First light with NEWFIRM

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ABSTRACT

NEWFIRM, the widefield infrared camera for the NOAO 4-m telescopes, saw first light in February 2007 and is now in service as a general user instrument. Previous papers have described it conceptually and presented design details. We discuss experience gained from assembly, laboratory testing, and on-sky commissioning. We present final system performance characteristics and summarize science use in its the first semester of general availability. NEWFIRM has met its requirement to provide a high efficiency observing system, optimized end-to-end for survey science.

Keywords: Infrared camera, infrared filters, optical fabrication, mechanical fabrication, instrument assembly

1. INTRODUCTION

The **N**OAO **E**xtremely **W**ide **F**ield **I**nfra**R**ed **M**osaic (**NEWFIRM**) program has delivered a new IR imaging capability, with hardware and software components optimized for deep survey style programs, for use at the Ritchey-Chrétien foci of the NOAO 4-m telescopes in Arizona and Chile. The program had several project components: a large cryogenic camera, the first implementation of a new general-purpose array controller (MONSOON), the development and production of a 4K x 4K InSb mosaic using buttable 2K x 2K components (ORION), the production of observing preparation and execution software for high efficiency at the telescope, and the development of an automated data reduction pipeline that keeps pace with the raw data flow from the sky. Previous papers in this series have described the science drivers and instrument concept[1], and mechanical, optical, and cryogenic design details[2] including some changes from the original concept. In Section 2 of this final paper we discuss further hardware design changes and improvements that were incorporated during the fabrication and assembly process. In Section 3 we discuss our experiences with integration, laboratory testing, and on-sky commissioning. We present system performance data obtained at the telescope in Section 4. Section 5 summarizes the variety of science programs carried out by external users during NEWFIRM's first full semester as a facility instrument. We highlight throughout "lessons learned" during these project phases that may be helpful to others engaged in similar endeavors. NEWFIRM will continue in service on the northern 4-m telescope through 2009 and be relocated to Chile in early 2010.

The emphases of this paper are (1) hardware components and (2) system performance on sky. Daly et al.[3] describe the development and performance of the extensive software package components of the NEWFIRM program in a separate paper in this Symposium. Hardware and software have been integrated in the NEWFIRM program right from the start to provide a high efficiency observing system optimized for survey observing projects.

2. THE NEWFIRM CAMERA: DESIGN CHANGES

The NEWFIRM camera houses a refractive, collimator - camera optical design, filter wheels, and the infrared array mosaic in a cryogenic Dewar. Cooling is by means of closed cycle helium gas refrigerators. Instrument and array control electronics are mounted on the Dewar. A truss structure couples the camera to the telescope and carries a dedicated guider and support electronics. The entire assembly weighs 1500 kg. Many design details are discussed in reference 2. Here we limit discussion to modifications and improvements made in the course of assembly and testing.

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2.1 Filters

The NEWFIRM camera uses cryogenic filters 124 mm in diameter. Out-of-band blocking to 3.6 microns is required by the InSb detector and cold optics materials. The initial set of *J, H,* K_S filters, acquired in a consortium purchase and specified for use with HgCdTe arrays, required additional blocking via a separate filter component. To reduce fabrication cost, and performance risk from pinholes, all other filters were also purchased as two components, a bandpass filter and a blocker on separate substrates. There are two filter wheels in series so one component is placed in each wheel due to thickness constraints. All composite filters meet bandpass performance requirements but the two-component, two-wheel implementation has proven to be a serious constraint on the filter configuration, and so the range of science, that can be provided for science users in a given observing block of several months' length. Changing filters requires a major incursion into the Dewar. We have replaced the *J, H,* K_S set with single piece filters and will require this construction for future purchases. To date all filters have been acquired from Barr Associates.

