SYSTEM DESIGN NOTE

NFM-AD-02-9502 NEWFIRM Scientific Use Cases for OCS Definition

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1. Introduction

This document describes observing sequences, or scientific use cases, which the NEWFIRM Observation Control System (OCS) is expected to support. It is written from the point of view of the astronomer user. That is, it describes how data will be taken at the telescope for various scientific programs. It describes briefly some anticipated interrupt conditions, and the real time feedback expected by the astronomer for evaluation of observing conditions. It also describes anticipated failure modes of the observing system.

I have not attempted to describe every conceivable observing sequence, only those that I expect to be commonly used. In general these appear to be amenable to pipeline processing of the data subsequently. This will be a two way street. A desire on the observer's part to use the pipeline may impose certain restrictions on what data are taken, and in what way, that are more restrictive than indicated here.

I discuss the basic scientific operating modes of NEWFIRM in Sec. 2, explain some terms and observing protocols common to IR observing in Sec. 3, and present observing sequences for calibration and for science observations in Secs. 4 and 5 respectively. A hypothetical night's work using these sequences is described in Sec. 6. Finally, Sec. 7 extensively considers a variety of failure modes while observing, and the required capabilities of the OCS to react to them and support observing workarounds.

A draft version of Secs. 1-6, circulated on 3/26/04 for comment, has been used as an informal reference for OCS definition. This final release adds Sec. 7 requirements but does not substantively change the previous sections.

2. Basic operating modes

There are two basic operating modes, described as follows in the NEWFIRM Operational Concepts Definition Document.

2.1. Survey Mode

In this operating mode large scale programs intended for general public use will be carried out. This may involve tens to hundreds of square degrees of sky observation, many nights of observing time distributed over a lengthy period, and public access to processed data. In this mode the instrument will operate in a pre-planned, systematic way with a minimum of real time decision-making during any night's observations. The telescope and instrument should function semi-automatically for long periods (hours), with only occasional intervention by telescope operators. In general, the presence of an expert astronomer will not be required. The overall requirements for this operating mode are maximum efficiency and consistent observing practices for the duration of a survey. Substantial data sets will result from such survey programs, requiring a processing pipeline from raw data to fully reduced and archived data and extracted source catalogs.

2.2 Common User Mode

In this operating mode an astronomer using the NEWFIRM instrument will conduct a limited program over a few nights with a specific immediate science goal and a requirement of proprietary control over the data for some reasonable length of time. Various filters may be used, as well as a variety of integration times, on targets in any accessible part of the sky. Scripted observing procedures that execute over ~1 hour periods will be preferred for efficiency. However, the astronomer user may interrupt the script, or may elect to use the instrument in a highly interactive manner with lots of real time decision making.

3. Terminology and protocols for IR observing

For a simple imager like NEWFIRM, and from the astronomer rather than the engineer's point of view, there are only three free parameters that determine the result of an exposure (image):

1. Where the telescope is **pointed** on the sky
2. What **filter** is inserted into the light path
3. The **integration time** during which photoelectrons are collected in the array

Looking at each parameter in turn,

Telescope pointing on the sky may be determined absolutely as Right Ascension and Declination (RA, Dec) coordinates, or relatively as some change in each coordinate from an absolute starting position. Frequently an absolute location is used as a starting point, and a series of relative position changes are used to determine subsequent positions. There are two kinds of relative motions, distinct in purpose and terminology:

1. Dithering: motion of a small fraction of the instrument field of view, typically arcseconds to tens of arcseconds
2. Offsetting: motion of a large fraction of the instrument field of view, typically 50-95% of the field dimensions

Dithering is used to build up total integration time within a single field of view while allowing removal of artifacts (bad pixels, meteor trails, etc.) and some averaging over flatfield uncertainties. Offsetting is used to map out large areas on the sky. While the astronomer can execute a dither pattern or an offset pattern by executing a string of individual telescope motion commands, it's common to automate these by use of predefined patterns in the instrument or telescope control program. Step size is usually a free parameter. For example, the astronomer may be able to call for a 2 x 2 position (i.e. square) dither pattern, specify how far apart successive positions are to be, and have this executed automatically. Similarly, a frequently used offsetting pattern is an N x M raster in (RA, Dec), with N, M, and distance as user defined parameters.

Either of these motions can be executed "open loop", with no feedback from the sky about where the telescope ended up. Or a guide probe, locked onto a guide star, can be used for "closed loop" positioning. In this mode the guide probe is first moved to the predicted location of the guide star with respect to the center of the field of view, the telescope is moved (presumably putting the guide star somewhere within the probe's field of view), then the guide star is centered by moving the telescope—not the probe. On our 4-m telescopes, closed loop positioning is more accurate in terms of locating the telescope to an absolute (RA, Dec) position, and more precise in terms of repeating a previous position—for example, going around a dither pattern several times, or returning to a previous offset position. The NEWFIRM guide probes have a very small field of view (~30 arcsec) so if guiding is to be used, guide star positions for a given telescope pointing must be determined in advance from a precision astrometric catalog. Either guided or unguided modes may be used in observing sequences.

NEWFIRM uses only fixed wavelength **filters**. There is a discrete set of filter wheel positions 1-16 and each position (or filter) is identified with a filter name that distinguishes the filter characteristics: "J", "Br gamma", "2.2 micron continuum", etc. A filter change consists of a change in filter name corresponding to a change in filter wheel position.

Integration time, like telescope position, comes in a couple of flavors. A basic distinction is whether or not information is preserved at less than the interval of time in question. A single integration time is the cycle time between initial array reset+read, and final read followed by a destructive reset. Only the total amount of collected charge is retained; information about what transpired within this period of time is lost. If the telescope is moved during this period, the image is smeared!

Single integrations can be summed and averaged, a process called **coadding**. This reduces the data rate downstream. But again, only the total amount of collected charge (or its average over N integrations) is retained, and information about the individual integrations that went into the coadded result is lost. Coadding also has to take place with no change in telescope position.

In the control program, the astronomer commonly specifies the integration time for a single integration, and the number of integrations to be coadded (which can be 1). The instrument control program then executes this automatically.

Total integration time is related to the science target rather than the telescope position. It's the total amount of time spent observing a particular target—a star, an extended object, an entire field of view—such that the resulting individual images can be shifted and registered into a single integrated image. Since this typically includes images obtained from coadded integrations at various dither positions that are preserved as distinct data, information about what transpired during the total integration time is retained.

Putting these parameters together, the telescope is pointed to some starting or "home" position and the desired filter inserted into the beam. The telescope is then dithered in a tight pattern around the home position. At each dither position, several integration sets may be taken; a set may consist of several individual integrations coadded. The entire dither pattern may be repeated to build up the total integration time. Then the telescope is offset to a new, largely non-overlapping, position and the process is repeated.

