Mosaic II

State of the Instrument, July 2005

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DRAFT

This document outlines the condition of the Mosaic II imaging camera as mounted on the prime focus of the V. M. Blanco telescope. The instrument is reasonably stable, productive and in demand from observers. It is expected to continue in service until replaced by a similarly or more capable facility, e.g. DECam (2008/9). This review aims to establish what might be necessary to achieve this within the current CTIO context.

The CCDs

The SITe CCDs used in Mosaic II, by modern standards, are slow and have a small full-well. The QE curve is no longer state-of-the-art. The CCDs could have better readout noise, but this is not a high impact parameter given the uses to which the instrument is put. The blue QE of these CCDs is quite good, but the transmission curve of the Blanco corrector does not allow this to be fully exploited. They are cosmetically adequate and, insofar as has been tested, appear to be stable in their response.

There is no evidence of any degradation in these devices (although the precision to which this can be stated is not clear). In the operational lifetime of the instrument, only one CCD has failed. While no cause was definitively identified, it is likely that the damage was due to human error. Should another fail, we will certainly have great difficulty in finding a replacement.

To replace the CCDs in Mosaic II with appreciably better detectors would require a completely new program involving market research, identification of funds, purchasing, installation, optimization and commissioning. 8 new CCDs alone would cost of the order of US$0.5M. Such a program, even if manpower were available on-demand, would take at least a calendar year to complete and probably significantly more.

Electronics

Arcons

The detector controllers used by Mosaic II are dependent on obsolete and unavailable components. CTIO in particular and NOAO in general no longer possess the in-house knowledge required to do more than routine and high-level maintenance of these controllers. CTIO's knowledge of the software running on them is minimal, KPNO lacks for hardware support (that is not to say that KPNO possesses all the software knowledge that CTIO lacks). KPNO depend on CTIO for repairs to failed Arcon boards. All development of these controllers has been frozen since the departure of R. Smith and M. Bonatti. In anticipation of their departure, higher priority was given to work in other areas and Mosaic documentation was not completed.

The remaining staff we have with significant knowledge of Arcon controllers is based in La Serena, have been working on later model controller systems in recent years, and have not been required to extend their knowledge of the older systems except insofar as is necessary to solve problems as they arise. The mountain staff have been encouraged to develop their expertise with Arcons, with some progress.

While reasonably stable, all Arcons have a tendency to intermittently freeze up with no obvious cause. The normal solution is a reboot or power cycle with the concomitant loss of observing time which constitutes a significant fraction of the total downtime of the Blanco observing system. The true frequency of these lockups is not known, although it is probably reasonable to estimate a hang at least every other night; a hang can cause the loss of an entire exposure. In principle, it should be possible to introduce some automatic method of detecting the hangs, but resources have not been available to do the work.

If better CCDs were purchased for Mosaic II, it would probably force the replacement of the Arcon controllers simply because they cannot be operated fast enough to take advantage of modern, faster readout CCDs. In the current system, the SITe CCDs provide the readout speed limit themselves, but Arcon is not far behind.

Sparcstation host computer

The Mosaic II control system is dependent on an interface to a Sparc host computer running SunOS, both of which are obsolete. The Arcon TRAMbox which manages communications between an Arcon and its host computer are specific to the S-bus hardware. Sparc host computers are still obtainable and CTIO can continue to maintain SunOS for the foreseeable future. This is not an ideal situation because it forces CTIO to retain obsolete skills and obstructs the continued rationalization of our computer stock. The alternative is either to replace the entire system with a newer generation controller, or to redesign the communications interface. The latter requires knowledge of the Arcon controllers at a level we no longer possess.

A complete Sparc/SunOS computer system is in hand and the computing group are working on purchasing two more for contingency.

It was intended that Rafael Hiriart be assigned some responsibility for this system, but his workload has prevented this.

TRAMbox

The greatest cause for concern within the Mosaic II controller system is the TRAMbox. These units manage communications between the host computer and the Arcon boxes. They are dependent on technology (transputers, and possibly others; transputers are also present in other Arcon components) which are no longer available – the boxes contain, among other things, a mother board and 4 daughter cards. Only two were built, one for each mosaic; mother boards are unobtainable, some (~2) spare daughter boards exist but the exact number and location are currently unknown.

A simple upgrade of the TRAMbox is unlikely to be practicable – we don't have enough knowledge of the interfaces and the concomitant risk in reverse engineering existing, working devices implies it might be best to "let sleeping dogs lie".