2.2 Optics and optical system mounting

The optical design includes three infrared fused silica (IRFS) lenses with a conic section (aspheric) surface. The vendor's proprietary fabrication methods for aspherics, despite previous successful use, proved inadequate for these lenses. They were finished by local hand polishing, leading to many months of schedule slip. One of these, the last optic before the detector, is a field flattener with a very deep aspheric curve. IRFS was chosen for this lens as part of the longwave blocking strategy for the InSb arrays. Producing this deep aspheric curve in the very hard and brittle IRFS material proved much more difficult than anticipated and revealed that the specifications given to the vendor were lacking a restriction on maximum slope deviation. The lens eventually produced by the original vendor met the specification for peak-to-valley surface error, but all the errors were concentrated in several small regions, resulting in extreme slope deviations in those regions. Because this lens was very close to the final focal plane, the final image quality showed strong local variations that were unacceptable scientifically. At additional expense we obtained a replacement lens element from another vendor that was better equipped and more experienced at producing aspherics in hard glasses. This second vendor worked with us closely during the negotiation of the terms to ensure that maximum slope deviations were specified in a way that met our image uniformity needs and were achievable. Lessons learned here are: 1) to be sure that potential vendors fully evaluate the difficulty of the tasks on which they bid; 2) to evaluate critically the bidders' experience and capabilities; and 3) to provide bidders with complete specifications that constrain all parameters of concern.

The optical components, with the exception of the first collimator lens, are mounted in a series of housings that form a unified Optics Support Structure (OSS) terminating with the mosaic array mount. Demanding alignment tolerances were met with build-to-print design adapted to fabrication methods, and very precise part-to-part registration. One key to success during OSS integration was close interaction between the instrument maker and the project scientist during fasbrication. While a housing in work was mounted in a Hurco CNC three axis mill, the registration of finished parts that stacked up on the housing was verified. The mill itself, equipped with feeler gauges in place of cutting tools, served as a high precision measuring machine to verify alignment precision.

2.3 Detector mount

The detector mount must simultaneously satisfy mechanical, cryogenic, optical, electronic, and interfacing needs. For NEWFIRM it had to interface three very dissimilar materials, aluminum, copper, and Invar. The design described in reference 2 has proven very satisfactory in use. However, the light baffling required some modifications.

Initially, non-contact baffling around the assembled mosaic was provided by a thin wall protruding above the aluminum mosaic mount, which fit into a groove machined into the lower housing of the OSS. The groove was lined with a black Delrin insert with machined baffles. This insert was divided into four separate pieces to allow for the substantial difference in thermal expansion between aluminum and Delrin. Warm laboratory tests for light leakage indicated that the resulting butt joints acted as light pipes. Also, the re-entrant, baffled, but non-labyrinthine wall-in-groove seal did not totally trap photons. Two improvements produced a satisfactory light seal around the mosaic mount. The Delrin insert pieces were redesigned with lap joints to provide a continuous, sliding contact to accommodate thermal contraction. The insert was also spring-loaded from the OSS side to press it lightly against the mount wall. This provides a continuous mechanical seal while maintaining thermal and electrical isolation between the OSS and the mount, and providing some latitude for mount adjustment for alignment purposes.

Electronic components mounted on each 2K x 2K array assembly, outside the photoactive area, can be a local source of stray light onto the arrays. A low wall formed of dark dyed aluminum nitride bars which shield the active area on two adjacent sides provides partial amelioration as part of the array package. A field-defining detector mask is fitted to the mosaic mount immediately above the arrays to baffle scattered light in the incoming beam. In our original design, this mask carried an O-ring which was intended to compress against the aluminum nitride bars to form a light seal. We found that small irregularities in lateral position and differences in height of the bars led to imperfect O-ring contact and light leakage. The solution was to replace the O-ring with four thin, mitered strips of 6 mil foil tape on the detector mask. When the mask is installed, these strips are deformed against the aluminum nitride bars to form an excellent contact seal.

