NICI Science Array Performance Requirements and Selection Criteria

NICI System Design Note # SDN1012

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1.0 Introduction

This document will specify the performance requirements for the NICI two science arrays and how these requirements influence the testing and selection of the arrays. NICI, being a dual array differential imager has some special array performance requirements. Persistence, uniformity, well depth and linearity are more important for the NICI arrays than would be the case for a basic imager

2.0 Science Derived Array Performance Requirements

This section will frame the performance goals in terms of observational or scientific requirements. The following subsections will discuss each key array parameter and specify which observing mode is driving the requirement.

2.1 Dark Current

In many of the planned NICI observing modes the background levels will be quite high and dark current will not be a concern. It is desirable to avoid having the background flux be dark current limited. The lowest background levels for NIC would be seen when using narrow ionization line filters at short wavelengths with spectral resolving powers of around 100 or with the grism mode with a resolving power of around 1200. The expected sky background in the J window is about 10 electrons/second/pixel. This would scale to 0.6 e/sec/pixel with a narrow filter and around 0.05 e/sec/pixel at short wavelengths with the grism. These levels are about a factor of 5 greater in the H and K windows on average, although they are much smaller between the OH lines. When used in a coronagraphic mode the backgrounds levels would always be higher than these levels but would approach these levels for faint targets.

Should the grism mode be allowed to drive the requirements? It is true that grism observations will represent a small fraction of NICI use but the characterization information that this mode yields is of great value scientifically.

This would argue for arrays with dark currents less than 0,1 electrons/second although it is not expected for the instrumental background to be less than a few tenths of an electron per second. Arrays with dark currents of more than a few tenths of an electron per second should be rejected.

2.2 Read Noise

The read noise level will determine the integration time required to achieve a background limited measurement. When the number of collected electrons are greater than the square of the read noise the shot noise from the background starts to dominate. When the number of collected electrons is equal to 4 times the read noise squared the contribution of the read noise to the total noise is only about 10%. This will be used for the definition background limited. The read noise requirements for NICI are again driven by the lowest background modes. Typical readnoise for the Aladdin arrays is around 35 electrons for short integrations and around 10 electrons for multiple read integrations. For low background observations the integration times will be long so the 10 electron readnoise value can be used. If the readnoise is 10 electrons then 400 electrons need to be collected to be background limited. This translates to integrations times to achieve background limited performance of 40 seconds in the J window, 700 seconds in a short wavelength narrow(1%) filter and around 8,000 seconds(2.2 hours) at the short end of the grism mode. All but the last of these are perfectly reasonable and the last is doable.

While lower readnoise is preferred there is not a strong driver for better than typical readnoise.

2.3 Uniformity

Uniformity here is used to describe the pattern effects caused by multiplexer variations, tree rings caused by doping gradations and quantum efficiency variations due to defects in the detector material, epoxy backfill or thinning process. Aladdin arrays show great variety in these areas. There is little to be done about the last three areas but careful adjustment of array biases and clocks can improve multiplexer artifacts. Since the core observing modes for NICI involve differencing images taken by two different arrays flat fielding of each arrays data will be very important. The less non-uniformity effects an array has the easier it will be to flat field. It is difficult to quantify the uniformity since the effects are so variable between arrays and change with array bias. A numerical method can be used to quantify variations in a flat exposure but must be qualified by the location of defects and overall appearance of the flat. Strong weight will be given to uniformity in the array selection.

2.4 Persistence

After images or persistence is always a concern but particularly so for high contrast observations. Blasting the array while setting up on an object can lead to after images that will look like a companion. Care will be taken with the observing procedure such as blanking off the science arrays during setup to avoid this. Persistence is still a serious concern for NICI. The after image strength decreases with time and readouts and appears to be affected by toggling some of the bias voltages. Preferably the persistence would be low enough to be ignored. If the persistence signal is a fraction of the dominant noise it will not be significant for a single frame. Sometimes many frames will be taken and combined which will effectively reduce the noise target. Since persistence signal decreases with the number of readouts and is negligible after 5-10 readouts this reduction of the noise is limited to a factor of a few. Therefore somewhere around a tenth to a quarter of the readnoise would be the threshold where the persistence signal is insignificant.

It is likely that the persistence levels seen in the Gemini arrays will be higher than this level. Since NICI is a two array instrument it would be preferred that the persistence levels be identical between the arrays. This is not likely. It is then preferred that the arrays have similar persistence.

It will be important that a procedure be developed that reduces the level to acceptable amounts. This procedure should take less than a few seconds.

2.5 Well Depth

Well Depth requirements are driven by the highest light levels. The highest light levels will be seen when observing in the thermal infrared or when looking at very bright stars in a non-coronagraphic mode. The background levels expected in the M' filter are about 100,000 electrons/second/pixel. A minimum full frame integration of 0.1 seconds with a CDS read would require a well of 20,000 electrons.