Finally this brings us to **scripts.** These are sequences of instructions that put these processes together to give a high degree of automation when observing. A typical script has interactive components at the beginning, for example to select a dither pattern from a list or to input an integration time, and then executes the resulting sequence. Dithering or coadding by the control program, mentioned above, are simple scripts. More complex sequences may be provided by the control program (with appropriate user adjustable parameters) or can be created by the astronomer. And scripts can be composed of smaller scripts, so quite lengthy procedures can be highly automated. It's vital to have appropriate pause, stop, and abort commands to avoid being locked in to a lengthy procedure when things don't go as planned.

In the sequences that are described below, typically the first steps consist of user setup: positioning the telescope, defining input parameters, selecting dither or offset patterns, etc. The remaining steps are highly repetitive combinations of telescope motion and signal integration. These processes will undoubtedly be provided as scripts in the final user level instrument control program.

4. Calibration observing sequences

These are for removal of system signature during initial reduction of the data to "science ready" form, and for photometric calibration of measured flux subsequently.

4.1 Dark current measurements

Typically done when not observing the sky (daytime, cloudy, etc.). Filter set to "cold dark slide", telescope not tracking, usually pointed to zenith with mirror covers closed. NEWFIRM's external warm shutter will also be closed.

a. Set filter position to cold dark slide.
b. Set integration time to desired value, typically a value commonly used during the night. Coaddition is not used.
c. Set number of frames to take, typically 10-20
d. Update header information such as root filename, descriptive title
e. Take data

f. Repeat until data sets are obtained for all desired integration times
g. User defined or canned scripts, with number of frames N and integration time T for each loop as variables, will frequently be used to take data without observer present.
h. Interrupts: User may abort a sequence (Step e), for example if integration time was specified incorrectly. Will start new sequence at step b.
i. Feedback: image statistics on representative section of each image

4.2 Dome flats

Typically done in daytime. Dome closed. Telescope pointed to white spot and not tracking. Mirror covers and external instrument shutter open.

a. Set filter to desired position.
b. Turn on dome flat illumination lamps and set to predetermined level.
c. Set integration time to predetermined value, typically a few seconds.
d. Set number of frames to take, typically 5-10.
e. Update header information such as root filename, descriptive title.
f. Take data.
g. Repeat for other filters, going from shortest wavelength to longest, e.g. J, H, K.
h. Turn off dome flat lamps.
i. Repeat in reverse filter order, matching integration time already used for each filter.
j. Scripted observing would be desirable but is not expected to be possible, due to necessary interaction with dome flat lamps.
k. Interrupts: User may abort a sequence (Step f) if real time image statistics indicate count rate is not what is desired. Will want to restart beginning with the corrected sequence.
l. Feedback: image statistics on representative section of each image

4.3 Twilight sky flats

Taken during evening or morning twilight, before/after night time science observing. Dome and telescope open, instrument warm shutter open. Telescope pointed to observer selected location, e.g. zenith or darkening sky opposite sunset point. Telescope tracking off.

a. Set filter to desired position.
b. Set integration time, typically a few seconds.
c. Set number of frames to take, typically 5-10.
d. Update header information such as root filename, descriptive title.
e. Take data.
f. Repeat for other filters.
g. This is a highly interactive process, driven by level of darkening sky and observer’s real time judgment. Unlikely that it can be scripted.
h. Interrupts: User may abort a sequence (Step e) if real time image statistics indicate count rate is not what is desired. Will want to begin again at step b.
i. Feedback: image statistics on representative section of each image

4.4 Night time sky flats

Taken during normal night time observing when the astronomer desires to have images of (relatively) empty fields specifically to construct flatfields. This may occur when the science fields are very rich in stars and/or contain extended objects.

Dome, telescope, and instrument shutters open to the sky. Telescope pointed to observer selected pointing, with open loop tracking on.

a. Point telescope to selected (RA, Dec) pointing as home position.
b. Select dither pattern from predefined list. Typically 5-20 dither positions.

c. Set dither step size, typically 10-30 arcseconds, and number of pattern repeats.
d. Set filter to desired position
e. Set integration time, typically 10-300 sec depending on filter choice.
f. Set number of frames and number of coadds to take at each dither position.
g. Update header information.
h. Execute dither pattern.
i. Optional: offset telescope and repeat Step h.
j. Return to step d and repeat in next filter.
k. May be executed from a script beginning at step b.
l. Interrupts: User may abort a sequence (Step h) due to error in input parameter (filter, integration time, dither pattern). Will want to restart sequence at home position.
m. Feedback: image statistics on representative section of each image.

4.5 Standard star observations

Taken during normal night time observing for flux calibration. Standard stars are typically at the bright end of the system dynamic range and use short integration times. Dithering is used, with dither step size sometimes approaching offset step size in order to cover a large part of the field of view with images of the standard star. Eventually NEWFIRM may use standard star *fields* each ontaining several standard stars distributed across the field of view.

Dome, telescope, and instrument shutters open to the sky. Telescope pointed to observer selected pointing, with open loop tracking on.

a. Point telescope to selected (RA, Dec) pointing corresponding to standard star coordinates as home position.
b. Select dither pattern from predefined list. Typically 5 dither positions.
c. Set number of dither pattern repeats.
d. Set dither step size. May vary from ~30 arcsec to ~300 arcsec.
e. Set filter to desired position
f. Set integration time, typically a few to 20 sec depending on filter choice.
g. Set number of frames and number of coadds to take at each dither position.
h. Update header information.
i. Execute dither pattern.
j. Return to step e and repeat in next filter.
k. May be executed from a script beginning at step b and running through a sequence of filters.
l. Interrupts: User may abort a sequence (Step i) due to error in input parameter (filter, integration time, dither pattern). Will want to restart sequence at home position.
m. Feedback: profile and count statistics on stellar image(s) of standard star(s) in field.

5. Science target observing sequences

Science targets will generally fall into one of three categories in terms of how they fill a single NEWFIRM field of view:

1. Sparse fields containing rather few, and point or pointlike, sources visible in a single integration time, sky subtracted image. Typical of IR imaging at the Galactic poles.

2. Rich fields containing many point sources, and perhaps small extended sources, at brightness levels that render them detectable in a single integration time, sky subtracted image. Typical of IR imaging in star forming regions, or near the plane of the Galaxy.

3. An extended, morphologically complex source filling much of the field of view. A large nebula or galaxy, or grouping of a few of these within the field.

The science programs will generally have one of three aims in terms of sensitivity and area coverage:

1. Very deep (i.e. faint limiting magnitude) sensitivity in a single NEWFIRM field of view, or at most a few fields per night.

2. Relatively bright limiting magnitude but coverage of a very large area—very many fields of view, up to ~100 per night.

3. Moderate depth over a moderate number of fields of view, ~10 per night.

A fundamental driver to all observing protocols is that for accurate sky subtraction, the sky level cannot be scaled or mapped from one part of the detector field of view to another. The same pixels must see source and sky sequentially. Fluctuations in the night sky DC level mean that these sequential observations can't be too far apart in time—typically a few minutes at most. The mean background sky may be determined from the science target data in the case of sparse fields, but must be determined from separately observed "sky" fields in the case of rich fields or extended sources. In the latter case, it may be advantageous for the geometrical pattern of positions sampling the sky fields to have an irregular character.