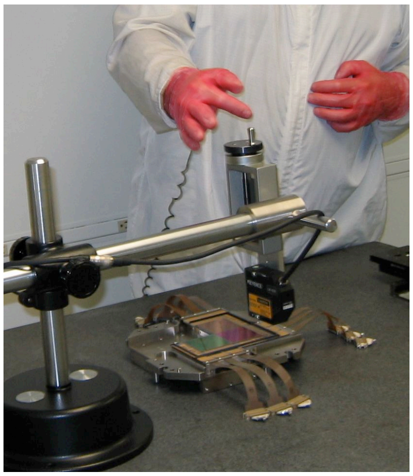

Fig. 1 Array coplanarity measurement

The array assemblies are installed in the mount with their oversized Invar baseplates in gentle contact. The array active area is slightly set back from the edge of the Invar along two sides. This produces a 2.5 mm (40 arcsec on the sky) gap between the mosaic elements. Piston and tilt adjustment is done with machined Invar shims. Vertical displacement of each array assembly as initially installed in the mount is measured with an optical (noncontact) depth gauge at multiple points around the edges of the photoactive InSb surface (this surface itself is not sufficiently reflective for measurement). The detector mount and depth gauge are placed on a high precision flat granite table for this measurement. The inverse of a best fit planar piston and tilt map of the array surface is then machined into the shim. The overall flatness of the final mosaic focal surface is ±25 microns, including wavy deviations of the InSb layers. This is within the a priori error budget for this subassembly.

2.4 Dewar thermal performance

It had been recognized that the 370 mm diameter entrance window/aspheric field lens, with its substantial view factor to the 65 K OSS, could experience condensation on its outer surface due to radiative overcooling. Design ameliorations were to shorten the collimator baffle stack, reducing the view factor to cold black surfaces, and insert a downlooking conical narcissus baffle just below the window. This approach, combined with a warm field stop at telescope focus, has been successful in blocking warm out-of-beam radiation. Dry nitrogen gas is also continuously flowed through the enclosed entrance column between the window and the telescope mirror cell. We have experienced condensation, however, due to a sudden sharp rise in ambient humidity of the telescope environment without a compensating increase in gas flow.

Dewar cooling is provided by three two-stage cold heads, coupled to the OSS by copper straps. Active temperature control is provided by heater resistors at the points of attachment of the straps to the cold heads. Warmup uses separate heater resistors mounted on the OSS. After some initial tuning of the strap cross sections and heater resistance values this is working well. Cooldown and warmup are done under closed-loop control with separate, dedicated controllers, to avoid reprogramming mistakes. The interior of the Dewar is heavily instrumented with about 60 passive temperature sensors, in addition to one control sensor for each active control loop (OSS, 65 K; detector mount, 32 K). This has permitted us to map the thermal behavior of the system, especially that of the lenses in their cells. One crystalline lens material, CaF_2, is notoriously susceptible to breakage from local thermal shock. Each lens has a sensor pressed against the glass, as well as one on the aluminum cell. The thermal behavior of the lenses in their cells is the deciding factor for temperature rate-of-change during thermal cycling. The lenses can lag the OSS bulk temperature substantially while the cells, despite incorporation of thermal breaks, track it more closely. This is especially pronounced for the middle element of one closely spaced camera triplet. The temperature ramp is held to 4 K/hour to avoid an excessive temperature difference between lenses and cells at points of contact. The required cooldown (or warmup) time is about 60 hours, longer than our initial expectation due to this empirically determined thermal behavior of the optics and cells.

2.5 Guider and truss

The external guider is conceptually simple: two cameras, each on X-Y stages, patrol rectangular strips on either side of the science field. The cameras use custom optics and small format, unamplified CCDs. For value engineering we chose a CCD guider package produced for the advanced amateur astronomy market, which include a sensor head and a standalone analog control box. The analog output is digitized and fed to existing telescope guider software to generate corrections. The system meets performance requirements on the telescope. However, its conceptual simplicity led us to underscope the design and implementation effort in our project plan. Stiffness, precision, and positioning speed requirements on the stages proved to be significant cost drivers, requiring expensive components and extensive testing. While the CCDs have adequate sensitivity, interfacing to the analog controller over slow serial lines is time-consuming, and the control is not user friendly. CCD package cost became a minor component of the total subsystem cost, so this choice was a false savings.

