



# NEWFIRM

<b>Title:</b> NFM-AD-02-4102 NEWFIRM temperature sensing and control requirements					
<b>Prepared by</b>	<b>Date</b>	<b>Approved by</b>	<b>Date</b>	<b>Rev.</b>	<b>Rev Date</b>
Ron Probst	2/19/03				
		Neil Gaughan	8/9/04	1	7/21/2004
<b>Related documents:</b>					

## 1. Introduction

This SDN states requirements for temperature sensing and temperature control in NEWFIRM. It identifies the various purposes for these functions; location, type, and number of sensors; active control accuracy and control frequency; and user interface features.

The emphasis is on required functionalities, not details of engineering implementation. The locations, and to a lesser extent the number, of various sensors may change as the instrument design progresses.

Valuable additional information resources with a great deal of technical information are the GNIRS System Design Notes SDN 13.06 Temperature Calibration and SDN 12.01 Dewar Wiring Parameters.

### 1.1 Revision history

#### 1.1.1 Revision 1 changes

- Eliminate some sensors in sensor tables, Sec. 4.1.1, reducing the total number from 68 to 54.
- Add requirements 5.1.5 and 5.1.6 for Optical Support Structure temperature control loop stability.
- Add requirements 5.2.4 and 5.2.5 for array temperature control loop stability.
- Add Section 7, the numbering scheme for temperature sensors.
- Delete previous text and add new text as necessary in support of above changes.

The previous version has been consulted extensively for temperature sensor layout. For clarity changes to that version are indicated with deleted text struck out ~~like this~~ and new text printed in red **like this**.

## 2. Applications of temperature sensing and control

The steady state design temperature of NEWFIRM is 65 K. This is notionally uniform throughout the optical support structure and all optics. Given the instrument's large size, multiple temperature sensors are needed to achieve and confirm uniformity.

For NEWFIRM we need to consider what component temperatures we need to measure, over what range, to what precision and accuracy, for what purpose. Temperature sensing is either passive, for information purposes only; or active, providing feedback for control purposes. Either case may also be relative, with only approximate calibration, or absolute with well calibrated sensors. The necessary precision may vary, as may the range of temperatures over which measurement is needed. The need may strongly drive the sensor type, associated electronics, and cost.



# NEWFIRM

Passive sensing in NEWFIRM is used to track cooldown and warmup temperatures and rates of change, and steady state temperatures and fluctuations (spatially and temporally). Typical applications are the temperatures of optics, optics cells, the optics support structure, radiation shields and motors. Of particular interest in NEWFIRM are temperature gradients between lens edges and lens cells across the contact interface. Gradients that are too steep, either during cooldown/warmup or in steady state, may place lenses at risk.

Active sensing means use of sensor data in a control loop, for the primary purpose of achieving temperature stability. Measuring the temperature absolutely is a secondary concern and may even use a separate, passive sensor. There are two such applications on NEWFIRM: control of the optics support structure, and control of the detector array mosaic. In both cases, the purpose is to stabilize a large thermal mass. This mass is strapped to a cold head(s) in such a way that its free-running temperature is somewhat below the desired value. Heater resistors are used to raise the mass temperature.

### 3. Sensor choice

#### 3.1 Wide temperature range, lower accuracy

- 3.1.1 Wide range temperature sensors in NEWFIRM shall function over 60 to 300 K. Performance at lower temperatures is a goal.
- 3.1.2 Absolute calibration shall be known to  $\pm 1$  K at 60 to 100 K, and  $\pm 1$  % of temperature at  $> 100$  K. More accurate absolute calibration, especially at the lower temperatures, is a goal.
- 3.1.3 Repeatability on successive thermal cycles shall be  $\pm 0.1$  K at 60 to 100 K. Higher accuracy is a goal.
- 3.1.4 Stability (indicated temperature – actual temperature) at fixed component temperature shall be  $\pm 0.1$  K at 60 to 100 K. Higher accuracy is a goal.

This is the sensor type that will be used to monitor temperatures around the dewar during cooldown and warmup, and to monitor stability and temperature gradients in the cold steady state. These may also be used in active control loops for the optical support structure temperature stabilization, and during warmup to control active heating circuits.

A satisfactory commercial sensor is the Lakeshore DT470 diode, uncalibrated, tolerance band 12 or 13.

A satisfactory homebrew sensor is a 1N914 diode, temperature cycled between 77 K and room temperature to verify repeatability and establish an approximate calibration. The screening and calibration method developed by Bill Ditsler should be used.