A new controller

The only realistic way forward with the Mosaic controller system is to completely replace it. The obvious candidate is a Monsoon system. The current CCD front end design provides 8 channels and 36 clocks. Two such controllers would be required to run Mosaic II. Alternatively, we could wait until a 16 channel version is produced, or press for its development with Mosaic II (and, presumably, Mosaic I) specifically in mind. If a single, 16-channel Monsoon is used, longer signal cables will be required (the connections emerge from the dewar at two opposed ports) which may have consequences for the performance of the Mosaic.

The current Monsoon design is not subject to any space constraint and is not optimized for heat dissipation. Space is not likely to be a problem for the Mosaics, but heat load may well be. There are plans for more compact and thermally efficient Monsoons and we may be able to piggyback on other development programs (e.g. DECam).

A Leach III controller might make an adequate second candidate, since we are developing expertise with its deployment on Cerro Pachon. Either way, if the Mosaic controllers are to be replaced, we must embark upon a program of development, including controller R&D, purchase/construction, installation, verification and commissioning phases.

Optics and Image Quality

The optical performance of the Mosaic II is adequate for the science currently being attempted, but it is not spectacular. Improving the image quality delivered by the Mosaic II is largely beyond the scope of this document, being controlled by such things as thermal equilibration in the dome and the figure of the primary mirror, but it is reasonable to make some statements concerning the corrector and modes of use of the Mosaic.

The Blanco prime focus corrector is known to compromise the data to some degree. Some of the more demanding observers have claimed various effects, including visibly elongated images, circular distortion patterns and failures of repeatability. None of these have been clearly substantiated, repeated, nor traced to a specific fault. Nevertheless, we do suspect the ADC to be affecting image quality with the Mosaic simply because it is damaged – the result of a failure of the mount which removed large chips of glass around ~75% of its circumference – the repair seems to have been successful, but a large fraction of the corrector's circumference remains unsupported.

Efforts to trace and quantify these problems have been limited – not for want of trying, several efforts have been obstructed by bad weather, but some recent results seem to suggest that in stable seeing, the changing pattern of stellar FWHM through focus across the mosaic is stable. Simple tests appear to show the corrector control to be working correctly, although on its removal and replacement early in 2004 the encoders were not reset and a number of observing runs were compromised before the problem was identified and fixed. More work should be done to verify the proper performance of the corrector.

Astrometric performance

The distortion terms change on the timescale of a year, introducing systematic errors of the order of 0.05-0.1 pixels. If the WCS distortion terms are verified on a regular basis (i.e. Armin Rest recommends approximately every second month, Buell Jannuzi suggests every six months) an astrometric accuracy between 0.1 and 0.2 pixels can easily be achieved. The pipeline now in use in the SMSN program provides high quality solutions that can be made available to the community.

Focus

Investigations of the focus procedure suggest that this may be a significant contributor to sub-optimal image quality. Work over 2003/4 with the Blanco active optics system has apparently improved image quality significantly and this has been ongoing together with study of the focus so it is difficult to disentangle the two.

Much of what is understood about Mosaic II & Blanco focus is anecdotal in origin and many observers have generated their own techniques for acquiring best focus. The default, and naïve mode is to use the canned IRAF/*mscfocus* routine. Unfortunately, while this software is relatively straightforward to use, it makes some questionable assumptions about the data and is time-consuming to use thoroughly.

The software takes series of stellar images acquired in a through-focus sequence, measures a FWHM (via a Moffat function by default), and fits a parabola to the lowest point in these sequences and its nearest two neighbors. The sequences of images used are identified interactively by the observer and who may interactively delete wild points before the fit.

It is rare that an observer has time to acquire sufficient sequences to properly map out the focus over the Mosaic's field of view, the trimming process is prone to error, and the minimum of the focus curve may not represent best focus. Careful examination of full focus frames, obtaining as many sequences as possible, show that the point of best focus can vary across the field of view, that focus sequences can contain stray points that are not easily identified in the *mscfocus* routine, and the variation of image size with focus value need not be smooth.

The last item may have a variety of causes. At the time of the first version of this document, recent work with the active optics seemed to have improved the situation somewhat[1], but poor astigmatism returned within a couple of months. The infamous "W"

[1] The author is suspicious of this improvement because it is based on an active optics lookup table built from a Hartman map with apparently more noise than signal and subsequent investigations have exposed bugs in the software used to generate these maps. On the other hand, the author doesn't go looking gift horses in their mouths.

shape to the curve may have gone away, but this may also be an artifact introduced when the focus is particularly good and the limitations of the corrector exposed.