The guider is mechanically separate from the instrument and located close to the warm telescope focal plane by the truss. The truss is tuned for predictable lateral translation of the Dewar under gravity. The truss also has precision dimensional requirements for interfacing to the Dewar and to the telescope mirror cell, and for preservation of an established instrument-to-telescope alignment when the truss is removed and replaced. It was fabricated by a local vendor. The marriage of design and fabrication for this complex three-dimensional weldment was via Solidworks software tools. Care in design, fabrication, and setup of fixturing, and close interaction between design engineer, instrument maker, and vendor personnel, produced a high accuracy result that met dimensional requirements without post-welding adjustments.

3. INTEGRATION, LABORATORY TESTING, AND ON-TELESCOPE COMMISSIONING

Parts, subassemblies, and the complete camera were integrated and tested in Tucson, then commissioned on the 4-m Mayall telescope on Kitt Peak. First light was in early February 2007. NEWFIRM saw initial competitively selected scientific use by external users in October-December 2007, and began intensive scientific observations in February 2008.

Fig. 2 Coauthors George and Probst with NEWFIRM mounted on the Flexure Test Rig

3.1 Facilities

OSS components were initially tested for mechanical fit and finish, and cells test-fit with optics, in shirtsleeve shop environments. After thorough cleaning, bench assembly of in-Dewar subassemblies was done in a 12 x 25 foot, Class 1000 clean room equipped with a travelling overhead hoist. Final integration into the Dewar shell was performed in an adjacent 12 x 15 foot high-bay clean room equipped with a gantry trolley and twin 2-ton coffing hoists. Integration was done with the Dewar mounted in a custom built cart that allowed easy access to either end. Rigorous standards for clean room tool, fixture, and personnel cleanliness were maintained, producing a contaminant-free assembled camera as evidenced by residual gas analysis during pumpout. The availability of clean overhead hoisting capabilities allowed convenient and safe handling of cumbersome and/or heavy assemblies during integration of this large instrument.

The external guider was built up separately on its baseplate, carried by a modified commercial automobile engine mount. This low-cost fixture allowed easy orientation changes for assembly and for flexure testing against variable gravity loads. Assembly was in the electronics laboratory since the guider operates in the ambient environment on the telescope.

Dewar, truss, and guider were integrated and tested as a unit in our Flexure Test Facility. A two-axis flexure test rig, sized for 8-m class instruments, allows instrument mounting and cryogenic testing with the same interfaces and range of orientations as will be experienced on the telescope. This facility's 5 ton overhead travelling crane is used to integrate and mount instruments. Cryogenic helium gas plumbing, multiple compressors, and an external heat exchanger are provided for instrument cooling. A modular 8 x 12 foot clean room is available for on-site incursions into the Dewar that do not involve extensive internal disassembly. This facility is also available to other instrument building groups for integration and test of large instruments.

3.2 Laboratory tests

The only cryogenic moving parts in NEWFIRM are in the double filter wheel subassembly. This large flat assembly, including the filter wheels, motors and gear trains, detent mechanisms, wheel position sensors, structural housing, and light baffles, slides into the OSS on one side. Individual filters can be changed, and detents and sensors adjusted, with the OSS installed in the Dewar. But it is otherwise inaccessible without a major dismantling of the instrument, so it was extensively tested both warm and cryogenically before integration. Tests resulted in a change to the detent spring loading force, adjustment of detent position sensors for reliable cold operation, and derating the motor speed about 10%. This last change increased filter positioning time but was unavoidable for reliable operation.

The OSS housings, without optics, were joined to the detector mount, without detectors, and the assembly tested for light leaks. We placed a small light source inside the OSS and examined the outside with an integrating CCD camera in the totally darkened clean room. Light leakage along the baffle at the front face of the detector mount led to the design modifications described in Sec. 2.3. After these were made the system was fully light tight in this warm test. This was later confirmed in cryogenic tests with the infrared arrays. Cryogenic testing identified a deficiency in the baffling around each 2K x 2K array, which was traced to the source and solved as described in Sec. 2.3.

The optical train, once assembled in the OSS, was warm bench tested interferometrically in double pass for alignment. This required fabrication of a null tester, consisting of a small spherical lens and spherical mirror, to take the place of the detector assembly. It also necessitated careful alignment of the separately mounted entrance field lens. Comparison of predicted and delivered interference patterns showed that our care in mechanical tolerancing, fabrication, and assembly of the optics had yielded a well aligned system. A slight respacing of the field lens was necessary, but no adjustments in translation, rotation, or tilt were required for the lens train.

