Performances and results of the detector acquisition system of the GIANO spectrometer

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ABSTRACT

GIANO is a high resolution (R \(\approx\) 50,000) cryogenic IR spectrograph covering the 0.95-2.5 \(\mu\)m wavelengths range. It is equipped with a Hawaii-II PACE array. We present the main results and performances of the detector and acquisition system. We also describe a few special features which have been developed to optimize the noise performances and minimize spurious effects intrinsic to the detector, such as reset anomaly, cross-talking and radioactive-like events.

Keywords: Ground based infrared instrumentation, infrared spectrometers, infrared detectors

1. INTRODUCTION

GIANO is a cross-dispersed, near infrared (0.9–2.5 \(\mu\)m) spectrometer\(^7\) which is about to be commissioned\(^8\) at the Italian \(\varnothing\)3.58 m TNG telescope. The instrument is cryogenically cooled through a relatively loose thermal contact (\(R_{\text{thermal}} \approx 0.5\) K/W) with a liquid Nitrogen tank inside the cryostat. It employs a HgCdTe Hawaii-2 PACE detector mounted on a 3-axis focus-tilt stage. The array temperature is stabilized using a weak (\(\leq 1\)W) heater mounted on the massive (\(\approx 2\)kg of Aluminium) structure of the stage. With such a configuration the cooling and heating rates of the detector are intrinsically limited to <5 K/hr, independently of the speed at which liquid Nitrogen is poured into the tank, or of the power given to the heaters.

The original science-grade detector of GIANO was defected and failed during a normal cooling sequence in March 2010. The manufacturing company kindly made available a replacement whose characteristics are summarized in Table 1. The array is characterized by a quite low readout noise and dark current at 80K, but has a relatively large number of bad pixels distributed in clusters and stripes (see Fig. 2). It also displays a relatively high rate of radioactive-like events, where the ramp-signal of some pixel suddenly jumps by \(\approx 10^3\) electrons.

The acquisition electronics were designed and built INAF-Arcetri.\(^2\) They feature four completely independent channels equipped with ultra-low noise Di-JFET analog amplifiers (AD8620) operating close to the detector, at cryogenic temperatures.

2. NOISE, DARK CURRENT AND CROSS-TALKING

The Hawaii-PACE detectors have totally separate and independent connections (including power-supplies and grounds) for the four channels. Since the electronic cross-talking could take place when two or more signals share a common path (power supply or ground are the same from this point of view), we intentionally designed the electronics with four independent acquisition channels, with separate power supply rails and grounds. Moreover, the AD8620 amplifiers are connected as differential amplifiers which send to the output a couple of difference balanced signals. With this feature the signal to noise ratio decreases by a factor \(\sqrt{2}\) relative to a traditional

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Table 1. Parameters of the GIANO detector and control electronics, all values are at T=80 K

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bad or (quasi-)blind pixels</td>
<td>0.15% of total</td>
</tr>
<tr>
<td>Warm pixels (dark current &gt;10 e^-/s for V_{reset}=0.13 V)</td>
<td>0.10% of total</td>
</tr>
<tr>
<td>Pixels affected by radioactive-like events</td>
<td>350 pixels per minute</td>
</tr>
<tr>
<td>Usable well capacity (V_{reset}=0.13 V)</td>
<td>30,000 e^-</td>
</tr>
<tr>
<td>Conversion factor</td>
<td>2.2 e^-/ADU</td>
</tr>
<tr>
<td>Readout noise in shortest double correlated frame</td>
<td>5.2 e^-</td>
</tr>
<tr>
<td>Measured dark current, including internal background</td>
<td>0.05 e^-/s</td>
</tr>
<tr>
<td>Noise for long integrations</td>
<td>set by dark current, see Fig. 1</td>
</tr>
<tr>
<td>Readout clock frequency</td>
<td>110 kHz</td>
</tr>
<tr>
<td>Readout scheme</td>
<td>1 channel per quadrant</td>
</tr>
<tr>
<td>Minimum integration time</td>
<td>10 s</td>
</tr>
<tr>
<td>Time necessary to read the array and store the image</td>
<td>9.4 s</td>
</tr>
<tr>
<td>Cross-talking</td>
<td>&lt;10^-5</td>
</tr>
<tr>
<td>Persistence of saturated signals</td>
<td>below 0.01% after 5 min</td>
</tr>
<tr>
<td>Recommended multiple-non-destructive read-out strategy</td>
<td>2 read-reset + N read, N&lt;61</td>
</tr>
<tr>
<td>Duty cycle = (effective integration time)/(total time)</td>
<td>N/(N+3), see Fig. 1</td>
</tr>
</tbody>
</table>

amplifier, and the amplified signals are less sensitive to capacitively or inductively coupled (pick-up) noise or cross-talk.

