1 UPGRADE CHANGES

1.1 Spectrograph

The Aladdin 3 1012x1024 InSb array in the spectrograph was replaced by a 2048x2048 Hawaii-2RG array. Performance of these two arrays is compared in Table 1. The most significant differences between the old and new arrays are the greater wavelength coverage of the H2RG due to its larger format and better near-optical response, and improved faint sensitivity due to its significantly lower read noise, dark current and persistence.

The different readout architectures of the Aladdin 3 and H2RG arrays result in observable effects. All 32 channels of the 1024x1024 Aladdin InSb spectrograph array are read out simultaneously. There are eight channels per array quadrant (i.e. per 512x512 sub-arrays). Channel one reads out column one, channel two reads out column two etc. repeating every eight columns across the array quadrant. Given slight variations in channel gain and 'burst' noise on read out this results in a distinctive array read out pattern at very low signal levels: slight offsets between the four quadrants and 'saw tooth' column to column signal variations. The one quadrant of the 1024x1024 Aladdin guider array that is read out has the same eight-column structure as before.

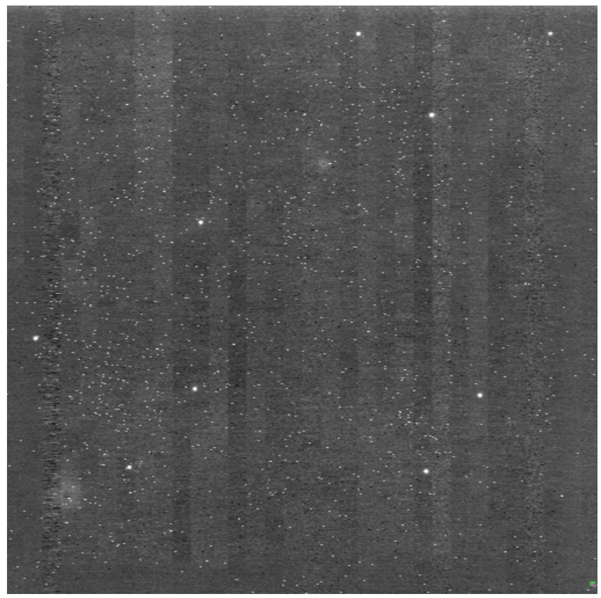

Figure 1-1. Dark exposure (60 s) showing a 64-pixel wide readout channel pattern on the H2RG array. The star-like features are alpha-particle hits from a ThF_4 AR coat on the surface of the lens facing the detector. The hit rate is about once every five seconds.

Similarly, all 32 channels of the 2024x2048 H2RG spectrograph array are read out simultaneously. In contrast, however, each channel reads out blocks of 64-pixel wide columns. Given slight variations in channel gain and 'burst' noise on read out this results in a distinctive array read out pattern at very low signal levels: a vertically striped pattern with slight offsets of a few DN between neighboring channels (see Figure 1-1). Offsets are typically several DN (the CDS read noise is about 8 DN) and are easily removed in data reduction.

Overall the QEs (and therefore relative throughputs) of the two devices are similar. The differences are probably due to the performance of the anti-reflection (AR) coat on the H2RG required to get good performance in the near optical (< 1 μm, see Figure 1-2).

Table 1. Spectrograph Array

Parameter	Aladdin 3	Hawaii-2RG	Comment
Format	1024 x 1024	2048 x 2048 2040 x 2040 light sensitive	
Number of readouts	32	32	
Sub-array?	Yes, any box	Yes, between rows only	
Pixel size	27 μm	18 μm	
Pixel operability	99%	99%	
Useful wavelength range	0.8-5.5 μm	0.7-5.35 μm	
Average QE	≈80%	≈80%	See plot below
Operating rev. bias	0.400 V	0.312 V	
Pixel rate	15 μs/pixel (20 slowcnts) 3.5 μs/pixel (3 slowcnts)	3 μs/pixel	
Min. full array read out time	0.51 s (15 μs/pixel) 0.12 s (3.5 μs/pixel)	0.463 s (3 μs/pixel)	
Read noise: single CDS	40 e RMS (15 μs/pixel)	12 e RMS (3 μs/pixel)	
Read noise: 32 NDRs	12 e RMS (15 μs/pixel)	5 e RMS (3 μs/pixel)	
Dark current	0.2 e/s	0.05 e/s	Median
Dark current + persistence	>1.0 e/s	0.10 e/s	
Gain	12 e/DN	1.5 e/DN	
Full well depth	7,000 DN 84,000 e	43,000 DN 65,000 e	To saturation
Linear well depth	4,000 DN 48,000 e	30,000 DN 45,000 e	Correctable to < 1%