The Flexure Test Facility was used for thermal performance testing, flexure characterization, optical performance tests, optimization of the array control electronics, and detector characterization. While optomechanical flexure testing was our primary use of this facility, the ability to test for other orientation induced problems prior to arriving at the telescope was a great help in speeding commissioning. The facility also provided a work environment in which the instrument team could focus its effort without distractions.

The OSS moves with respect to the Dewar shell under changing gravity load. The camera design incorporated carefully tuned passive flexure compensation to keep the input and detector focal planes aligned[4]. A pinhole placed at the warm input focal plane was used to verify that this had been achieved. The entire Dewar assembly, and the guider, will each sag in the truss under gravity. An external telescope simulator, fixed to the flexure rig, provided an artificial star to test the flexure of the infrared camera and the visible light guider separately. The camera was found to move as predicted. The guide probes showed slight excess motion, traced to guider baseplate flexure. While the guider did not perfectly track the camera, the error was small enough that it was decided to evaluate performance on the telescope before taking any remedial action. Performance on the telescope has been found satisfactory.

3.3 Commissioning

On-telescope commissioning tasks included hardware systems verification; camera photometric, astrometric, and electronic performance characterisation; end-to-end tests of the observation control software; guider tests and calibration; and trials of the scientific reduction pipeline. Commissioning was allocated five observing runs, totaling 55 scheduled nights on sky. One run was cancelled due to array electronics problems, one run was cut short by a wildfire that required evacuation of the summit, and the remaining three lost time to bad weather. In total we had 23 usable nights on sky. All technical commissioning tasks were accomplished. The commissioning plan included a substantial component of "science verification", the execution of short, science driven observing projects selected to exercise all the observing modes of the NEWFIRM system. This activity was severely curtailed in response to the loss of on-sky time.

Two changes to the 4-m telescope were necessary for NEWFIRM operations. NEWFIRM's multiple cold heads required that a high flow rate He gas system utilizing multiple compressors be installed and plumbed to the Cass cage. Copper tubing was used for all fixed (nonflexing) lines; previously, we had used stainless steel for such systems. The copper lines required thorough pre-cleaning and care during soldering to avoid introduction of contaminants. This system has operated trouble-free since installation. A new Cass cage bottom was fabricated to accommodate the length of the Dewar, provide access to on-instrument electronics boxes, and reduce overall weight and moment on the telescope bearings.

A custom cart was fabricated for transport and installation of the camera. Shock protection for the instrument during highway transport was a significant concern. Our solution uses a combination of wire-rope springs suspending the Dewar, pneumatic shock absorbers between the cart and an outer frame bolted to the truck, and spring-loaded steel wheels on the cart. Vibration measurements made continuously on the instrument during truck transport from Tucson to the summit show a maximum acceleration of 1.1 G upwards, below the 3 G specification of the cold optics mounts, provided care is taken when crossing open steel gratings on the mountain road.

Fig. 3 NEWFIRM in its cart, ready for telescope installation. Wire rope suspension is visible at bottom center.

First light was 02 February 2007. There were no basic installation or operability problems. Within an hour of first light, a science verification team was obtaining useful characterization data with narrowband filters in a Galactic star-forming region. Subsequent in-Dewar rework was limited to tuning the active thermal control components (cold straps and heaters), replacing an incorrectly sized light baffle in the collimator stack, and modifying the cold preamp boards for optimal thermal coupling to the radiation shields. Alignment of the mosaic focal plane to the delivered focal surface was determined to be within specification without requiring adjustment. This was maintained during later replacement of the field flattener lens and changeout of two individual 2K x 2K arrays for the final science grade arrays. The care taken to hold tight tolerances during fabrication, assembly, and integration of the detector mount saved many weeks of potential schedule for warm adjustment and cold test of alignment.

