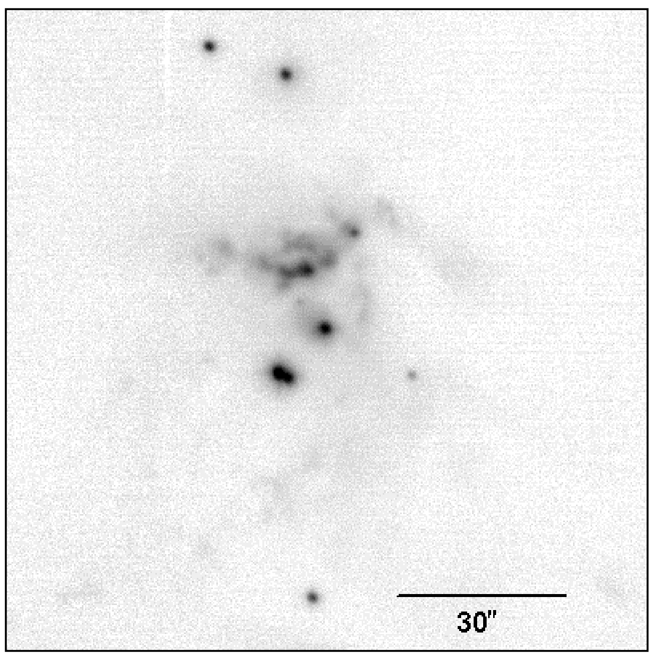

Figure 2: H-band image of the the Galactic Reflection Nebula NGC 2071 made with the 2.4-m Hiltner Telescope using the *f*/7 camera. A log intensity stretch was chosen to emphasize the faint nebulosity. Seeing for this image was 0.9" (FWHM).

4 SPECTROSCOPIC MODE

Spectroscopic capability is provided by grisms inserted into the beam by the filter wheel. Table 2 summarizes the resolutions and wavelength coverages of the various possiblities.

Table 2: MOSAIC Spectroscopic Modes

Grism	Resolution (2 pixel)	Wavelength coverage
J/K	1360	900–1300 nm (2nd order)
		1800–2700 nm (1st order)
H/L	1100	1100–1800 nm (2nd order)
		2200–3600 nm (1st order)
J+H	780	900–1800 nm (1st order)
JHK	650	1200–2400 nm (1st order)

Note that the actual wavelength coverage will depend on the filter selected in the other filter wheel (i.e. if using the J/K grism and the K filter as a blocker, the wavelength coverage will only be 2000 to 2400 nm due to the transmission of the filter); in Spring 1998 we will be installing special filters to use specifically as spectroscopic blockers. The table gives the resolution assuming the 50 micron slit is also inserted into the beam; this corresponds to roughly two pixels FWHM for unresolved lines. There is also a 100 micron slit that will give four pixels per resolution element and correspondingly lower spectral resolution. Note that this slit is recommended when the seeing is poor or when observing spectroscopically on the KPNO 4m (where the 50 micron slit is only 0.36" wide). Note that there may be a 25 micron slit in the instrument (as of January 1998). This slit in principal could be used with the f/17 camera to give resolutions as high as ~2800, but the slit width is very narrow (only 0.28" on the MDM 2.4m; 0.16" on the KPNO 4m) and thus has poor effective throughput.

5 THE *ALADDIN* ARRAY

The ALADDIN InSb array installed in MOSAIC has 27μm pixels and two adjacent working quadrants giving an active area of 512×1024 pixels. The optics, detector mounting, and array controller electronics are all designed to eventually accommodate a full 1024×1024 array once one becomes available to us.

There are many dead, hot, unresponsive, and just plain bad pixels on the array. There is a large group of essentially dead pixels in the upper left corner of the array (referred to as the "fingerprint" region for obvious morphological reasons) and many scattered bad pixels in the upper right corner of the detector. The large number of bad pixels makes it essential to "dither" images so that all pieces of the sky are measured by a good pixel. To assist observers, we keep a current bad pixel mask on the instrument web page at OSU.