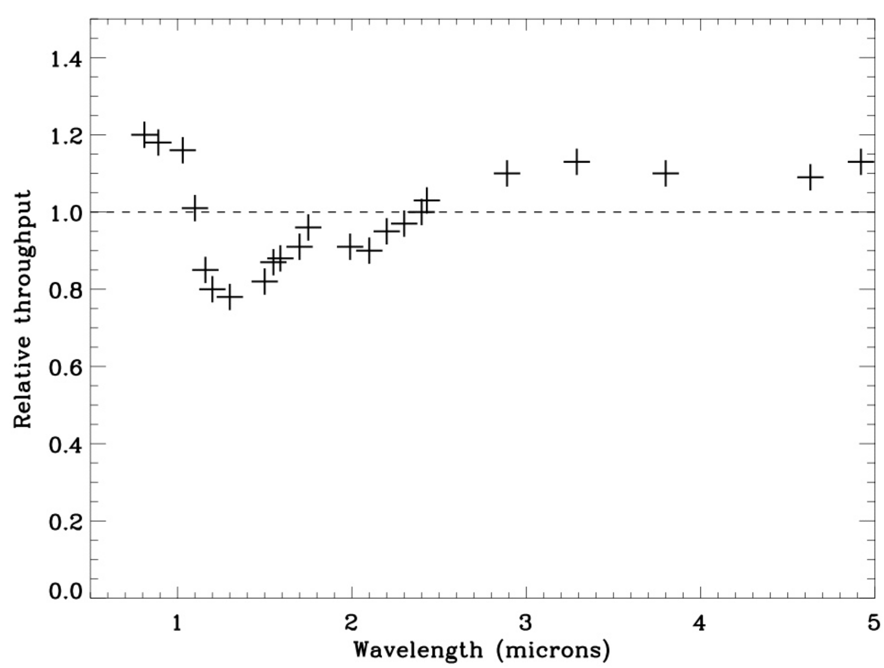

Figure 1-2. Spectroscopic throughput of post-upgrade SpeX relative to pre-upgrade SpeX. Throughput was measured by comparing flux of the same standard star through the 3.0″-wide slit (no slit loss). Since the optics are the same this is a direct comparison of the QEs of the H2RG and Aladdin 3 arrays.

An important feature of array operation is the need to keep exposure levels below the intensity level that can be reasonably corrected (to 1% or better) for non-linearity. This level is about 20,000 DN (half full well). An approximate way to do this is simply to adjust the on-chip integration time by measuring the maximum counts in DV. However, when multiple non-destructive reads are done to reduce read noise, as is the default, DV displays the average of the NDRs and so half the NDRs will be above the average intensity level by an amount depending upon photon rate from the object. **We therefore recommend that observers measure the maximum signal rate with a short integration (≤10 s) with NDR=1 and then use the following formula to set the '*itime*':**

$$itime = \frac{20{,}000}{2 \times rate} - 0.5$$

Where *itime* is in seconds and *rate* is in DN/s. To measure the *rate* set the *itime* manually and then click the '*Test Go*' button. This will turn save off, put the telescope beam in position A, set NDRs to one, take an image and then restore to the original set up. Finally, measure the *rate* using the maximum level reported in DV (avoiding hot pixels and scaling to one second), and adjust the itime. Observers can always use shorter *itimes* appropriate to their S/N requirements. For faint objects we do not recommend *itimes* longer than about 200 seconds even if the rate measurement allows it. Also, due to changes in array clocking *itimes* round down to the nearest multiple of 0.463 s (the minimum full array read out time).

The full array read out time of 0.463 s is the time required for one NDR. By default the array does as many NDRs as possible up to a maximum of 32. For example, for an *itime* of 9.26 s (9.26/0.463 = 10) ten NDRs will be done, reducing the read noise by about $10^{1/2}$. Since there is little improvement in read noise above 32 NDRs *itimes* longer than 14.82 s default to 32 NDRs. The penalty paid for doing multiple NDRs is an increase in the time required by *0.461 s × the number of NDRs*. To increase observing efficiency observers can choose to reduce NDRs manually.

When the array is idling between exposure sequences it is read out destructively and frequently using 'global resets' to prevent it saturating on any signal. Saturation needs to be avoided to prevent residual image effects. On switching from global resets to the slower pixel-to-pixel resets needed for low noise integrations the first frame in a sequence shows a 'picture frame' offset effect at an intensity level of 10-20 DN as shown in Figure 1-3. To minimize this offset in faint object exposures the '*FlushGo*' button takes a 15 second un-stored exposure to flush the array before immediately executing the commanded exposure sequence (i.e. before global resets resume).