Prior to first light, electronic noise from the array controller seen in the laboratory environment had been greatly reduced by a change from switching to linear power supplies for the array control electronics. However we also found an unacceptably high level of electronic noise in the telescope environment. Some pickup problems due to shielding, grounding, connector, and cable routing issues were solved on the telescope. Subsequently, the grounding scheme for the control electronics was reviewed and extensively revised. This effort uncovered a feature which caused cancellation of the second engineering run. Previous electronics tests with a bare multiplexer had all been done cold. In a warm MUX test for noise performance after grounding changes, we found that we could not initialize the MUX. Extensive troubleshooting, focussed on hardware errors due to the extensive wiring changes, did not find a cause. We determined that cold-to-warm impedance changes in the MUX affected the order in which control voltages were being applied at startup, causing it to hang. Microcode changes resolved the problem.

The biggest problem area during commissioning was getting the complex, multicomputer observing system to work reliably across multiple sub-nets. The problems were mostly communications issues that surfaced in the heavily networked mountain computing environment. These had not been seen, and could not be duplicated, in the less traffic-intensive Tucson laboratory. Finding and solving these problems was a serial activity, moving from array operations to data capture to metadata integration. We required three telescope runs to thoroughly test and debug the observation control and data capture system end-to-end. Intensive and extensive participation of the software engineers at the telescope while observing was a crucial element in working through these issues. Daly et al.[3] further discuss software aspects of the NEWFIRM program.

4. PERFORMANCE ON THE TELESCOPE

System characteristics and performance achieved on the telescope are summarized in Tables 1 and 2 and Figure 4. Comparison with available data for other instruments indicates that NEWFIRM is competitive with its peers, WFCAM on UKIRT[5] and WIRCAM on CFHT[6]. One NEWFIRM array has a somewhat lower *J, H* responsivity from the other three due to a different antireflection coating. This is reflected in the *J, H* performance numbers in Table 2.

Table 1. System performance characteristics

Field of view	27.6 x 27.6 arcmin including 35 arcsec mosaic gap
Sampling	0.4 arcsec per pixel
Well capacity	~95,000 electrons at 400 mV bias
System gain	8 electrons per ADU
System read noise	35 electrons rms with 1 Fowler sample
Dark current	0.3 electrons per pixel per second

Table 2. Star and sky levels for broadband filters

Filter	**J**	**H**	**Ks**
Counts on 10.0 Vega mag star, e-/sec	6.9E5/9.0E5	9.6E5/10.9E5	4.9E5
Sky background, e-/sec-pixel (1)	435/565	2900/3300	3800 @ 22 C 2300 @ 12 C
3σ in 60 sec, point source, Vega mag	20.3/20.5	19.7	18.8 @ 22 C 19.0 @ 12 C

(1) J levels are for 50-60 degrees away from full Moon; see also Figure 2

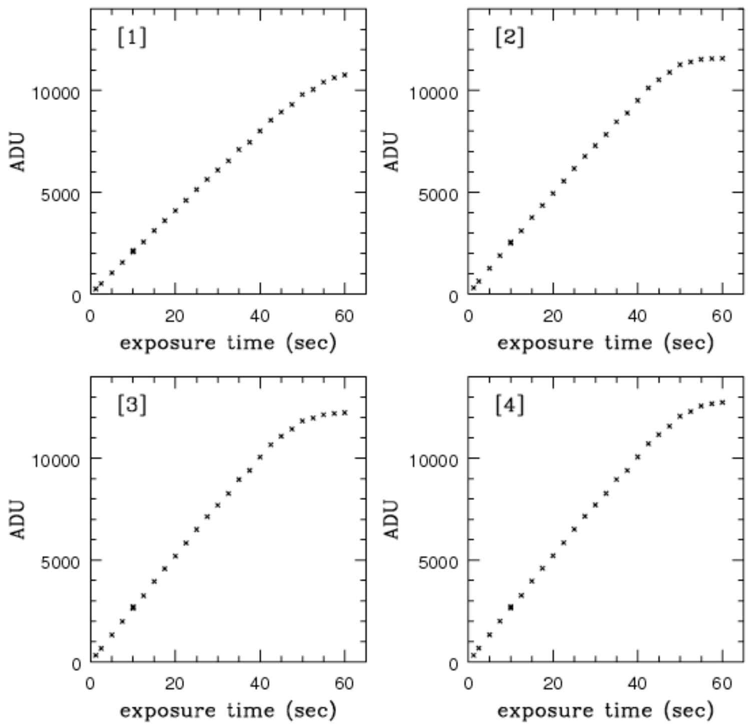

Fig. 4 Well capacity and nonlinearity of response to constant source for each array at 400 mV bias.