These source properties, observational goals, and sky and detector behaviors lead to a variety of different observing sequences. In large part these are different combinations of the same few basic operations.

5.1 Quick-look integration at a given pointing

This is done to verify the positioning of the telescope. Typically only one filter is used. Sky subtraction corrects or suppresses most of the first order system signature and allows identification of fainter sources.

a. Point telescope to desired (RA, Dec) home position.
b. Select filter.
c. Set integration time.
d. Set number of frames and number of coadds, typically (1, 1).
e. Update header information
f. Take data.
g. Dither telescope, typically 10-30 arcsec, in an arbitrary direction.
h. Take data.
i. Subtract second image from first and display the difference image.
j. Correct pointing if necessary.
k. This sequence could be scripted through step i.
l. Interrupts need not be considered for this very short sequence.

5.2 Deep integration at a single, sparsely populated pointing

In this case the science target images provide their own mean sky frame for sky subtraction. Dithers and other offsets are kept small and centered on the home position in order to maximize the field of view contained by the coincidence of all the stacked image data. Aborts or other interrupts may be driven by simple setup errors, or by clouds or other external transients noted during execution of the observations. The use or non-use of the guider to control telescope positioning introduces some variants into the protocol.

a. Point telescope to desired (RA, Dec) home position.
b. Acquire and lock on guide star.
c. Select dither pattern from predefined list.
d. Set dither step size, typically 10-30 arcsec, and number of dither pattern repeats.
e. Confirm guide star is accessible at all points in dither pattern.
    Variant 1. If not true, change dither pattern or select new guide star.
    Variant 2. If not true, opt to turn off guiding whenever guide star goes out of range.
f. Select filter.
g. Set integration time.
h. Set number of frames and number of coadds at each dither position.

i. Set number N of sequence repeats to be performed, to achieve the desired sensitivity.
j. Update header information
k. Execute dither sequence. Telescope positioning is under guider control throughout sequence.
   Variant 1. Telescope positioning is entirely open loop.
   Variant 2. Telescope positioning is corrected under guider control whenever telescope returns to home position.
l. Return to home position.
m. Move the telescope slightly by an amount and direction that differs from the dither pattern.
n. Return to step j and repeat N times.
o. Return to step f and repeat in next filter.
p. May be executed from a script running through a sequence of filters, or a series of scripts, one for each filter.
q. Interrupts: User may abort a sequence (Step j), usually due to error in input parameter (filter, integration time, dither pattern). No data taken are assumed to be useful. Will want to restart at home position.
r. User may abort the series of N sequences at some value < N, e.g. if sensitivity is judged to be satisfactory before N is reached.
s. Interrupts: User may pause a sequence at any position in the dither pattern after the data are obtained for that position. In this case the user will want to resume at the next position in the dither pattern. All data taken are assumed to be useful.
t. Interrupts: User may stop a sequence at any position in the dither pattern in order to go back, repeat some positions, and continue to the end. The user will want to resume at an arbitrarily specified position in the pattern. The initial data for repeated positions are assumed to be NOT useful.
u. Feedback: Running image statistics on a representative image section, for monitoring sky levels.
v. Feedback: Running sky subtracted difference images displayed and available to image query tools, at observer’s option. Observer defined sky frame may be from earlier data, first frame of dither sequence, immediately preceding frame, etc.

5.3 Deep integration at a single, richly populated pointing

In this case the telescope must be offset at intervals to an “empty” sky field to obtain data for sky subtraction. These intervals will be on the order of a few minutes of time, while the offset position may be degrees away from the science target. Hence telescope motions between science and sky fields may be large and frequent. Equal amounts of time must be spent on the science field and the sky field. It’s important to re-aquire the science home position accurately. Guiding is typically used only on the science field, but NEWFIRM survey science may introduce a requirement for guiding on both fields. This might be implemented with Guide Probe 1 set up on the science field and Guide Probe 2 set up on the sky field.

a. Point telescope to desired (RA, Dec) home position for science field.
b. Acquire and lock on guide star.
c. Select dither pattern from predefined list.
d. Set dither step size, typically 10-30 arcsec, and number of dither pattern repeats.
e. Confirm guide star is accessible at all points in dither pattern.
   Variant 1. If not true, change dither pattern or select new guide star.
   Variant 2. If not true, opt to turn off guiding whenever guide star goes out of range.
f. Select filter.
g. Set integration time.
h. Set number of frames and number of coadds at each dither position.
i. Set number N of sequence repeats to be performed, to achieve the desired sensitivity.
j. Update header information
k. Execute dither sequence. Telescope positioning is under guider control throughout sequence.
   Variant 1. Telescope positioning is entirely open loop.
   Variant 2. Telescope positioning is corrected under guider control whenever telescope returns to home position.
l. Return to science field home position.
m. Offset telescope to blank sky home position.

n. Update header information to label new position.
o. Execute dither sequence on blank sky with open loop telescope positioning.
   Variant 1. Dither sequence on sky is executed under closed loop guider control.
   Variant 2. Telescope positioning is corrected under guider control whenever telescope returns to blank sky home position.
p. Return to science field home position.
q. Correct telescope open loop positioning by locking on science field guide star.
r. Move the telescope slightly by an amount and direction that differs from the dither pattern.
s. Return to step i and repeat.
t. When enough data have been obtained, return to step f and repeat in next filter.
u. May be executed from a script that alternates science and sky fields and runs through a sequence of filters.
v. Interrupts: Same as for 5.2. User may abort and restart a dither sequence, pause and resume a sequence, or stop and repeat a sequence, with data kept or discarded as indicated in 5.2. This is the case for either science field or blank sky field. User may abort at fewer than N sequences if sensitivity is judged to be satisfactory.
w. Feedback: Same as for 5.2. Running image statistics, and option of running sky subtracted image display using user specified sky frame.

5.4 Deep integration at a single pointing containing an extended source or sources

While this situation is scientifically distinct, it is operationally identical to 5.3. The step-by-step procedure given in 5.3 applies to 5.4 also.