- 3.1.5 If selected 1N914 diodes are used, an approximate calibration shall be determined for each diode. This calibration shall be linked to the diode's installed position on the instrument for incorporation into readout and display software.

#### 3.2 Narrow temperature range, high accuracy

- 3.2.1 Narrow range sensors shall function over 30-100 K. A broader range is a goal.



# NEWFIRM

3.2.2 Within this range they shall be both repeatable and stable to  $\pm 20$  millik.

3.2.3 These sensors shall be accurate to  $\pm 0.25$  K. Higher accuracy is a goal.

Note that stability and repeatability are more important than absolute accuracy. A satisfactory commercial sensor is the Lakeshore DT470 diode, tolerance band 11.

At present the only application for this sensor type is in the array temperature control loop. This is treated in more detail in a separate SDN.

### 3.3 Sensor mounting and wiring

Sensors must be mounted so as to have a good conductive path to the component being monitored, while not subject to heating or cooling from other sources. They must also not transport heat into the component. Since NEWFIRM detectors are sensitive to 5.6 microns, the sensors and their wiring must not radiate thermal energy into the science beam. The following requirements and recommendations come from practices known to be satisfactory with other NOAO produced instruments.

3.3.1 Sensors shall be encapsulated in a conductive material and mounted to dewar components by bolting, except as noted in 3.3.2 .

Lakeshore diodes can be purchased in a bolt-through package. A successful homebrew package is a selected 1N914 diode epoxied into a small rectangular copper block with a bolt hole on one end.

3.3.2 Sensors used to determine the temperatures of optical surfaces, such as lenses, shall be loaded against the surface by pressure but not otherwise affixed to the surface.

An approach used successfully in ISPI is to load a diode against a lens surface with a fiberglass block and arm, slightly bent upon installation so as to be springy.

3.3.3 No conductive grease shall be used in mounting temperature sensors.

3.3.4 Wiring types, lengths, cross sections, and layouts shall be chosen to minimize heat flow into the optics support structure.

Useful discussions and calculations for wiring choice vs heat flow are given in GNIRS SDN 12.01 Dewar Wiring Parameters.

3.3.5 Wiring that leads to sensors on or inside the optics support structure shall be conductively heat sunk to an actively cooled radiation shield ahead of the sensor.

Heat flow may be both conductive and radiative. Both are minimized if the heat flow is intercepted at a cold station outside of a critical area. Successful designs for cold stationing have included capturing ribbon cables in a flat plate clamp, and using a thin printed circuit board with wide leads in series with the wiring. Either is then attached to a radiation shield in a way that maximizes surface contact area.

3.3.6 Wiring inside the optics support structure shall be located and shielded to minimize radiation at 3-5 microns into the science light path.



# NEWFIRM

Minimizing wire runs next to the light path is the first defence. Covering them, e.g. with copper tape, is the next measure. An electrically insulating coating around a wire should not be considered adequate as a heat shield. These can be translucent at infrared wavelengths.

## 4. Sensor positions

### 4.1 Wide range sensors

4.1.1 Wide range sensors shall be located as follows:

Component	Number and Location	Sensor Count	Running Total
Lens 1	1, front surface + 1, rear surface, opposite each other, as far from lens edge as possible but clear of beam	2	2
Environmental cover	1 sensor on an inside surface	1	3
Lens 2-8 and cells	A pair of sensors for each lens + cell, 1 at lens edge and 1 opposite it on cell finger, on whichever lens face is convenient; <b>except lens 4 cell finger, lens 5 cell finger, and lens 6 cell finger shall share a common cell temperature sensor</b>	<del>14</del> 12	<del>17</del> 15
Fold mirror	1 sensor centered on mirror rear surface	1	<del>18</del> 16
Filter wheel assembly	1 on each motor, 1 on middle of housing face	3	<del>21</del> 19
Front baffle tube	1 at top, <del>4 at midpoint</del> , 1 at bottom	<del>3</del> 2	<del>24</del> 21
Tangent bars	Three on one bar, near dewar wall, near optics support structure, and halfway between; one each on remaining bars at halfway points	5	<del>29</del> 26
Upper optics Support structure	3 sensors, locations TBD <sup>a</sup> ; this structure holds Lenses 2 and 3 and contacts the tangent bars and filter wheel assembly	3	<del>32</del> 29
Middle optics support structure	3 sensors, locations TDB <sup>a</sup> ; this structure holds lenses 4, 5, and 6	3	<del>35</del> 32
Fold mirror structure	1 sensor on each side face; this structure makes the 90 degree bend and holds the fold mirror cell. <b>One of these sensors shall be used for the OSS active temperature control loop.</b>	2	<del>37</del> 34
Lower optics support structure	3 sensors, locations TDB <sup>a</sup> ; this structure holds lenses 7 and 8	3	<del>40</del> 37
Active radiation shield	3 sensors along the length of the shield	3	<del>43</del> 40
Passive radiation shields	1 on each <b>the outer passive</b> shield	<del>2</del> 1	<del>45</del> 41
<del>Filter wheel radiation shield</del>	<del>1, on inside of upwards facing surface</del>	<del>1</del> 0	<del>46</del> 41
Detector mount radiation shield	1, on inside surface	<del>1</del> 0	<del>47</del> 41