Ghost images from bright stars are a concern with refractive optics. The location, size, and intensity of ghosts was carefully investigated during the optical design stage. In use, we find that bright stars produce three different pupil ghosts: (1) A ~300 pixel diameter ghost, 17 mag/sq arcsec fainter (in J band) than the integrated magnitude of the source star, and offset from the source radially with respect to field center by hundreds of pixels. (2) A ~100 pixel diameter ghost, 14 mag/sq arcsec fainter (J) than the integrated magnitude of the source star, and nearly centered on it. (3) A compact starlike ghost (~4 pixels FWHM), 8.5 magnitudes (integrated) fainter than the source star in J, and offset radially from it by hundreds of pixels in a field-position-dependent manner. Given the ~10 mag dynamic range of the arrays, ghost #1 may be detectable only for the brightest stars (3-5 mag). Its size makes it difficult to remove by dithering. Both its location and its surface brightness are predictable so it may be removable by modeling. Ghost #2 may produce compact, low level "nebulosity" around somewhat fainter stars, 7-8 mag. Ghost #3 has the potential for producing false "field stars". However, a modest dither pattern of tens of arcseconds shifts the ghost by more than its FWHM, so it will likely not print through in a median-combined image.

Image persistence is a well known characteristic of InSb arrays. Saturated images of bright stars on our arrays produce faint residual images at the same pixel locations in subsequent dithered frames. These are ~12 mag (integrated) fainter than the source star. Their structure is smooth and flat within the outer contour of the originating star's PSF. These residual images rapidly fade into the background sky noise in raw frames. However, they can be problematic for defining a blank sky frame from a running median of dithered images. We are still gaining experience with science data to determine how best to handle ghost images and image persistence in the data reduction pipeline.

One unanticipated performance characteristic remains under investigation. The sky background level seen in the J filter is a strong function of angular distance between the telescope pointing and the Moon. This background is significantly more elevated at moderate distances (20-40 degrees) than that seen on the 4-m by a narrower-field instrument, FLAMINGOS[7] (11 x 11 arcmin FOV). NEWFIRM does not exhibit this behavior in the H or Ks bands. We suspect that this is due to moonlight scattering off elements of the glossy white telescope structure, which becomes illuminated for angular distances less than about 50 degrees. At present this is a constraint on scheduling observation time with NEWFIRM for some scientific programs.

