# NEWFIRM Quick Guide for Proposal Preparation

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September 2008

NEWFIRM is a 1-2.4 micron IR camera for the NOAO 4-m telescopes. It has a flexible complement of broad and narrow band filters, a dedicated guider, and the largest field of view available at the f/8 R-C focus without vignetting by the telescope structure. Software packages for observation scripting and execution, “quick look” data reduction in near real time, and full pipeline image processing to a science ready state are being provided. This document provides information necessary to write a technically sound proposal for execution of a scientific program with NEWFIRM.

## Availability and scheduling

NEWFIRM will be shared between the Mayall (northern) and Blanco (southern) 4-m telescopes. Both standard and survey programs may be proposed. NEWFIRM will be available for observations on the Mayall telescope during semester 2008A through the end of 2009B. A policy statement explaining how science programs will be scheduled under these constraints can be found at **NEWFIRM Scheduling Policy through 2011.**

## Geometry

The detector focal plane consists of four 2048 x 2048 arrays arranged in a 2 x 2 mosaic. Figure 1 shows the mapping of individual arrays, identified by their serial numbers SNxxx, onto the sky. The orientation is fixed; the instrument cannot be rotated.

Field of view: 27.6 x 27.6 arcmin including a 35 arcsec wide, cross-shaped gap between the arrays composing the mosaic.

Sampling: 0.40 arcsec/pixel

Dithering: independent of S/N considerations, a dither pattern of at least 3 points in an “L” shape spannng at least 70 arcsec separation on each axis is recommended to bridge cosmetic defects and the mosaic gap, and eliminate spurious pointlike sources due to ghosting on bright stars. See also **cosmetics** and **ghosting** in the section on **Illumination issues** below. Programs needing greater sensitivity might wish to fill in this area with a denser dither pattern.

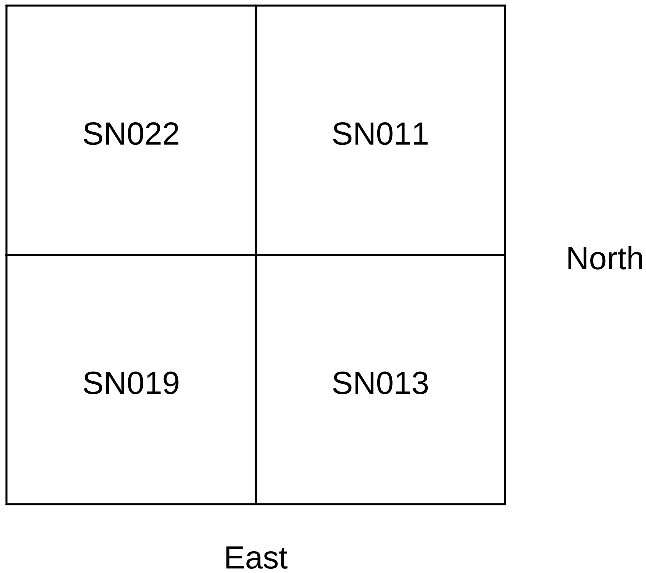


**Figure 1.** Mapping between arrays and sky.

**Filter complement**

There are more NEWFIRM-specific filters than can be accomodated in the Dewar at one time. Some have been provided with non-NOAO funds and have restrictions placed on their use. For a policy statement on filter availability and filter changes, see **NEWFIRM Filter Availability and Policy on Filter Changes**.

A set of broadband and narrowband filters has been tested on-sky in NEWFIRM and is presently installed in the intrument. Performance data are tabulated below.

Broadband: J, H, Ks
Narrowband: 1.64 micron [Fe II], 2.12 micron $H_2$, 2.17 micron Br $\gamma$

Broadband filters follow the "MKO" prescription of Tokunaga et al., PASP **114**, 180, 2002. A J, H, Ks filter set will remain permanently installed in the Dewar.

The narrowband filters are designed to capture the designated emission line feature with high transmission over the entire field of view at zero redshift. Resolution is about 1.3%. The filter bandpass shifts in wavelength with radial position in the field of view. At field center, the designated line falls near the blue edge of the high transmission window; at field corner, near the red edge.

The 1.64 micron [Fe II] filter may also be used in conjunction with broadband H for on/off methane band detection of brown dwarfs. The bandpass will shift across the methane absorption edge from field center to field corner as noted above.

## Signal levels on star and sky for broadband and narrowband filters

Important signal level performance issues for proposal planning:

(1) Array SN019 has reduced response in the J and H bands compared to the other arrays, due to a different antireflection coating on this array (see Tables 1 and 2)

(2) The J sky background varies substantially with angular distance between the field of view and the Moon (see Fig. 2)

(3) The Ks sky background varies substantially with sky temperature, e.g. between summer and winter (see Tables 1 and 2)

J and H band performance are tabulated separately for array SN019, and for the other three arrays which are very similar in performance.