When looking at bright objects in a fast framing speckle mode small subarrays such as 128x128(2.3 arcseconds) would be used. A 128 subarray would have a minimum integration time of about .006 seconds. To observe a 0.0 magnitude star the well would have to be ??????? electrons

Well depth is not a strong driver for NICI and typical well depths should be adequate. Arrays will well depths of 100,000 electrons or greater will be acceptable.

2.6 Linearity

Non-linearity is caused by the change in detector capacitance as the bias voltage changes. Aladdin arrays show fair variability in linearity. The primary concern with linearity is typically photometric accuracy. For NICI the concerns are photometric accuracy and how linearity affects the difference signal between the two arrays. Standard techniques for measuring and correcting linearity can be used since the linearity is well behaved and consistent, although it must be done on a per pixel basis. Of particular interest is how to properly measure flux levels of a faint object buried in background. Measuring a standard star in conditions similar to the science object is difficult since the background is usually different. Since NICI will not usually be pushing to the top of the well there will usually not be much linearity problem. When the uncorrected linearity of the arrayis not adequate for the experiment there is little choice but to measure and correct the linearity during the data reduction. It is desirable for the selected arrays to be as linear as possible but this is not a strong driver in array selection.

2.7 Maximum Readout Rate

Since NICI has very small pixels the readout rates required by most modes is very modest. Minimum integration times for most modes is only around 0.5 – 1 seconds. Some special modes require faster times such as high speed speckle observations. For this mode a subarray at 50-100 hz is usually used. Arrays capable of 10 Hz CDS full frame rates will be adequate.

2.8 Cosmetics

This category covers bad pixels, hot pixels, cracks, repaired peds as well as issues already discussed under the uniformity discussion. IT is difficult to define a numerical method to select the array based on this category. Numerical methods should be used to define these effects but the final judgement will be more qualitative. It is desired that the central (+/- 100 pixels) area of the array be free of defects.

3.0 Selection Criteria

The following two sections define the required array data and discuss the trade offs between these requirements

3.1 Recommended Array Performance Data

3.1.1 Dark current

Measurement of dark current versus detector bias level for full well, half well and quarter well biases. Data should be presented as an an image, a histogram and numeric values for the mean and standard deviation for the whole frame excluding bad and hot pixels.

3.1.2 Readnoise

Measurement of the readnoise with no illumination for single read, CDS and multiple non-destructive reads versus number of reads. Noise should be measured by taking numerous frames and comparing values for the same pixel. Read noise measurements should be made for both 5 second and 0.1 second integration times. The results should be presented as an image, a histogram and numeric values for the mean and standard deviation for the whole frame excluding bad and hot pixels.

3.1.3 Uniformity

Measurement of the variation from the mean pixel level for 100 coadded CDS frames for low illumination level with low bias, full well for low bias, full well for medium bias and full well for high bias. Bad and hot pixels should be excluded from the variation calculation. Data should be presented as an an image, a histogram and numeric values for the mean and standard deviation for the whole frame excluding bad and hot pixels.

3.1.4 Persistence

Measurement of the amount of persistence expressed as a function of a fraction of the readnoise versus illumination level using levels below and above levels that would cause array saturation. Determine if persistence is a function of bias.

3.1.5 Well Depth

Measurement of the well depth versus detector bias.
Selection of low medium and high bias levels for the other tests
Measurement of conversion factor(noise versus counts)

3.1.6 Linearity

Measurement of output versus integration time for low medium and high biases.
Measurement of the detector load curve

3.1.7 Maximum Readout Rate

Measurement of maximum readout rate up to 10 Hz.

3.1.8 Cosmetics

Measurement of the following values:

Bad pixel map vs. bias(inoperable or unusable)
Bad Pixel count vs. bias
Hot pixel map vs. bias(dark current >5x)
Hot pixel count vs. bias
# of pixels lost to cracks
# of repaired peds

3.1.9 Qualitative Assesments

The following are categories difficult to reduce to numerical measurement. A qualitative assessment is required in written terms comparing the candidate arrays in like manner.

Assessment of epoxy void presence and depth – some arrays have a void in the center where the backfill epoxy did not flow. Is this visible? What is the size and depth of the effect.

Uniformity qualitative score – Compare all candidate arrays and rate them based on uniformity.

Cosmetics qualitative score - Compare all candidate arrays and rate them based on uniformity.

3.2 Weighting of Performance Parameters

The criteria and tests presented in the previous sections will allow the de-selection of some of the candidate arrays. Since the arrays never have perfect performance the final choice most often involves a trade-off between different negative aspects of the best arrays. The table below summarizes the selection criteria and gives relative weights. These weights are subjective and meant to communicate relative importance to NICI. A weight of 10 means great importance to NICI and 1 means little importance.

Parameter	Goal	Acceptable Limit	Relative Weight
Dark Current	0.1 e/sec/pixel	0.3 e/sec/pixel	7
Readnoise	35 e (10 e ndr)	50 e (15 e ndr)	5
Uniformity	Maximum		10
Persistence	Minimum		10
Well Depth	150,000 e	100,000 e	5
Linearity	< 1% for low bias	< 3%	7
Maximum Readout Rate	10 Hz	5 Hz	5
Cosmetics	Best		9