5.5 Quick, shallow mapping of a large area containing mostly point sources

Previous sequences have involved lots of dithering around a single home position, plus possibly an offset to a spatially disjoint position for blank sky. In contrast, a quick large area map involves lots of offsetting to adjacent fields with only a few dither positions around each offset pointing. Typical time spent at a given offset pointing is ~5 minutes. As in 5.2, the science target fields provide the mean sky image for sky subtraction. Guiding will typically not be used, since setting up on a new guide star for every offset position would impact system efficiency.

a. Point telescope to desired (RA, Dec) home position for start of map.
b. Optional: acquire and lock on guide star in order to have very well defined starting position.
c. Select offset pattern and offset step size. Typically this will be an N x M mosaic with 5-50% overlap between adjacent offset positions. Note the pattern is specified by the user as a starting (RA, Dec) position plus (_RA, _Dec) motions, *not* a list of absolute (RA, Dec) positions.
d. Select dither pattern; typically 2-5 dither positions.
e. Set dither step size, typically 10-30 arcsec, and number of dither pattern repeats.
f. Select filter.
g. Set integration time.
h. Set number of frames and number of coadds at each dither position.
i. Update header information
j. Execute dither sequence around initial home position, returning to home position at the end.
k. Offset the telescope to the next offset position.
l. Repeat from step i (in order to capture time and positional information) until the offset pattern is completed.
m. Return to offset starting position from step a.
n. Repeat from step f until data have been obtained in all desired filters.
o. May be executed from a script beginning at step c and running through step n.
p. Interrupts: User may abort a sequence (Step j), usually due to error in input parameter (filter, integration time, dither pattern). No data taken are assumed to be useful. Will want to restart at Step a home position.

q. Interrupts: User may pause a dither sequence at any position in the dither pattern after the data are obtained for that position. In this case the user will want to resume at the next position in the dither pattern. All data taken are assumed to be useful.
r. Interrupts: User may pause the offset sequence at any position in the offset pattern after the data are obtained for that position. In this case the user will want to resume at the next position in the offset pattern. All data taken are assumed to be useful.
s. Interrupts: User may stop an offset sequence at any position in the offset pattern in order to go back, repeat some positions, and continue to the end. The user will want to resume at an arbitrarily specified offset position in the offset pattern. The initial data for repeated positions are assumed to be NOT useful. Note: this stop-and-back-up interrupt applies only to offset positions; this implies that internal dither sequences are repeated in their entirety.
t. Feedback: Running image statistics on a representative image section, for monitoring sky levels.
u. Feedback: Running sky subtracted difference images displayed and available to image query tools, at observer's option. Observer defined sky frame may be from earlier data, first frame of dither sequence, immediately preceding frame, etc.

5.6 Quick, shallow mapping of a large area with extended sources

This is distinguished from 5.5 by the need to offset to a blank sky field at regular intervals. This is similar to the difference between 5.2 and 5.3. Note that the same blank sky data may be used for sky subtraction from different offset positions. Hence the frequency of switching between science map and blank sky is driven only by the variability of the sky DC level. Significantly more time may be spent executing the map than acquiring blank sky frames.

It's important to resume the science map at the correct (RA, Dec) position to keep an N x M raster pattern square. It remains to be seen if this will require telescope position correction using a guide star. I have included this as a variant operation.

a. Point telescope to desired (RA, Dec) home position for start of map.
b. Optional: acquire and lock on guide star in order to have very well defined starting position.
c. Select offset pattern and offset step size. Typically this will be an N x M mosaic with 5-50% overlap between adjacent offset positions. Note the pattern is specified by the user as a starting (RA, Dec) position plus (_RA, _Dec) motions, *not* a list of absolute (RA, Dec) positions.
d. Select dither pattern; typically 2-5 dither positions.
e. Set dither step size, typically 10-30 arcsec, and number of dither pattern repeats.
f. Enter blank sky position as absolute (RA, Dec) position. Same dither pattern will be used for the blank sky data.
   Variant. Enter blank sky position as (_RA, _Dec) offset with respect to start of map.
g. Select filter.
h. Set integration time.
i. Set number of frames and number of coadds at each dither position.
j. Enter number N of raster map positions to observe between offsets to blank sky position.
k. Offset to blank sky position.
l. Update header information.
m. Execute dither sequence at blank sky position. Telescope pointing is open loop.
   Variant. Acquire and lock onto guide star for blank sky position. Telescope pointing is under guider control.
n. Offset to home position for start of map.
o. Update header information.
p. Execute dither sequence around offset home position, returning to home position at the end.
q. Offset the telescope to the next offset position in science raster map.
r. Repeat from step o until N raster map positions have been completed.
s. Offset to blank sky position.
t. Move the telescope slightly by an amount and direction that differs from the dither pattern.

u. Update header information.
v. Execute dither sequence at modified blank sky position.
w. Offset to next position in science raster map.
   Variant. Correct position by locating guide probe to nominal position for preselected guide star, then move telescope to center on guider. Turn off guider.
x. Repeat from step o until science raster map is complete.
y. Repeat steps s-v to acquire final blank sky data.
z. Return to home position of start of map from step a.
aa. Repeat from step h in next filter.
bb. Continue until data have been obtained in all desired filters.
cc. May be executed from a script or a series of scripts, one for each filter.
dd. Interrupts: Same as for 5.5, applying to both science raster map and blank sky sequences.
ee. Feedback: Same as for 5.5.

5.7 Moderate depth map of moderate area containing only pointlike sources

This is similar to 5.5, with fewer offsets and more dithered positions at each offset pointing. Closed loop guider control is used to avoid positional drift. While the desired total integration time could be obtained at a given offset position before moving to the next one, I specify here the alternative of moving through the entire map repeatedly to build up the total time. This smooths out effects of DC sky variations, changing extinction, and other slowly varying secular effects in the system signature.

a. Point telescope to desired (RA, Dec) home position for start of map.
b. Acquire and lock on preselected guide star for initial raster map home pointing.
c. Select offset pattern and offset step size. Typically this will be an N x M mosaic with 5-50% overlap between adjacent offset positions. Note the pattern is specified by the user as a starting (RA, Dec) position plus (_RA, _Dec) motions, *not* a list of absolute (RA, Dec) positions.
d. Select dither pattern from predefined list.
e. Set dither step size (typically 10-30 arcsec) and number of dither pattern repeats.
f. Select filter.
g. Set integration time.
h. Set number of frames and number of coadds at each dither position.
i. Set number of passes N through the raster map required to build up desired total integration time.
j. Update header information
k. Execute dither sequence around initial home position, returning to home position at the end.
l. Offset the telescope to the next offset position.
m. Acquire and lock on preselected guide star for this position.
n. Repeat from step j until the offset pattern is completed.
o. Return to offset starting position from step a.
p. Repeat from step j until N passes through the raster map have been completed.
q. Repeat from step f until data have been obtained in all desired filters.
r. May be executed from a script, or a series of scripts (e.g. one for each filter).
s. Interrupts: User may abort a sequence (Step k), usually due to error in input parameter (filter, integration time, dither pattern). No data taken are assumed to be useful. Will want to restart at Step a home position.
t. User may abort the series of N sequences at some value < N, e.g. if sensitivity is judged to be satisfactory before N is reached.
u. Interrupts: User may pause a dither sequence at any position in the dither pattern after the data are obtained for that position. In this case the user will want to resume at the next position in the dither pattern. All data taken are assumed to be useful.
v. Interrupts: User may pause the offset sequence at any position in the offset pattern after the data are obtained for that position. In this case the user will want to resume at the next position in the offset pattern. All data taken are assumed to be useful.
w. Interrupts: User may stop an offset sequence at any position in the offset pattern in order to go back, repeat some positions, and continue to the end. The user will want to resume at an arbitrarily specified offset position in the offset pattern. The initial data for repeated positions

are assumed to be NOT useful. Note: this stop-and-back-up interrupt applies only to offset positions; this implies that internal dither sequences are repeated in their entirety.

x. Feedback: Running image statistics on a representative image section, for monitoring sky levels.
y. Feedback: Running sky subtracted difference images displayed and available to image query tools, at observer's option. Observer defined sky frame may be from earlier data, first frame of dither sequence, immediately preceding frame, etc.