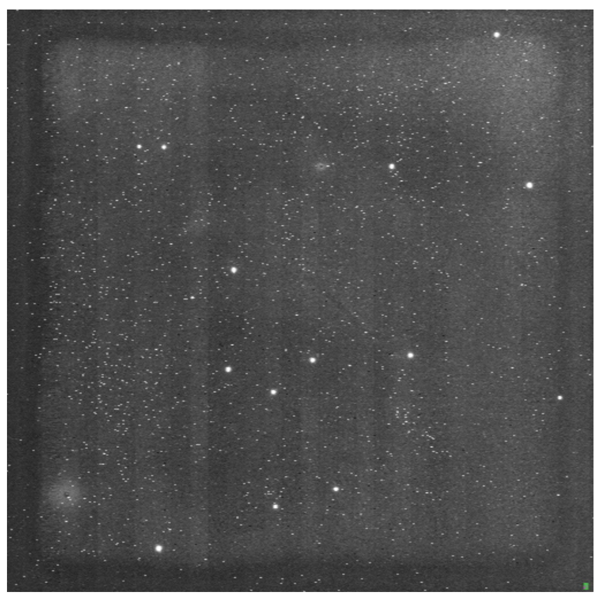

Figure 1-3. The 'picture frame' effect that occurs in the first frame of a series of exposures when the read out switches from global resets to pixel-to-pixel resets. Shown is an 'un-flushed' 60 s dark exposure.

We also strongly recommend that observers acquire at least three AB cycles (six spectra) of their targets whatever the brightness. This allows any systematic effects in the data to be removed by applying a median combination to the spectra. The most prominent of these effects are the star-like features that are randomly distributed on the array due alpha-particle decays from Thorium used in the AR coats (see Figure 1-3). (The AR coats were applied in 1999 when the potential problem was not recognized.) These features were also present at the same frequency in the original Aladdin 3 data but the smaller pixels and better sampling of the new H2RG makes the features appear star-like rather than 'blocky'. Although a median combine works very well (to the level of the read noise) we are planning to replace the final (ZnS) lens in the optical train by a similar lens with an AR coating free from radioactive elements.

The spectrograph modes before and after the upgrade are listed in Table 2. In PRISM mode the short wavelength limit of 0.70 μm is set by strong absorption in the AR coats, which were originally optimized for 0.8-5.5 μm, while the effective long wavelength limit of 2.52 μm is set by sky background noise at the low resolving power of the prism. The long wavelength limit in LXD_long mode is set by the cut-off wavelength of the H2RG array. All the other wavelength limits are set by the size of the array. Spectra are also better sampled because of the smaller pixel size (e.g. there are now three pixels across the 0.3″ slit instead of two previously).

Table 2. Spectrograph modes before and after upgrade. The given resolving power (*R*) is matched to the 0.3″-wide slit but wider slits are available (0.3″, 0.5″, 0.8″, 1.6″ and 3.0″)

Spectrograph mode	**Wavelength Range**	**R (0.3″ slit)**
Pre-upgrade		
PRISM	0.80-2.5 μm	200
SXD	0.80-2.4 μm	2000
LXD1.9	1.95-4.2 μm	2500
LXD2.1	2.15-5.0 μm	2500
LXD2.3	2.25-5.5 μm	2500
Single order short	0.90-2.4 μm	2000
Single order long	3.10-5.4 μm	2500
Post-upgrade		
PRISM	0.70-2.52 μm	200
SXD	0.70-2.55 μm	2000
LXD_short	1.67-4.2 μm	2500
LXD_long	1.98-5.3 μm	2500
Single order short	0.90-2.4 μm	2000
Single order long	3.10-5.4 μm	2500

With the 1024x1024 Aladdin 3 array originally in SpeX the file size was 4.2MB (and sometimes 2.1 MB at low flux). Now, with the 2048x2048 H2RG array in the spectrograph the individual file size is 16.8MB. However, we now store three files per image: pedestal minus signal, pedestal, and signal, for a total image size of 50MB. The reason for the extra files, which are stored as extensions to each image, is to accurately compute corrections for non-linearity. Consequently, observers should note that spectrograph images take about ten times longer to ftp and require ten times more disk space to store than with the old SpeX.

1.2 Slit Viewer

The Aladdin 2 512x512 InSb engineering grade array in the slit viewer was replaced by the Aladdin 3 1024x1024 InSb array originally in the spectrograph, although one 512x512 quadrant of this array is used. Performance of these two arrays when in the slit viewer is compared in Table 3. The most significant differences between the old and noise arrays are the better cosmetics and reduced odd-even fixed pattern news of the Aladdin 3 array. Sensitivity is not significantly improved.