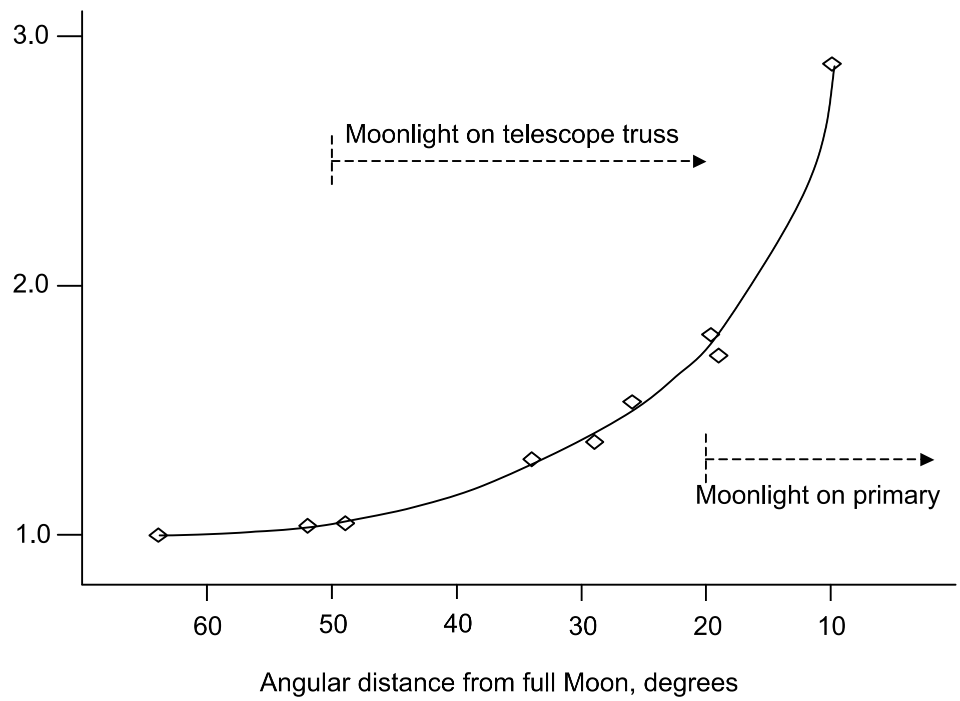

Fig. 5 Relative increase in J sky background with proximity to full Moon

5. INITIAL SCIENTIFIC PROJECTS

Some competitively scheduled science programs (27 nights, 5 programs) were undertaken in late 2007. The first half of 2008A has seen heavy scientific use of NEWFIRM with 79 nights scheduled; this includes 67 continuous on-sky nights in February-April 2008. It was immediately apparent at the start of this run that we had successfully transitioned from getting the instrument system working reliably, to learning how best to use it for science. NEWFIRM's many external science users have made important contributions to this by exercising the system intensively, sometimes in unanticipated ways.

The total set of 12 science programs scheduled in 2008A divides into three distinct time assignment groups: short, 1-4 nights; medium, 11-14 nights; and one large survey program with 24 nights in 2008A out of 64 allocated in all. The science being undertaken ranges from discovery of nearby brown dwarfs to searches for primordial galaxies. A lot of effort is going into the characterization of galaxy formation and the evolution of structure in the astrophysically crucial redshift range $1 < z < 3$. Optical diagnostics of key physical processes for these activities have redshifted into the near infrared over this range in lookback time. The stellar content of the outer regions of nearby, well resolved galaxies is another research direction, and determining the populations of individual stars in Milky Way clusters and star forming regions is a third. In almost all cases the NEWFIRM data are being acquired as part of larger, multiwavelength programs that address several immediate science goals. Extensive NEWFIRM data will complement data obtained with Spitzer and Chandra. Groundbased telescopes such as WIYN and Subaru are providing optical imaging and spectroscopy. The NEWFIRM data, and usually that obtained on other instruments as well, will also flow into public archives with a promise of high future utility. The multiwavelength approach to answering critical science questions is upon us, and NEWFIRM is a full participant.

One operational issue, resulting from design decisions flowed down from conceptual use cases, has come to the forefront. A scientific strength of NEWFIRM in the context of its peer instruments appears to be the relative ease with which programs using non-standard cryogenic filters can be accomodated by NOAO's competitive proposal process. The highest ranked and most time-intensive survey program initiated in 2008A uses an extensive set of PI-supplied custom filters[8]. Although NEWFIRM has a total of 16 filter positions in two wheels, this isn't enough to accommodate all available filters at one time (see also Sec. 2.1). Filter changes are not technically trivial, and significant down time is required to effect them. This leads to science-driven allocations of large blocks of time with filter configurations which enable some types of science but preclude others.

6. ACKNOWLEDGMENTS

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The high precision machining of OSS components was done by NOAO Senior Instrument Makers Ron Harris and Randy Bennett. We thank Senior Detector Engineer Al Fowler (NOAO, retired) for consultations on IR array operation.

Finally, we wish to recognize the contributions of several vendors not previously identified in this series of papers: Meyer Tool and Manufacturing, Oak Lawn, IL (Dewar shell); Vroom Engineering, Tucson (truss weldment); SSG-Tinsley Division of L-3 Communications, Richmond, CA (aspheric field flattener lens); and Abrams Airborne, Tucson (anodizing and specialty painting).

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