# NEWFIRM

Wide range sensor locations, continued:

Component	Number and Location	Sensor Count	Running Total
Cold heads	2 on each head; 1 at first stage and 1 at second stage; install on strap manifolds	6 <sup>b</sup>	<del>53</del> 47
Cold straps	4 at cold ends of selected straps <sup>c</sup>	<del>8</del> 0	<del>61</del> 47
Array baseplate mount	2; one on cold mass for active control loop and one elsewhere on Invar plate to which array modules are referenced.	2	<del>63</del> 49
Array alignment mount	1, location TBD on outer plate that couples to lower optics housing	1	<del>64</del> 50

Note a : One sensor on the optics support structure element is to be very close to a lens cell interface. The others are to be on the outside of the structure, opposite each other, and not close to any cold strap connection.

Note b: The count assumes that two of the cold head second stages will not be used for active cooling of internal components via cold straps. These may be used to cool freestanding panels for cryopumping the dewar volume.

Note c: The count assumes two straps will be monitored from every cold head stage.

There are two motivations for this large number of sensors. The first and primary rationale is that the thermal performance of the instrument is only approximately known and the thermal layout (cold strapping) will be somewhat empirical. The design specification is for a uniform temperature of 65 K throughout the optical support structure. There is no single dominant mass in the structure; there are a large number of bolted interfaces; there are multiple possible points for connecting cold straps; there is a large surface area; and the conductive path to ambient temperature is at one end of the structure. Hence there are multiple reasons to expect thermal gradients both along and around the structure. It will be very important to know how well we are doing, in terms of temperature uniformity, and to have the necessary information to improve performance by “tuning” the thermal distribution system.

The second rationale is, given the need for a thorough distribution of sensors anyway, to record data that can be related back to analytical calculations or thermal finite element analysis to improve our understanding, modeling, and prediction capabilities for the next large instrument.

## 4.2 Narrow range sensors

4.2.1 Narrow range sensors shall be located as follows:

Component	Number and Location	Sensor Count	Running Total
Detector arrays	1-4, near the hybrid array or on the baseplate thermal mass TBD These are provided as part of the 2K x 2K array package	1-4	1-4

~~This is for the array temperature control loop. The array vendor provides a Lakeshore DT670 sensor integrated into the 2K x 2K array assembly. This may be used if doing so does not degrade array performance. This remains to be determined. For further discussion see the SDN on detector temperature control- Sec. 2.1 above.~~



# NEWFIRM

These sensors will not be used in an active control loop. They will be read out for information purposes only. Since they glow when operating, they must be switchable on or off.

## 5. Temperature control loops

### 5.1 Optical support structure

Sensors provide temperature indication. The other half of an active control loop is the means for providing or moderating heat input. The optical support structure is cooled (negative heat input) by the first stages (77 K) of three closed cycle coolers operated open loop at full rated power. Passive moderation of cooler output will be provided by the design of cold strapping to various points on the instrument. Active moderation may also be needed for limiting the cooldown rate and maintaining temperature stability in the steady state. Positive conductive heat input directly to the optical support structure may be desirable to speed the instrument warmup.

5.1.1 Active temperature control of the optical support structure during cooldown and steady state operation shall be provided.

5.1.2 This control shall be implemented with carbon power resistors thermally sunk to cold masses at the closed cycle cooler first stages.

Carbon power resistors are a proven solution in NOAO instruments. The cold masses will be the cold strapping manifolds at the cold head first stages. This approach is adopted from GNIRS.

5.1.3 The sensor feedback in a control loop shall be derived from ~~an average of up to five~~ a single sensor reading~~s~~ on the optical support structure.