5.1 Thermal Control

The dewar work surface of MOSAIC is maintained at 77K using LN_2 in a “wet” optical bench. The InSb array, compared to the HgCdTe array we used in the first-stage instrument, requires additional cooling at the detector surface (to at least 35K) and additional thermal shielding to reduce the thermal loads on the detector mounting. Rather than use large external closed-cycle coolers (like the CTI and Balzers coolers with high-pressure Helium lines plumbed into the telescope currently in use at KPNO and CTIO), we have adopted a modified detector mounting that includes an integrated split-Sterling closed-cycle refrigerator (see O'Brien et al. 1998 in these proceedings). This cooler operates internal to the dewar, with no high-pressure Helium lines. This unit has proven to have more than sufficient capacity to cool the detector reliably to 35K with comfortable overhead. This makes the MOSAIC system very portable, as we do not need to rely on external cryocooler infrastructure.

5.2 Dark Current, Readout Noise, and Linearity

The dark current in the array is low. We currently measure ~0.3 DN/sec dark current, some of which may be due to background radiation in the dewar. The dark current is measurably higher during the first 36 hours after cooldown (about the equilibrium time for all elements on the cold optical bench), or if the array cryocooler has lost power

The read noise of the array is ~10 DN. The effective read noise of the detector can be reduced by reading each pixel's signal non-destructively many times; factors of 2–3 improvement are possible. Note, however, that a read noise of 10 DN is low compared to the shot noise for signals greater than ~1000 DN, which happens quickly in most imaging and low-resolution spectroscopic observations.

The array becomes significantly non-linear before the well capacity of the detector is reached. Further, an accurate non-linearity correction depends on the signal rate as well as the total signal collected. However, non-linearity is <1% for <11,000 DN at signal rates ranging up to ~600 DN/sec (about the background rate at K on a warm night with the f/7 camera). We are working on obtaining more information about the reproducibility and signal-rate-dependence of the non-linearity; we currently find that if observers keep interesting signals <8000 DN the non-linearity corrections are <0.2%. Hard saturation of the detector array occurs at about 25,000 DN. The array becomes seriously non-linear (>5%) at about 17,000 DN.

5.3 Residual Image

The ALADDIN array in MOSAIC exhibits a residual signal from bright sources. The magnitude of the residual image seems to depend on the brightness of and total signal recorded from the source. For typical observations the residual will be 0.5–2% of the originally detected signal. Reading the array several times reduces the magnitude of the residual image to <1% of the original signal.

We do not yet know if the cause of the residual image is our particular read-out electronics (reset voltages, bias level, etc.) or if it is intrinsic to the detector array. Other InSb arrays operated by KPNO do not seem to show this level of residual image, but the particular detector in MOSAIC has not been thoroughly evaluated using a KPNO system. For high photon-rate situations, we have adopted the strategy of dithering the telescope faithfully between images and reading the array several times (3–4), keeping only the last frame as the "science" exposure. For bright objects where intrinsic integration times are naturally very short, the loss of efficiency is a small price to pay to ensure photometric accuracy. Due to the effects of the current El Niño, however, we do not yet have enough data acquired under photometric conditions to quantify the absolute accuracy of bright-object photometry acquired in this way.

6 ACKNOWLEDGEMENTS

The construction of MOSAIC was initially funded by OSU, MDM, and the Massachusetts Institute of Technology (MIT). We thank G. Wegner (MDM/Dartmouth) and Paul Scechter (MIT) for their support. NOAO and USNO paid for the development of the ALADDIN arrays and contributed the array currently in use in MOSIAC. R. Green (NOAO), and S. Wolff (NOAO) were important contributors to this effort; A. Fowler and R. Joyce (NOAO) provided much useful technical support. The upgrade of the instrument for spectroscopic use was funded by NSF grant AST-9605012.

The movement between and use of MOSAIC the four telescopes on Kitt Peak has been handled by the KPNO mountain staff and MDM technical support. We particularly wish to thank B. Barr (MDM) and B. Bohannon (KPNO) for their patience and understanding through the transitional times.

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