5.8 Moderate depth map of moderate area containing extended sources

This is like 5.7, with the need to offset to blank sky at regular intervals. Together, 5.7 and 5.8 are similar to 5.5 and 5.6, with the addition of closed loop telescope positioning and guiding to avoid telescope positional drift as one passes repeatedly through the raster pattern.

a. Point telescope to desired (RA, Dec) home position for start of map.
b. Acquire and lock on preselected guide star for initial raster map home pointing.
c. Select offset pattern and offset step size. Typically this will be an N x M mosaic with 5-50% overlap between adjacent offset positions. Note the pattern is specified by the user as a starting (RA, Dec) position plus (_RA, _Dec) motions, *not* a list of absolute (RA, Dec) positions.
d. Select dither pattern from predefined list.
e. Set dither step size (typically 10-30 arcsec) and number of dither pattern repeats.
f. Enter blank sky position as absolute (RA, Dec) position. Same dither pattern will be used for the blank sky data.
   Variant. Enter blank sky position as (_RA, _Dec) offset with respect to start of map.
g. Select filter.
h. Set integration time.
i. Set number of frames and number of coadds at each dither position.
j. Enter number M of raster map positions to observe between offsets to blank sky position.
k. Set number of passes N through the raster map required to build up desired total integration time.
l. Offset to blank sky position.
m. Update header information.
n. Execute dither sequence at blank sky position. Telescope pointing is open loop.
   Variant. Acquire and lock onto guide star for blank sky position. Telescope pointing is under guider control.
o. Offset to home position for start of map.
p. Acquire and lock on preselected guide star for starting position.
q. Update header information.
r. Execute dither sequence around offset home position, returning to home position at the end.
s. Turn off guiding.
t. Offset the telescope to the next offset position in science raster map.
u. Acquire and lock on preselected guide star for this position.
v. Repeat from step q until M raster map positions have been completed.
w. Offset to blank sky position.
x. Move the telescope slightly by an amount and direction that differs from the dither pattern.
y. Update header information.
z. Execute dither sequence at modified blank sky position.
aa. Offset to next position in science raster map.
bb. Repeat from step p until science raster map is complete.
cc. Repeat steps w-z to acquire final blank sky data.
dd. Repeat from step o until N passes through the raster map have been completed.
ee. Return to home position of start of map from step a.
ff. Repeat from step g until data have been obtained in all desired filters.
gg. May be executed from a script, or a series of scripts (e.g. one for each filter).
hh. Interrupts: Same as for 5.7.
ii. Feedback: Same as for 5.7.

6. Observing scenarios

A scenario is a combination of observing sequences that makes up a night's observations. Here is an example.

Program scenario: Moderate depth, moderate sensitivity observations in a series of star forming regions.

The night's program is to obtain data in three star forming regions. Two are in dark clouds known to be free of extended IR nebulosity, while one is in an optical H II region so probably has extended nebular emission in the IR as well. Broadband J, H, and K filters will be used. Integration times have been determined in advance from experience with sky background levels on the 4-m telescope. Guide stars have been selected in advance (as noted earlier in this document, a necessity with NEWFIRM). Science field centers, blank sky field centers, and accompanying guide star positions have been loaded into a cache accessible through the 4-m Telescope Control System.

1. Dark current measurements (4.1) are obtained during the afternoon for all integration times to be used during the night.
2. Dome flats (4.2) are taken in late afternoon in the J, H, and K filters. The observer intends to use sky flats to reduce her data but takes these as a precaution.
3. After telescope pointing and focus checks at the start of the night, the observer obtains J, H, K data on a standard star (4.5) near the zenith. She uses a facility "observe standard star" script.
4. Another standard star is observed near the first target field.
5. The observer moves to the first target field, in a dark cloud, and checks the field centering on the array with a quick-look observation (5.1).
6. The telescope position is moved slightly and the initial home position (RA, Dec) of this field in the cache is modified accordingly.
7. The observer begins a script for a moderate depth, moderate area map (5.7). She calls up a generic facility script and sets offset, dither, and integration time parameters. Only one filter will be used, the J filter. The observer calculates that, including overheads, this will take 45 minutes to complete as three, 15 minute passes through the raster map.
8. The data taking sequence is begun, under closed loop (guider) control of telescope position.
9. The observer monitors the sky level as the observations progress.
10. The observer uses interactive query tools and the image display to monitor image FWHM and the count rates on some 2MASS stars of known brightness in the field. No problems are noted.
11. The data taking sequence terminates.
12. The standard star from step d is re-observed (4.5).
13. The observer returns to the first target field and maps it again (5.7) in the H filter.
14. The sequence is planned for 45 minutes, but the observer notes that adequate signal to noise has been obtained after 30 minutes, so aborts the final pass through the raster map.
15. The standard star from step d is observed again (4.5). This is sooner than the observing plan called for, but waiting until the K observations are done would be a longer time between standard star observations than the observer likes.
16. The observer returns to the first target field and begins to map it again (5.7) in the K filter. Due to higher sky background, the entire sequence has five passes through the raster map and will take 1.5 hours.
17. After 45 minutes, the image FWHM is seen to increase and the sky background begins to rise noticeably. The observer issues a PAUSE command for the offset sequence, to take effect when the dither set for the current sequence is done.
18. While the dither set completes, the observer goes outside to look at the sky. The Moon is up. A small, isolated cloud is seen to be drifting across the mountain.
19. Back in the control room, the observer converts her PAUSE command to a STOP command.
20. Examining sky subtracted images off line, she decides to discard the data for the last two offset positions.
21. After 15 minutes the cloud has gone by. The K band map is restarted, repeating the last two offset positions, and going on to the end.
22. The entire K band sequence terminates after 45 more minutes.