It is also clear that seeing variations have a significant effect and it is possible that a large fraction of focus frames are compromised – if the seeing changes significantly during a focus frame, which are often obtained under precisely such conditions (e.g. at the beginning of the night while the dome & telescope are still equilibrating), then the result will be to apparently shift the point of best focus. This could contribute up to around ~0.2" to the seeing under typical conditions, without the observer being aware.

The Blanco Instrument Review Panel report on the DECam instrument recommended that we explore installing an independent focus stabilization mechanism. What the panel had in mind was something like the system used to great effect at AAT where an invar wire between the primary mirror and prime focus camera is used to actively measure the expansion and contraction of the telescope and adjust the focus accordingly. AAO reports stable focus with this mechanism over timescales of months after a single focus calibration. Blanco's flip ring would undoubtedly complicate such a system, but it may be worth exploring the possibility.

Kitt Peak are developing a system for determining focus drifts (*not* point of best focus) using the unused guide camera to measure changes in stellar FWHM. It may be useful to adapt Mosaic II to this system once its effectiveness has been explored.

A program for automatically identifying sequences in a focus frame has been written and tested although a version suitable for use at the telescope is not yet available. Using a simple template-matching algorithm, this program will typically generate reliable focus measures without the limitations of *mscfocus* and using the entire field of view of the Mosaic.

Filters & filter mechanism

The Mosaic II filter mechanism exhibits occasional failures usually to do with the compressed air supply and easily repaired. In recent years, filters have occasionally been found loose in their holders and twice have fallen out; changes to operational procedures have resolved this issue. Recent inspections have revealed the presence of fine metallic dust in the mechanism, probably due to normal wear and tear – subsequent investigation off the telescope proved this to be the case and repairs were effected. There is no obvious reason to explore changes to the filter wheel mechanism.

CTIO & NOAO's stock of filters for the Mosaics has been sufficient to supply the vast majority of observing programs. A small number of programs have been able to purchase their own filters for particular purposes. There is no obvious need to consider expanding our suite of filters.

The discussion of focus issues elsewhere in this document has the obvious corollary that the focus offsets between our filters are not known with a high degree of confidence, although they appear to be reasonably well determined for most programs.

Operational issues

Operational Performance

The greatest limits to Mosaic II's performance in use are the readout time and the stability of the software. Both have been mentioned above, and neither have an immediate nor straightforward solution. The long readout time impacts not just in-program efficiency, but also the ease and thus frequency of focusing, and the accumulation of twilight flat fields. The stability of the software impacts all aspects of the instrument's use but overall is at the level of a minor irritant such that lock-ups often go unreported even after reporting procedures have been better enforced.

Software and data handling

The Mosaic II software interface is adequate to the task. The implementation of *mosocs* has significantly enhanced functionality with minimal cost. We may wish to consider extending this facility. VNC has proved very successful, enabling fairly routine remote observing from La Serena and facilitating easier monitoring and troubleshooting. Save the Bits runs smoothly and successfully fills its role as a means of data insurance. Integration into the nascent observatory database is obviously something we should pursue, but progress is resource-limited and not yet of high priority. No complaints have been received regarding the data transport methods available to observers, although recent observers have requested DVD format.

Guiding

The Mosaic II guiders appear to work adequately for the purposes of all proposed programs. That is, no-one has complained although there are occasional instances of extended images and the guiders are an obvious target. Nevertheless, they have not been found to be the direct cause.

Temperature control

Examination in 2003 of accumulated data headers showed that the Mosaic II FPA is not held at a constant temperature. Investigation of the Arcon controller software revealed that the temperature control loop was deliberately disabled at some unknown point, probably during commissioning of the instrument during efforts to improve thermal contact between the FPA and the LN_2 can. As it was, thermal contact was not improved to the point that the planned for temperature set point (-100ºC) could be achieved and the code modification was forgotten.

The result is a variation in FPA temperature with amplitude up to 10ºC over the course of a year (or up to ~3ºC in a night). Curiously, correlation with ambient temperatures is not obvious, although there may be some correlation with dewar orientation.

In most cases, this variation is not likely to have a significant impact on the data. The one major exception is the SDSS *z* filter which does not have a red cutoff. The red limit to observations with this filter is therefore provided by the sensitivity limit of the CCD which has significant temperature dependence. Observers have reported difficulty calibrating *z* band data taken with Mosaic II and this may explain why.