**Table 1. Star and sky levels for broadband filters**

| Filter | **J** | **H** | **Ks Summer ( 22 C )** | **Ks Winter ( 12 C )** |
|---|---|---|---|---|
| Counts on 10.0 mag star, e-/sec (1) | 6.9E5 (SN019)<br>9.0E5 (others) | 9.6E5 (SN019)<br>10.9E5 (others) | 4.7E5 | No change |
| Sky background, e-/sec-pixel (2) | 435 (SN019)<br>565 (others) | 2900 (SN019)<br>3300 (others) | 3800 | 2300 |
| Zero Point: mag corresponding to 1 ADU/sec | 22.3 (SN019)<br>22.6 (others) | 22.7 (SN019)<br>22.8 (others) | 21.9 | No change |
| Brightest star observable, mag (3) | 10.7 | 10.9 | 10.1 | No change |
| Faintest star, 3σ in 60 sec, mag (4) | 20.3 (SN019)<br>20.5 (others) | 19.7 | 18.7 | 19.0 |

Notes:

(1) Vega = 0.00 mag; scaled from fainter standards and 2MASS stars
(2) J levels are for 50-60 degrees away from full Moon; see also Figure 2
(3) Assumes 1.7 sec integration time and well depth corresponding to 25% nonlinearity correction at peak pixel level (see Fig. 3).
(4) Integrated over 40 pixel (3 arcsec) aperture, sky brightnesses as tabulated, and no S/N degradation from sky subtraction. Vega magnitudes.

**Table 2. Star and sky levels for narrowband filters**

| Filter name | **1644 nm [Fe II]** | **2124 nm $H_2$** | **2168 nm Br $\gamma$** |
|---|---|---|---|
| $\lambda_{eff}$ , microns | 1.644 | 2.124 | 2.168 |
| Bandpass, microns (1) | 0.015 | 0.020 | 0.020 |
| Sky background e-/sec-pixel | 145 (SN019) | 190 (summer) | 255 (summer) |
| | 165 (others) | 115 (winter) | 130 (winter) |
| Counts on 10.0 mag F6 star, e-/sec (2) | 4.9E4 (SN019) | 3.7E4 | 3.2E4 |
| | 5.6E4 (others) | | |
| Flux density of 10.0 mag star, mJy (3) | 104 | 68 | 66 |
| Flux density of 10.0 mag star, W $m^{-2}$ $\mu^{-1}$ (3) | 1.2E-13 | 4.5E-14 | 4.2E-14 |

Notes:
(1) Bandpass at 90% of maximum transmission. FWHM typically 1.2X wider.
(2) Vega = 0.00 mag
(3) Derived from Tokunaga and Vacca (PASP **117**, 421, 2005) flux densities for MKO broadband filters, with scaling to effective wavelengths for 6400 K star. Vega magnitude.

Figure 2 shows the increase in J band sky background, under full Moon, as the angular distance between the telescope pointing and the Moon decreases. The Y axis gives the multiplier for the J band background levels quoted in Table 1. It is very difficult to shield the telescope truss structure from moonlight. At angular distances less than about 20 degrees, the primary mirror is directly illuminated.

Lunar phase and distance from target fields should be considered when specifying the range of acceptable scheduling dates for a proposal.