23. The standard star from step 4 is observed again (4.5). Another standard fairly close to the next science field is also observed (4.5).
24. Due to the cloud, and the possibility of further cloudiness later, the observer decides to modify her program for the night and obtain just a quick shallow map of the second science field. This requires real time modification of her previous observing script. Changes are made to the selected dither pattern, integration times, and number of coadds per dither position.
25. The second field is acquired and pointing checked (5.1). This field is also in a dark cloud.
26. A quick map is executed in J, and repeated in H and K (5.5). Running sky level and image quality checks don't indicate any problems. This takes an hour with no interruptions.
27. The nearby standard star from step 23 is reobserved (4.5).
28. The third field is acquired and pointing checked (5.1). This field requires accompanying blank sky field observations.
29. The observer sets up for execution of a moderate depth map with offsets to sky field (5.8). Since this is a complex sequence she has written a custom script before the observing run using the Observing Tool. As with the first field, she intends to observe it in J, H, and K with standard star observations in between.
30. The J band sequence is initiated. This takes 75 minutes including the time on the blank sky field.
31. At the third offset position there is an error condition. The guide star is out of range of the probe for two dither positions. The observer uses a GUIDER OVERRIDE command to obtain data at these positions with open loop telescope tracking, then resume guiding at the remaining positions.
32. Otherwise the sequence continues uneventfully, and the sky continues to be clear.
33. The standard star is reobserved (4.5). The H and K sequences are done (5.8) with a standard star observation following each one.
34. In addition to keeping an eye on running sky and image behavior, the observer has been doing a quick-look reduction of the map of her second science field. Position 3 looks interesting!
35. Since there were no further problems, the modified program has finished a little ahead of schedule. The observer decides to return to Position 3 of the second field and integrate on it in the K band until the sky is too bright to observe. This requires real time creation of a simple script for dithering around a single pointing.
36. The telescope is pointed at Position 3 of the second field. Since this was originally intended to be observed under guider control, there is an identified guide star for it. The observer sets up for a deep integration sequence in the K band only (5.2) that will take 60 minutes to complete.
37. After 45 minutes the sky is too bright to continue. The sequence is stopped.
38. After the telescope and instrument are closed up, a script is started to repeat the dark current measurements (4.1). These are left running and the observer goes to bed.

7. Failure modes

Several kinds of occurrences have been noted in previous sections that require adaptability to events on the part of the software; for example, the guide star moving out of range of the guider during a dither pattern; on-the-fly modification of an observing script; a passing cloud causing an observer to pause, abort, and restart a data-taking sequence with repetition of some positions. These are considered to be within the normal range of events for groundbased observing, so the observation control software is required to handle them smoothly.

In this section I list plausible failures of communication between system components, and hardware failures, and the resulting requirements on the observation control software to react to them. Some cases may require observer intervention at the level of command-line engineering commands to the instrument controller or guider electronics from the OCS in order to configure the instrument into a fixed but usable state. It is assumed that the online NEWFIRM Observer's Manual will contain a Troubleshooting section to help users recognize specific failure modes and to walk them through recovery procedures, so not all the intelligence need reside in the OCS. In general, the goal is to press on with observing and postpone major troubleshooting and down time for daylight hours if a reasonable level of efficiency can be maintained.

Some of the failure responses listed below involve actions other than through the OCS, such as visual inspections or power cycling. These are included for coherency and completeness in the discussion of required OCS responses to failure modes. Interventions that involve commands issued directly to the instrument controller or guider, bypassing the OCS (e.g. via a laptop connected to the controller) are considered to be engineering or troubleshooting activities that are outside the scope of this discussion.

7.1 Filter wheel failures

These failure modes may result from a loss of communication with the filter wheel, or a hardware failure with a motor, sensor, wiring, etc.

Communications failures include commands sent, but not received or acknowledged, between the observing control software and the instrument controller or between the instrument controller and the filter wheel. It also includes failure to read back filter wheel position. The result is either that the filter wheel won't move, or that it won't stop moving. This is probably a temporary glitch with a straightforward recovery to full operability. However, if full communication can't be restored, the recovery mode is to "park" the filter in a legal and known position, and disable further motion commands pending troubleshooting by support personnel. Hardware damage from a communications failure is unlikely.

Hard failure means a piece of hardware is not functioning properly: a cable is disconnected, a motor has died, a gear train has jammed, internal wiring has broken, a limit switch or sensor is stuck, etc. It may be initially difficult to discriminate between communications failures and hard failures. Operationally the results are the same: either the filter wheel won't move, or it won't stop moving. If full operability can't be restored, the goal is likewise to "park" the filter in a legal and known position, and disable further motion commands. However, recovery options are more limited and restoration of at least partial operability may be less likely with a hard failure. In the event of hardware failure a high priority is to prevent further damage.

Likely failure modes are:

7.1.1 Filter wheel will not move on command from a known legal position.

- A script in course of execution shall go into a "pause" mode to permit observer interventions with the filter wheel.
- The observation control system shall issue an appropriate advisory message, and provide a "try again, yes/no" option to the observer.
- The OCS shall provide for appropriate software restarts, for example quitting and restarting a communications daemon.
- The online manual shall indicate appropriate hands-on hardware inspection, such as for loose connectors. Given the highly enclosed and hardwired nature of external connections on NEWFIRM, these will probably be very limited.
- The online manual shall indicate appropriate hardware restarts, for example powering the instrument controller off and on, accompanied by appropriate software shutdown and restart.
- If none of this succeeds in restoring motion, the filter is still in a known legal position so some subset of science observations can continue.
- The OCS shall provide a "disable filter commands" option.
- This option shall allow scripts to be run unchanged but skip over any subroutine that involves a filter other than the current position.
- Alternatively, scripts shall be readily editable in real time so that blocks of actions involving a different filter can be suppressed.

7.1.2 Filter wheel is moving and won't stop.

If a communications error, this is probably due to a glitch in reading a position sensor or limit switch. If a hardware failure, this is likely due to position sensor failure or a stuck limit switch inside the Dewar. In either case the software is waiting for a position update that never comes. The good news is that continuous motion indicates no problems with electrical power, motors, gear trains, etc. At a minimum there is probably some way to stop and stay at a known position.

- The OCS shall issue an appropriate advisory message. This might be triggered by total number of steps sent to the motor without receiving positional feedback.
- The online manual shall indicate an appropriate hands-on diagnostic. For example, the motor, gear train, and detents may normally make noises that are readily audible when the wheel is moving.
- The OCS shall provide a “filter motion abort” command that stops wheel motion.
- The OCS shall provide for appropriate software restarts, for example quitting and restarting a communications daemon.
- The online manual shall indicate appropriate hands-on hardware inspection, such as for loose connectors. Given the highly enclosed and hardwired nature of external connections on NEWFIRM, these will probably be very limited.
- The online manual shall indicate appropriate hardware restarts, for example powering the instrument controller off and on, accompanied by appropriate software shutdown and restart. This is necessary in the event “filter motion abort” doesn’t work.
- The OCS shall provide a “find home” command that moves the wheel slowly until the home position is sensed.
- The OCS shall provide open loop motion commands that position the wheel from home by counting motor steps, without using intermediate position readout feedback.
- The OCS shall provide a “position open loop” option that allows existing scripts to run using this mode for implementing commanded filter motions.
- The OCS shall provide a “step” option that moves the wheel in an open-loop fashion, issuing motor steps, under observer control. This is the recovery of last resort if the wheel can’t find home. It would be followed by the “disable filter motion” command.
- Some of these commands may be engineering commands at the controller level that are issued to the instrument controller via a window in the OCS.