~~This number is chosen to allow use of two sensors monitoring the structure and three monitoring a temperature sensitive lens at the cell base, cell tip, and lens surface.~~

5.1.4 ~~The design shall permit a separate feedback loop for each cold head.~~ The design shall use a single temperature feedback loop moderating the inputs of all cold heads.

~~The upper, middle, and lower optics support structure subunits make up much of the metal mass. Each has several temperature sensors. It may prove advantageous for each cold head to be associated with a particular subsection of the optics support structure. These requirements give reasonable flexibility for dealing with temperature gradients while not being too demanding in terms of electronics complication.~~

In the final design there is no allocation of particular parts of the structure to particular cold heads. Also, the Optical Support Structure is well coupled thermally. The requirement has been changed accordingly.

5.1.5 The Optical Support Structure temperature control loop shall maintain a measured temperature of the OSS to within  $\pm 0.1$  K of the set point temperature over a 1 hour interval.

5.1.6 The Optical Support Structure temperature control loop shall maintain a measured temperature of the OSS to within  $\pm 1$  K of the set point temperature over a 12 hour interval.

The temperature stability requirement for OSS control is derived from the tolerance to temperature change of the optical design determined by the optical designer. OSS temperature changes directly affect



# NEWFIRM

the longitudinal spacing of optical elements. Optical element temperature changes, driven by the OSS, affect element shapes and indices of refraction. All of these variations impact the imaging performance specified in SDN 1101 NEWFIRM Imaging Performance Requirements. The above requirements assume telescope refocusing is allowed from time to time during an observing night but not during ~1 hour intervals of data taking. The long term (12 hour) requirement is set so that telescope refocusing is largely driven by telescope truss flexure and ambient temperature variations, independent of instrument behavior.

The OSS is a large structure composed of multiple pieces with bolted interfaces. In the above requirement, “measured temperature” refers to the point on the OSS at which the control loop sensor is attached (the fold mirror housing). Temperatures throughout the structure will be monitored with multiple sensors that are not part of the control loop. The expectation is that while there may be spatial temperature variation from place to place in the OSS, the temporal temperature stability criterion will be met locally throughout the OSS.

- 5.1.7 Warmup of the optical support structure shall be implemented with power resistors thermally sunk to appropriate points on the structure.
- 5.1.8 The sensor feedback shall be derived from the same sensors and in the same manner as 5.1.2
- 5.1.9 The design shall permit a separate warmup feedback loop for the upper, middle, and lower optics support structure subunits.
- 5.1.10 Power and control electronics for warmup shall be self-contained, shall connect directly to the dewar with a dedicated connector, and shall go into a power-off condition as a safe mode.

These requirements also provide control flexibility. Active power input for warmup should not be under remote computer control, as protection against software and communications glitches. Loss of power, monitoring, or communications with the dewar should immediately produce a power-off state requiring manual restart. Any possibility for a runaway power input during warmup should be protected against.

## 5.2 Array temperature control

The array mosaic and array mount are cooled by the second stage (10 K) of ~~one~~ **two** closed cycle coolers operated open loop. Passive moderation will be provided by the design of cold strapping to a thermal mass on the array baseplate. Active moderation will be needed for temperature stability.

The desirability of array warmup by resistive heating of the thermal mass is unclear at this time.

- 5.2.1 Active temperature control of the infrared array mosaic shall be implemented with carbon power resistors thermally sunk to a cold mass at the array base plate.
- 5.2.2 The control loop sensor feedback shall be derived from a single sensor on this cold mass, ~~or from an average of sensors integrated into the 2K x 2K array mosaic elements.~~
- 5.2.3 ~~For the single sensor alternative,~~ At least two sensors shall be available for use and switch selectable in the electronics box, as a backup against sensor failure.
- 5.2.4 The array temperature control loop shall maintain a measured temperature of the reference thermal mass to within  $\pm 0.023$  K of the set point temperature over a 15 minute interval.



# NEWFIRM

5.2.5 The array temperature control loop shall maintain a measured temperature of the reference thermal mass to within  $\pm 0.20$  K of the set point temperature over a 12 hour interval.

The temperature stability requirements for array control are derived from the amount of thermally induced electrical offset of the array signal that is scientifically acceptable over various time scales. This is discussed in SDN 1102 NEWFIRM Array Mosaic Baseplate Requirements, Secs. 2.3 and 4.4. The expected performance of the array mosaic mount design is discussed in SDN 4506, NEWFIRM Array Mount Transient Thermal Study II. The above requirements on control loop stability are equivalent to a further 10% degradation in short term and long term, respectively, array temperature stability.