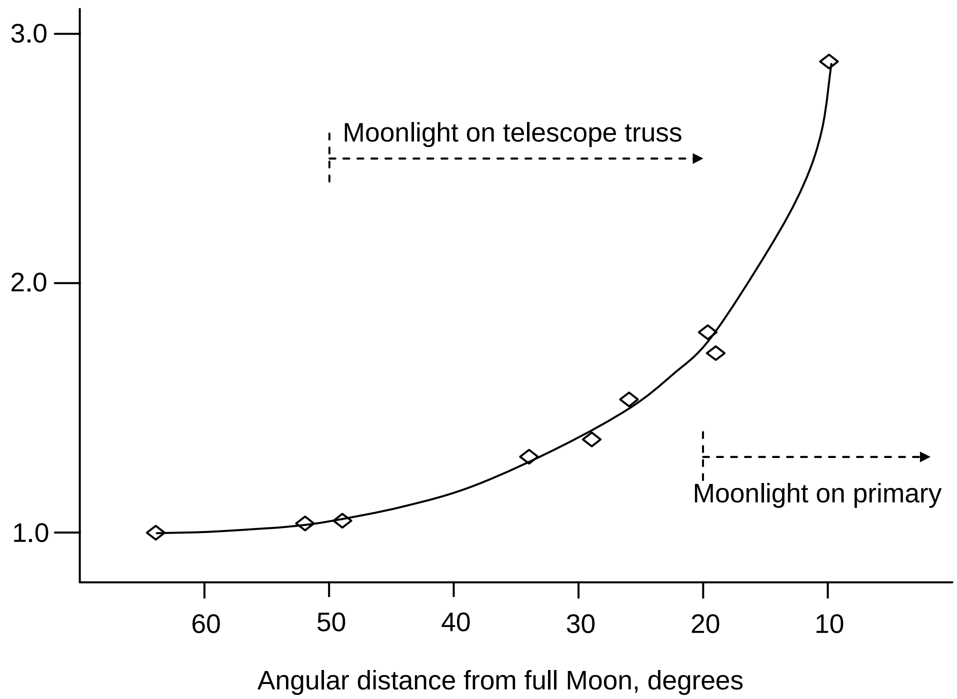


**Figure 2.** Relative increase in J sky background with proximity to full Moon

**Non-NOAO filters**

The non-NOAO filters listed in Table 3 have been purchased by individual researchers for potential use with NEWFIRM in upcoming semesters. Whether or not programs using these filters will be scheduled depends on the recommendations of the TAC, the feasibility of scheduling them for use, and any restrictions placed on use by their owners. Please see **NEWFIRM Filter Availability and Policy on Filter Changes** for further information before proposing to use any filters in this list.

Signal levels on star and sky generally scale relative to the broadband J and H filters in proportion to bandpass. The ultra-narrowband 1056 nm and 1063 nm filters are located in OH line-free regions so the sky background is nill. Detection sensitivity with these filters will likely depend on systematic effects with the sky background and readout electronics, rather than on photon statistics or read noise.

**Table 3. Non-NOAO Filters**

| Name | Central Wavelength, microns | Band pass, microns |
|---|---|---|
| 1187 nm | 1.186 | 0.011 |
| 2096 nm | 2.096 | 0.020 |
| J1 | 1.048 | 0.161 |
| J2 | 1.190 | 0.153 |
| J3 | 1.284 | 0.152 |
| H1 | 1.556 | 0.175 |
| H2 | 1.710 | 0.168 |
| 1056 nm | 1.0564 | 0.0007 |
| 1063 nm | 1.0631 | 0.0008 |

## Detector performance and cosmetics

NEWFIRM uses four, 2048 x 2048 ORION InSb arrays produced by Raytheon Vision Systems. Arrays are characterized in NOAO's Infrared Detector Test Lab as well as at the telescope.

Well capacity: ~100,000 electrons at 400 mV bias

System read noise: 35 electrons rms, 1 Fowler sample

Dark current: 0.3 electrons per pixel per second

System gain: ~8 electrons per ADU

Nonlinearity: Few percent at ~40% of full well. Differs between arrays. See Table 4.

Responsivity: differs between arrays due to different antireflection coatings. See Tables 1 and 2 for count rates at the telescope.

**Table 4. Departure from linear response**

| Nonlinearity | Onset, ADU | | |
|---|---|---|---|
| | **SN011** | **SN013** | **SN019** |
| 1% | 6700 | 4600 | 4500 |
| 3% | 7000 | 6000 | 5200 |
| 5% | 7700 | 6500 | 5800 |
| 10% | 8700 | 7700 | 6800 |
| 15% | 9500 | 8400 | 7500 |
| 20% | 10300 | 9000 | 8000 |
| 25% | 10800 | 9600 | 8400 |

Cosmetics: these arrays exhibit scattered localized or small-area responsivity defects. These include Photo Emissive Defects (PEDs) that have been passivated and have no response; some inoperable rows/columns, usually associated with a PED; fixed cracks; and small debonded regions with no response along edges or at corners.Figure 1, obtained during laboratory tests, illustrates these phenomena on array SN013.