7.1.3 Filter wheel has stopped between legal filter positions. The OCS has a last known legal position, and an approximate idea of where the wheel is from the number of stepper motor steps issued since then.

- The OCS shall issue an appropriate advisory message.
- The OCS shall provide for appropriate software restarts, for example quitting and restarting a communications daemon.
- The OCS shall provide a “find next” option that moves the wheel slowly, open-loop, until the next detent position is sensed and read.
- Other commands and operational options are as in 7.1.1.1 and 7.1.1.2 .

7.2 Guider failures

The guider has mechanical functions to position the guide probes in commanded locations, and electro-optical functions to create, read, and transmit a video image of the sky. As with the filter wheels there can be communications failures or hardware failures and it may not be initially clear which is occurring. Troubleshooting and OCS responses are similar to the actions for filter wheel failures. Some significant differences are

- Mechanical motions can’t continue indefinitely; there are limit switches and hard stops
- There is redundancy due to having two separate guide probe assemblies
- There are no detented or otherwise predefined legal positions
- If a probe can’t be moved, it’s useless; there is no usable “parked “ position
- Useful observations can continue even with total failure of both guider channels

Likely failure modes are:

7.2.1 Guider probe will not move on command from a known position. This may be X, Y, or Z motion of the guider stages, or rotary motion of the cylinder lens in the optical train. Some motions may be unaffected and presumably continued to completion.

- A script in course of execution shall go into a “pause” mode to permit observer interventions with the guider.
- The observation control system shall issue an advisory message indicating which probe and which axes are affected.
- The OCS shall report any motor feedback that is out of normal operating range (e.g. current overload, excessive torque, etc.)
- The OCS shall provide a “try again, yes/no” option to the observer.
- The OCS shall provide for appropriate software restarts, for example quitting and restarting a communications daemon.
- The online manual shall indicate appropriate hands-on hardware inspection. Given the tight enclosure of the guide probe assemblies, these will probably be very limited.
- The online manual shall indicate appropriate hardware restarts, for example powering the guider electronics off and on, accompanied by appropriate software shutdown and restart.
- The OCS shall provide a “disable guide probe motion” option for each probe
- This option shall allow scripts to be run but skip over any commanded motions of the affected probe, reverting to open-loop tracking.

7.2.2 Guide probe motion does not halt at commanded location.

- The OCS shall issue an appropriate advisory message when an expected halt doesn’t occur, including an abort option to stop the affected motion.
- The OCS shall issue an appropriate advisory message when motion is halted by a limit switch.
- The OCS shall provide a “find home” command that recovers from an abort or a limit switch cutoff by operating the affected motion until the home position is sensed.
- The online manual shall indicate appropriate hands-on hardware inspection. Given the tight enclosure of the guide probe assemblies, these will probably be very limited.
- The OCS shall provide for appropriate software restarts, for example quitting and restarting a communications daemon.
- The online manual shall indicate appropriate hardware restarts, for example powering the guider electronics off and on, accompanied by appropriate software shutdown and restart.
- The OCS shall provide open loop motion commands that position the wheel from home by counting motor steps, without using intermediate position readout feedback.
- The OCS shall provide a “position open loop” option that allows existing scripts to run using this mode for implementing commanded guider motions.
- The OCS shall provide a “disable guide probe motion” option for each probe
- This option shall allow scripts to be run but skip over any commanded motions of the affected probe, reverting to open-loop tracking.

Some of these commands may be engineering commands at the controller level that are issued to the instrument controller via a window in the OCS. Troubleshooting of guider probe motions can take place on the telescope by removing protective covers. However, this will be a daytime activity that is beyond the range of night time failure recovery actions.

7.2.3 Weak or no video signal received from a guide probe.

- The OCS shall report inability to determine an image centroid by the guider software.
- The OCS shall report average and peak signals in the video data, corresponding to mean sky level and brightest star level. These can be compared between the two probes.
- The online manual shall indicate appropriate hands-on hardware inspection such as for loose connections, noisy or defective cables, etc.
- The OCS shall provide for appropriate software restarts, for example quitting and restarting a communications daemon.

- The online manual shall indicate appropriate hardware restarts, for example powering the video electronics off and on, accompanied by appropriate software shutdown and restart.
- The OCS shall provide a “disable guide probe motion” option for each probe
- This option shall allow scripts to be run but skip over any commanded motions of the affected probe, reverting to open-loop tracking.

7.3 Telescope failures

The telescope has to focus, point, and track (open loop and guided). These actions are controlled by the Telescope Control System (TCS). Some of these actions may be commanded from the OCS to the TCS, hence are subject to communications failures. The TCS also passes telescope status information to the OCS for incorporation into image headers. This is subject to communications failures. There are some fallbacks to alternative working modes or science programs in the event of failures of either software or hardware on the telescope side of the operation. While alternatives that permit continued observing shall be provided, some of these failures can have such severe impacts on successfully completing the science program that a program halt for perhaps extensive troubleshooting is warranted. Such troubleshooting is outside the purview of this document.

Likely failure modes are:

7.3.1 Telescope motions communications failure between the OCS and the TCS: telescope focus or motion (pointing or offset) commands aren’t executed when sent from the OCS, or the subsequent acknowledgement (handshake) doesn’t occur after proper execution of the hardware action.

In the event of a handshake failure following proper execution of a commanded action:

- The acknowledgement timeout period shall be short (seconds).
- The initial handshake failure shall be followed by an automatic retry.
- A subsequent failure shall produce an error message on the observer GUI.
- A script in course of execution shall go into a “pause” mode.
- Observer must manually confirm that the desired telescope action was carried out.
- Observer shall have an override command to manually acknowledge that the commanded action occurred, so that the script can proceed.
- Observer shall have a global override command with observer-adjustable timeout period, to ignore all handshake failures and proceed with observing.

In the event of a failure to execute a commanded motion:

- The execution and acknowledgement timeout period shall be short.
- The initial command shall be followed by an automatic retry.
- A subsequent failure shall produce an error message on the observer GUI.
- A script in course of execution shall go into a “pause” mode.
- Observer must manually confirm that the desired telescope action was not carried out.
- Telescope operator shall execute the commanded motion (if this fails, we are in a hard failure mode; see 7.3.5 below).
- Observer shall have an override command to manually acknowledge that the commanded action has occurred, so that the script can proceed.
- Observer shall have a global override command such that all script commanded telescope motions are executed by the telescope operator, not by the OCS.

7.3.2 Telescope status communications failure between the TCS and the OCS: telescope position, focus value, time, and/or other status information is not successfully passed to the OCS for incorporation into image headers. While workarounds described below are to be supported, this failure mode is one for which a program halt to identify and fix the problem should be seriously considered.