~~Further requirements and discussion for the detector mount thermal design and temperature control is contained in a separate SDN on this topic.~~

## 6. Sensor readout and control

### 6.1 Readout frequency

6.1.1 The total number of sensors tabulated in Sec. 4.1.1 shall be capable of being read out, and the data recorded, at a maximum frequency of 0.2 Hz and a minimum frequency of once per hour.

6.1.2 All sensors shall be clocked at the same frequency.

6.1.3 Readout need not be simultaneous. Sensors may be grouped for multiplexing.

Any such grouping should be rational, e.g. mating lens surface and lens cell sensors should be read out together.

6.1.4 A single time tag shall be affixed to the readout of all sensors.

Slight time offset errors are of no consequence, given the purposes of these data. Time tagging is a software function included here for completeness.

### 6.2 Control frequency

This is largely a question of (i) how quickly will a thermal mass respond to an input, and (ii) how quickly do we want it to change temperature.

6.2.1 Control loop frequency for the optical support structure active temperature control shall be adjustable with a maximum of 0.1 Hz.

6.2.2 Control loop for the optical support structure warmup shall incorporate a programmable rampup from cold starting temperature to room temperature.

This rampup will occur over many hours, notionally 24 hours to inhibit the formation of temperature gradients at lens/cell interfaces.

Control frequency for the detector array assembly is deferred to the SDN for that assembly.



## NEWFIRM

### 6.3 Readout and control electronics

- 6.3.1 Temperature sensor readout electronics for the sensor list in 4.1.1 shall be incorporated into the instrument control electronics box.
- 6.3.2 Control electronics for the optical support structure active temperature stabilization shall be incorporated into the instrument control electronics box.
- 6.3.3 Power consumption for these electronics shall be minimized, consistent with the desired performance.

Power consumption for warmup is estimated at 500 W (heat content of  $4 \times 10^7$  Joules supplied over 24 hours). Power consumption for active temperature control is estimated as 50 W (4 K first stage modulation at each of three cold heads). Power consumption for temperature sensing is estimated as 1 milliwatt.

- 6.3.4 Control electronics for the optical support structure active warmup shall be incorporated into a separate box with its own power supply, internal programmability as necessary, and a dedicated connection to the dewar

This is to prevent any, perhaps inadvertent, reliance on external communications and/or software. This also permits instrument warmup when off the telescope and disconnected from the instrument control system.

There is no requirement regarding commercial vs. custom electronics for any of these purposes. The engineer is encouraged to consider cost to delivery, lifetime cost, ease of programmability by existing staff, and ease of incorporation into the overall instrument control package when making build/buy and other design decisions. Existing design solutions are highly favored.

### 6.4 User Interface requirements

This discussion presumes the existence of an engineering interface for instrument control that knows nothing about the telescope or the array readout; and of an astronomer user interface that does communicate with these other system elements. These are software requirements rather than requirements on sense and control hardware. The hardware must enable them to be met, however.

- 6.4.1 A data logging function shall be provided that records all sensor readings and their time tag on every sensor read cycle. A format that permits data retrieval and display as a table is required.
- 6.4.2 Capacity of this logging function shall allow data storage of up to 10 days' data at the maximum readout frequency specified in 6.1.1.
- 6.4.3 Data display as a table, of all sensors or an arbitrarily selected subgroup, shall be provided.
- 6.4.4 Starting and ending times for tabular display shall be user adjustable, with "all data" as the default.
- 6.4.5 These requirements apply to both the engineering interface and the user interface.



# NEWFIRM

6.4.6 The user interface shall have a graphical capability to display user identified temperature data against a time axis.

6.4.7 All temperature data shall be logged into the engineering portion of each image header.

Note this may be asynchronous, i.e. the sensor readout frequency may not match the science data frequency. In this case the most recent temperature data shall be logged into the image header.

6.4.8 Control loop temperature set points shall be adjustable from either interface. Adjustment of set points via the user interface shall be protected against access by general users, e.g. a superuser logon required.

6.4.9 Passive temperature readout frequency shall be adjustable from either interface without access restrictions.

6.4.10 Warmup temperature set points shall be separately adjustable via the dedicated warmup control box specified in 6.3.4.

A graphical user interface is preferred and shall be regarded as a goal, for temperature readout and for instrument control in general.