This issue could be resolved by:

1. Running the mosaic hot so that the temperature control loop can operate appropriately. This will probably increase the dark current in the instrument and will adversely affect programs not using the *z* filter.
2. Improving thermal contact between FPA and LN_2 can. This is not a trivial exercise and considerable effort has been made already. Nevertheless, it may be worthwhile revisiting the issue.

A related issue is the impact of the Mosaic II on its own environment. Recent inspection with the thermal IR camera has revealed that the Mosaic controller is one of the few significant heat sources in the Blanco telescope's dome and the top end power draw lies between 200 and 600 watts.

Absolute timing

After the Arcon NTP time synchronization software was engaged, the uncertainty of the absolute timing keywords given in the image headers improved to within an envelope of width 1.5 seconds. The remaining error appears to contain internal structure which implies a computational or truncation error in the code somewhere.

The vast majority of observing programs are unaffected by such an error and the cost/benefit ratio of an attempt to improve precision further is probably too high to be worthwhile.

Exposure Time Calculator

The web ETC is based on the IRAF CCDTIME calculator and is believed to be reliable. However, the sky background used is the CTIO dark-sky during the solar minimum and is not appropriate for the rest of the solar cycle.

Manual

The original manual available on the web is out of date. It has accreted a number of associated pages with varying degrees of usefulness. It would probably be a good idea to go over these, clean them up and integrate them.

Maintenance

The Mosaic camera requires periodic renewal of the data used for calibrations, including:

1. Flat fields for use in the real time display
2. Astrometric fields for update of the WCS distortion terms

The camera requires monitoring for general system integrity through:

1. Transfer curve data to measure the gain and linearity of each amplifier chain
2. Bias frames to measure noise in each amplifier chain
3. Flat fields to monitor changes to cosmetic appearance of the CCDs

4. Flat fields to measure possible biases in A-to-D converters
5. Flat fields to measure possible changes to the shutter pattern
6. Dark frames to verify the low level of dark current and qualitative estimation of CTE.

In practice, all of the above data is collected on an *ad hoc* schedule, i.e. when the support team are able to, sufficient T&E time is available and the weather cooperates. Ideally, the first list of data should be acquired at the beginning of each scheduled observing block with the instrument, and the second on the 6-months to one-year timescale.

The shutter and filter track mechanisms should be occasionally inspected for problems. After filters were found to be shaken loose by the filter track action, their fixtures are inspected on a regular basis. There are occasional issues with filter track compressed air, but in practice these are rectified when they appear and would probably not be anticipated through routine inspections.

Software backups should take place on a regular basis. As it is, they are made when the issue is remembered.

In practice, the Arcon controllers are never left alone long enough for a preventative maintenance schedule to be required. In principle, this implies that we should be working to make the controllers more reliable, but the discussion above describes the obstructions to this.

Recommendations

It is difficult to identify a course of action which could significantly improve the performance and productivity of this instrument within the scope of resources currently available at CTIO. Indeed, given its current stability, productivity and popularity with observers, it is also not obvious that it is necessary. Nevertheless, we must preserve Mosaic II's good condition for the foreseeable future as its likely successor is DECam which will not be available until 2008/9. Therefore, a continued program of maintenance and monitoring is probably the best course, including:

- Collection of occasional in situ detector test data sets (as indicated above).
- Occasional backups of the Mosaic II software environment.
- Regular inspection of all moving parts (shutter, filter slide).
- Continued T&E nights with an aim to keeping the astrometric solution up to date and to monitor such things as image quality, photometric zero points, etc. according to the needs perceived by the science support team.

Collection of detector test data could be delegated to mountain support staff as a relatively straightforward, daytime task. Likewise the mountain staff could take on responsibility for ensuring software backups are made with appropriate frequency.

Given the value of the instrument to the observatory and the difficulty associated with repair and replacement of certain parts, great caution must be taken when troubleshooting any controller-related problems. It is proposed that, in the event that problems appear to indicate intervention at the controller level, including something as seemingly trivial as a board swap, La Serena staff *should always be consulted first*. This should include either Ricardo Schmidt or Ramon Galvez and at least one member of the science support team. No action should be taken which may threaten the integrity of the focal plane array nor its immediate control electronics without collaboration of the entire instrument support team.

Given that DECam will probably require some form of liquid cooling and Mosaic II has been identified as a significant dome heat source, it may be worth considering installing a heat exchanger to run off the dome glycol system and to feed a coolant circuit up to the prime focus and mosaic controller. This can be done relatively cheaply (est. ~US$5,000).

Investigations of image quality should continue, including means to better establish and control good focus.

Appendix: Inventory of Arcon cards

(Accompanying MS Excel file)