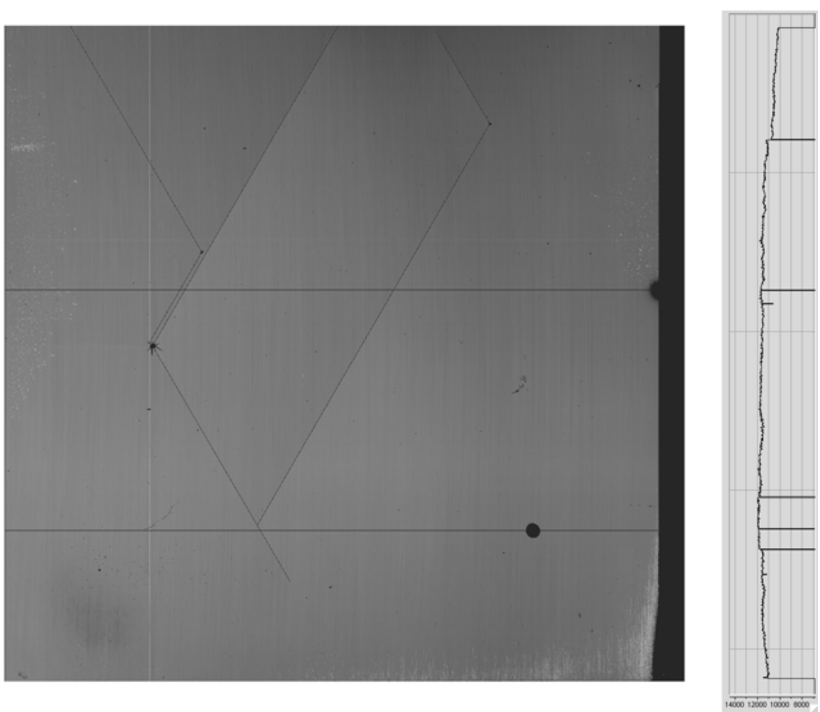


Fig. 1 PEDs, inoperable rows, diagonal cracks, and debonded corner on SN013.

**Illumination issues**

System responses to illumination by the sky and by pointlike or extended sources need to be taken into account in the observing protocols and time estimates. It does not appear that unusual protocols or reduction procedures, compared to other infrared cameras, will be necessary to remove these aspects of the instrument signature to a satisfactory level.

Focus and image quality: At optimum focus for each bandpass, zenith FWHM in 10 sec exposures is 2.3 pixels (0.9 arcsec) in very good seeing. There are calibrated focus offsets between J, H, and Ks bands.

Flatfield response: This is a combination of intrinsic detector performance and the illumination pattern produced by NEWFIRM's optics. We see ±5-10% response variations from the mean with low spatial frequency in the J, H, Ks sky and dome flats.

Pupil ghost: a background enhancement of up to 1.15 above the mean sky level has been reported for the J filter in the central few arcmin (radially) of the field. This appears to be an additive phenomenon. We are investigating means to define flatfields with this effect modeled and removed.

Narrowband flatfields and fringing: narrowband filters show distinct radial response patterns of about one cycle from field center to corner, possibly produced by the bandpass shifting across regions with more or stronger night sky lines in wavelength space. These low frequency patterns sky subtract well. Some high spatial frequency bulls'eye fringing can be seen in raw images. These might prove troublesome if the night sky emission is varying rapidly, but in my experiments the fringes sky subtract out. More experience is needed here.

Ghosts on bright stars: bright stars can produce three different pupil ghosts. Their characteristics in the J filter are as follows:

1. A ~300 pixel diameter ghost, 17 mag/sq arcsec fainter than the integrated magnitude of the source star. Offset from the source radially with respect to field center by hundreds of pixels; offset depends on source distance from field center.

2. A ~100 pixel diameter ghost, 14 mag/sq arcsec fainter 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, 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. However, both its location and its surface brightness are predictable.

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”. Fortunately, 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.

The pipeline reduction team is investigating how best to handle ghost suppression in the data reduction.

Residual images (sometimes called “retained charge”): very bright stars may produce faint residual images at the same locations in subsequent dithered frames. These residual images fade into the background sky noise over the course of subsequent array reads. From experiments with bright stars, these residuals appear to be ~12 mag (integrated) fainter than the source star. Structure is smooth and flat within the outer contour of the originating star’s PSF. Flux is ~10 electrons per second per pixel in the first subsequent frame, decaying to a few e-/sec-pix in following frames. We are investigating means to remove or ameliorate these effects when shifting and combining images in the pipeline reduction software.

**System operational and efficiency issues**

Minimum integration time = readout time: 1.7 seconds with one Fowler sample.

Coadding is supported. This reduces the data volume with the short integration times necessary for broadband H and Ks observations.

Fowler sampling (multiple nondestructive reads) is supported. The minimum integration time becomes 1.7 seconds X number of samples. This technique reduces read noise if it is a significant noise source, e.g. with narrowband filters.

NEWFIRM is conceived as a system for carrying out survey-type programs with high efficiency. Observations are driven by scripts created in advance using an observing tool. In this automated mode we have achieved up to 80% efficiency when executing a script with short unguided integrations. Multiplying calculated on-sky integration time by 1.3 should give a good estimate of the total clock time required to execute a program of some hours duration, including modest amounts of time for target acquisition and setup, and assuming good weather.