- The status update and acknowledgement timeout period shall be short.
- The initial status update shall be followed by an automatic retry.
- A subsequent failure shall produce an error message on the observer GUI.
- A script in course of execution shall go into a "pause" mode.
- Observer shall have a means to verify that telescope status information has not been updated on the OCS side
- The OCS GUI shall open a status update window in which the observer can enter values by hand, for whatever status entries he/she chooses. Others will remain blank.
- This window shall include an override command to accept manual status entries and proceed with the script.
- Observer shall have a global override command to ignore all status requests and simply proceed with the script.

7.3.3 Telescope won't focus. Focus motion might be initiated by command from the OCS, by command from the TCS, or with a hardware input (focus button on console). If initiated from the OCS, focus motion may be incorporated into a script (as assumed below) or commanded by the observer outside of script execution.

- If nonresponsive to focus command from the OCS, the execution and acknowledgement timeout period shall be short.
- The initial command shall be followed by an automatic retry.
- A subsequent failure shall produce an error message on the observer GUI.
- A script in course of execution shall go into a "pause" mode.
- Observer must manually confirm that the desired focus motion was not carried out.
- Telescope operator shall execute the commanded motion from the TCS.
- Observer shall have an override command to manually acknowledge that the focus motion has occurred, so that the script can proceed.
- Observer shall have a global override command such that all scripted focus motions are executed by the telescope operator, not by the OCS.
- If nonresponsive to focus commands from the TCS, the telescope operator shall use the hardware input.
- If nonresponsive to direct hardware input, observer must decide to either continue or to halt the science program and troubleshoot the telescope problem.

7.3.4 Telescope won't track under guider control. This section assumes that guider failures treated in Sec. 7.2 are not at issue. The guide probes are moving properly and the video input signal is at a level appropriate for the brightness of the guide star. In what follows I assume that the difficulty is on the telescope side, with guider software or communications to the TCS. The OCS is involved to the extent that it must support a fallback mode of operation. The observer may choose to terminate the current program and switch to one which can be executed successfully without guiding; or to stop science observing and troubleshoot the telescope problem.

- TCS shall generate an error condition and pass it to the OCS.
- A script in course of execution shall go into a "pause" mode.
- Observer and telescope operator shall confirm that guiding is not occurring properly.
- Observer shall have an override command to ignore the error condition and proceed with the script.
- Observer shall have a global override command to disable all scripted closed loop tracking. This might, for example, execute scripted guide probe motions but ignore the resulting TCS "no guiding" error condition.

7.3.5 Telescope won't track open loop (i.e. within a normal range of open loop tracking error). This is a hard failure on the telescope side. The science observing must stop while the problem is resolved. There is no OCS action other than termination of an observing script, as provided for elsewhere in this SDN.

7.4 Array controller (MONSOON) and Data Handling System (DHS) failures

MONSOON is the system that controls and reads out the NEWFIRM arrays, including some low level image processing (image descrambling). The DHS joins array data with TSC-provided header information ("metadata") and routes the resulting files to storage media. The OCS issues instructions to these systems, coordinates their actions, and monitors for proper execution. These are complex, interlocking hardware/software systems with built-in redundancies and failure recovery modes. The failure response discussion here is given from the observer's point of view and is somewhat superficial.

MONSOON and the DHS both have internal automatic responses and soft failure modes in the presence of problems. These include retries in the event of communications glitches, redirection of data from failed hardware to remaining parallel channels, and generation of warning and diagnostic messages. The OCS must provide information that enables the observer to distinguish between self-recovered transient problems; those that produce permanent data dropout (effectively a hole in sky coverage if the observing protocol isn't modified); and those that call for cessation of science observing for immediate troubleshooting. In the latter two cases the OCS must support appropriate manual interventions by the observer.

Likely failure modes are:

7.4.1 One or more arrays don't read out properly. This refers to gross image effects such as all zeroes or all saturated pixels which are obvious to the observer via the image display. Due to hardware redundancies at intervening levels, this is likely a symptom of low level array or pixel acquisition node (PAN) electronics failure. In keeping with the tenor of this section, the OCS shall support reconfiguration of the observing protocol to maintain sky coverage at lower system efficiency (more pointings). OCS capabilities to do this are redundant with those already called out in Sec. 5. The observer has to provide the higher level intelligence, e.g. what is the appropriate revised pointing pattern.

- The OCS shall prominently display warning and diagnostic messages generated by the MONSOON or DHS systems for loss of usable science signal.
- The OCS shall provide for observing sequence abort.
- The OCS shall provide for real time script modification or creation.
- The OCS shall provide for real time guide star selection from appropriate catalogs, or accept input from the external tool that does this as part of observation planning.

7.4.2 All arrays suddenly fail to read out. This is likely a MONSOON software failure, such as a lockup of all the PANs or a power glitch to the electronics causing loss of fundamental configuration information. These call for manual interventions in software (restart, configuration reload, etc.)

- The OCS shall prominently display warning and diagnostic messages generated by the MONSOON or DHS systems in this event.
- The OCS shall provide for an abort from scripted data-taking for this circumstance.
- The online manual shall indicate appropriate hands-on diagnostic and recovery procedures.

7.4.3 Data or metadata communications failures, automatically recovered. There is no halt to the data flow. The observer must decide whether or not to continue with the science program, depending on the frequency and efficiency impact of such failures. The job of the OCS is to bring them to the observer's attention.

- The OCS shall prominently display warning and diagnostic messages generated by the MONSOON or DHS systems for communications retries.
- The online manual shall indicate appropriate hands-on diagnostic and recovery procedures.

7.4.4 DHS partial hardware failure. There are several identical subsystems running in parallel to handle the four arrays' output. The system is internally configured to redirect incoming data from a failed machine to the remaining machines. So there is no halt to the data flow. The job of the OCS is to both bring this to the observer's attention, and warn of impacts on observing protocol.

- The OCS shall prominently display warning and diagnostic messages generated by the DHS system for subsystem failure and data redirection.
- The OCS shall produce a warning message about acceptable data rate (e.g. new minimum integration time set by the slowdown in data handling) and other observing protocol impacts of the reconfiguration.

7.4.5 Total failure of DHS. This might be due to the failure of all the DHS machines, or a communications break such as a disconnected or broken fiber. In this event the image data produced by MONSOON has nowhere to go. The MONSOON PAN's can each internally store ~100 images before the system comes to a complete stop. Science observing must terminate but there is the opportunity to do so gracefully, e.g. complete the current image sequence.

- The OCS shall prominently display warning and diagnostic messages generated by the DHS system.
- Alternatively, the OCS shall recognize this condition and display its own warning message.
- The OCS shall start a frame countdown and warn the observer of remaining internal image storage space, with an abort option, before taking each subsequent image.
- The online manual shall indicate appropriate hands-on diagnostic and recovery procedures, including a procedure for pulling data from the local PAN disk to permanent storage to prevent data loss.