## 7. Numbering scheme for temperature sensors

The following numbers are to be assigned to the specified sensor locations. These identifications shall be marked on mechanical pieces wherever possible. Circuit diagrams, connector pin layouts, etc. shall be consistent with these numbers.

Temperature Sensor Number	Component sensed	Location
1	Lens 2	Rim of lens 2
2	Lens 2 cell spring finger	Lens 2 cell finger close to sensor 1
3	Lens 3	Rim of lens 3
4	Lens 3 cell spring finger	Lens 3 cell finger close to sensor 3
5	Upper housing	Interior of upper housing near 2 or 4
6	Upper housing	Exterior of upper housing, opposite 7
7	Upper housing	Exterior of upper housing, opposite 6
8	Middle housing	Exterior of middle housing, opposite 9
9	Middle housing	Exterior of middle housing, opposite 8
10	Lens 4	Rim of lens 4
11	Lens 5	Rim of lens 5
12	Lens 6	Rim of lens 6
13	Lens 4-5-6 cells	Lens 4 cell base
14	Middle housing	Interior of middle housing, near 13
15	Fold mirror	Fold mirror rear surface
16	Lens 7	Rim of lens 7



# NEWFIRM

17	Lens 7 cell spring finger	Lens 7 cell finger close to sensor 16
18	Fold mirror housing	Exterior of fold mirror housing, opposite 19
19A *	Fold mirror housing	Exterior of fold mirror housing, opposite 18
19B *	Fold mirror housing	Exterior of fold mirror housing, next to 19A
20	Lens 8	Rim of lens 8
21	Lens 8 cell spring finger	Lens 8 cell finger close to sensor 20
22	Lower housing	Exterior of lower housing
23	Lower housing	Exterior of lower housing, 120 deg from 22
24	Lower housing	Exterior of lower housing, 120 deg from 23
25	Lens 1	Lens 1 exterior face, opposite 26
26	Lens 1	Lens 1 interior (vacuum) face, opposite 25
27	Environmental cover	Interior fixed surface of this assembly
28	Filter wheel motor, upper wheel	On motor mounting plate near upper motor
29	Filter wheel motor, lower wheel	On motor mounting plate near lower motor
30	Filter wheel housing	On interior surface of fixed housing
31	Collimator cold baffle tube	Exterior upper end of baffle tube
32	Collimator cold baffle tube	Exterior lower end of baffle tube
33	Tangent bar #1	On tangent bar 1 close to Dewar wall
34	Tangent bar #1	On tangent bar 1 halfway along length
35	Tangent bar #1	On tangent bar 1 close to OSS attachment
36	Tangent bar #2	On tangent bar 2 halfway along length
37	Tangent bar #3	On tangent bar 3 halfway along length
38	Active radiation shield assembly	Near upper end of active radiation shields
39	Active radiation shield assembly	At midpoint, 120 deg circumferentially from 38
40	Active radiation shield assembly	At midpoint, 120 deg circumferentially from 39
41	Outer passive radiation shield	On inner surface of outer passive shield
42	Cold head #1, 65 K stage	Cold head #1 first stage cold strap clamp
43	Cold head #1, 10 K stage	Cold head #1 second stage cold strap clamp
44	Cold head #2, 65 K stage	Cold head #2 first stage cold strap clamp
45	Cold head #2, 10 K stage	Cold head #2 second stage cold strap clamp
46	Cold head #3, 65 K stage	Cold head #3 first stage cold strap clamp
47	Cold head #3, 10 K stage	Cold head #3 second stage cold strap clamp
48	Array alignment mount outer plate	Near a contact point with lower optics housing
49	Array mount Invar baseplate	On rear surface
50A **	Array mount thermal mass	On thermal mass where convenient
50B **	Array mount thermal mass	On thermal mass where convenient
51 ***	2K x 2K array A	Incorporated in vendor supplied array package
52 ***	2K x 2K array B	Incorporated in vendor supplied array package



# NEWFIRM

53 ***	2K x 2K array C	Incorporated in vendor supplied array package
54 ***	2K x 2K array D	Incorporated in vendor supplied array package

\* 19A, B are identical high precision sensors. Both are wired into the Lakeshore temperature controller, and are switch-selectable for which one is active. These are for the OSS active temperature control loop.

\*\* 50A, B are identical high precision sensors. Both are wired into the Lakeshore temperature controller, and are switch-selectable for which one is active. These are for the array active temperature control loop.

\*\*\* 50-54 are to be switchable on or off. These are incorporated into the array package provided by the vendor. Operating them produces a glow which illuminates the array.