Table 3. Slit Viewer Array

Parameter	**Aladdin 2**	**Aladdin 3**	**Comment**
Format	512 x 512	512 x 512 (only one quadrant is used)	
Number of readouts	8	8	
Sub-array?	Yes, any box	Yes, any box	
Pixel size	27 μm	27 μm	
Pixel operability	98%	99%	
Useful wavelength range	0.8-5.5 μm	0.8-5.5 μm	
Average QE	≈80%	≈80%	
Operating rev. bias	0.400 V	0.400 V	
Pixel rate	10 μs/pixel (20 slowcnts) 3 μs/pixel (3 slowcnts)	7 μs/pixel 15 μs/pixel	TBC
Min. full array read out time	0.34 s (10 μs/pixel) 0.10 s (3 μs/pixel)	0.24 s (7 μs/pixel) 0.48 s (15 μs/pixel)	TBC
Read noise: single CDS	60 e RMS (10 μs/pixel)	45 e RMS (15 μs/pixel)	TBC
Read noise: 32 NDRs	20 e RMS (10 μs/pixel)	12 e RMS (15 μs/pixel)	TBC
Dark current	2 e/s	2 e/s	Median (long – short itime)
Dark current + persistence		>3 e/s	TBC
Gain	15 e/DN	17 e/DN	TBC
Full well depth	8,000 DN 120,000 e	7,100 DN 120,000 e	To saturation
Linear well depth	3,000 DN 45,000 e	3,000 DN 51,000 e	Correctable to < 1%

1.3 Sensitivity

The sensitivity of the spectrograph is given in Table 4.It is calculated using an instrument model and the measured array performance from Table 1.

Table 4. Spectrograph one-hour 50σ sensitivity with the 0.3″ slit and seeing of 0.7″. On-chip integration times are SXD 200 seconds, LXD 5 seconds, PRISM 200 seconds. Observing overheads are not included.

λ (μm)	**SXD (0.3″ slit) R=2000**		**LXD (0.3″ slit) R=2500**		**PRISM (0.3″ slit) R~200**	
	Aladdin 3	H2RG	Aladdin3	H2RG	Aladdin 3	H2RG
1.02	14.47	15.12			17.55	17.98
1.25	14.45	14.98			17.61	18.00
1.30	14.60	15.17			17.29	17.52
1.65	13.71	14.01			16.16	16.37
1.67	13.78	14.09	12.25	12.82	15.80	15.98
2.20	13.62	14.29	11.76	12.46	15.64	16.09
2.25	13.50	14.02	11.77	12.47	15.46	15.83
3.65			9.61	9.96		
4.77			7.23	7.46		

A seeing of 0.7″ FWHM measured in the *K* band has been assumed. It is convolved with a guide error of ± 0.125″ (effectively broadening the seeing profile by 0.25″). In SXD mode (R=2000, 0.3″ slit) in between OH lines observations are typically read noise and dark current limited and sensitivity is improved by about 0.5 magnitudes due to the better read noise and dark current performance of the new H2RG array. The lower resolving power of PRISM mode (R~200 see Figure 1-4, 0.3″ slit) means that the OH background is more evenly distributed and so the improvement is slightly less (0.25-0.5 magnitudes). In LXD mode (R=2500, 0.3″ slit) on-chip integration times are limited to a few seconds to prevent saturation on the sky at 4-5 μm. At these wavelengths the 0.2 magnitude improvement is sensitivity is mostly due to the slightly better throughput (see Figure 2-2). The necessarily short on-chip integration times in LXD mode mean that the 1.67-2.4 μm region, where sky background is much reduced, is read noise limited, and sensitivity is improved by about 0.5 magnitudes due to the lower read noise of the new H2RG array.

The limiting flux calculator on the SpeX webpage is more conservative than the instrument model used for Table 4 and although the exact sensitivities may differ the same improvements are predicted.

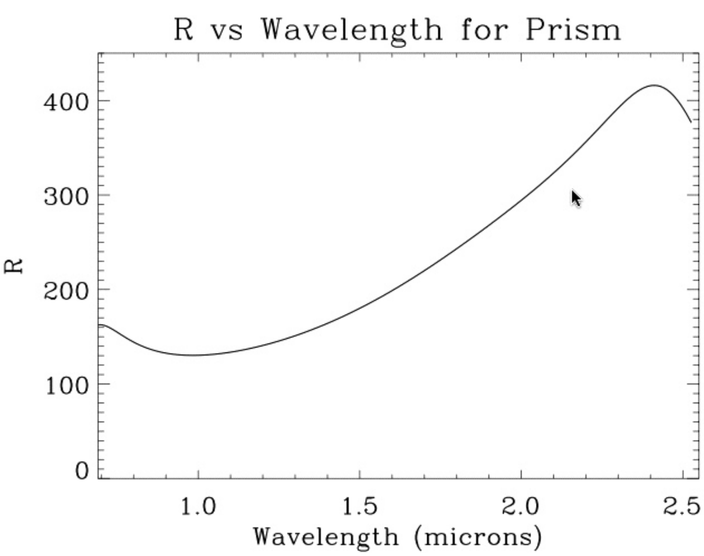

Figure 1-4. Variation of prism resolving power R with wavelength for a slit width of 0.3″.