With our electronics we could achieve the remarkable result where the cross-talking level is <10^-5, i.e. non-measurable. This advantage could be lost when reading with 32 channels, because the 8 channels of each quadrant share the same power supply and ground inside the detector. Moreover, similar results could be difficult to obtain with the newer generation Hawaii-RG detectors because they have a common ground for the 4 quadrants.

The noise performances are also extremely good, thanks to the great care which was put in the design and choice of the electronic components. The read-out noise in the shortest (10 seconds) double-correlated frame is 5.2 e^-, with a negligible (≈1 e^-) contribution by the acquisition electronics. The read-out noise decreases with multiple non-destructive readout, following the standard Fowler sampling scheme.

For integrations longer than a few minutes the noise is dominated by the dark current and internal background of the instrument, whose combined effects amount to 0.05 e^-/s. This value is close to the 0.033 e^-/s reported on the detector data-sheet provided by the manufacturer. We therefore estimate that the internal background of the instrument is lower than 0.02 e^-/s.

A dark current frame is displayed in Fig. 3 which shows a very low glowing of the MUX amplifiers and a relatively large number of warm pixels, with about 4000 pixels with dark current larger larger 10 e^-/s. These results are obtained using V_{reset}=0.13 V. The number of warm pixels can be decreased by using lower values of V_{reset}. However, this decreases the saturation level and, most important, introduces a chessboard-like pattern in the frame which also seems to affect the flat-field accuracy. The effects of varying V_{reset} can be summarized as follows.

<table>
<thead>
<tr>
<th>V_{reset}</th>
<th># warm pixels</th>
<th>usable well capacity</th>
<th>chessboard-like pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.13 V</td>
<td>4100</td>
<td>30,000 e^-</td>
<td>absent</td>
</tr>
<tr>
<td>0.06 V</td>
<td>3100</td>
<td>20,000 e^-</td>
<td>very weak</td>
</tr>
<tr>
<td>0.03 V</td>
<td>2400</td>
<td>17,000 e^-</td>
<td>strong</td>
</tr>
<tr>
<td>0.00 V</td>
<td>1100</td>
<td>13,000 e^-</td>
<td>very strong</td>
</tr>
</tbody>
</table>

We presently adopted V_{reset}=0.13 V as a compromise between warm pixels, well capacity and flat-field stability. We plan to investigate the possibility of using lower values during the commissioning at the telescope.
3. RESET ANOMALY, READ-OUT STRATEGY AND DUTY-CYCLE

Alike other sensors of the same type, our detector is affected by reset anomaly. This phenomenon produces extra-noise and patterns in the first frame(s) taken after the pixels reset. In our case it generates stripes-like patterns peaked toward the center of the array and aligned along the read-out directions (see Fig. 4). The strength of the reset anomaly depends on the previous status of the array and on the clock time used to reset the pixel. We found that the best strategies to mitigate its effects are as follows

- Using the shortest possible clock time to reset the pixels (see Fig. 4)
- Taking two read-reset frames at the beginning of each integration, and ignore the first frame.

However, the effects produced by the reset anomaly is always much larger than the noise obtained by excluding the read-reset from the integration. Therefore, the strategy to cancel all the effects of reset-anomaly is starting the integration with 2 reset-read sequences, followed by a series of non-destructive reads. The first frame is always ignored, while the second is only used to compute the flux of pixels exposed to strong signals which approach the saturation in <30 seconds. For all other pixels, only the non-destructive reads are used to compute the flux via Fowler sampling.

The ratio between usable and total integration time (i.e. the duty cycle), is given by

\[
\text{Duty cycle} = \frac{N}{N + 3} ; \quad N = \frac{\text{Effective integration time}}{10s}
\]

The variation of duty cycle with effective integration time is plotted in the upper panel of Fig. 1.

4. RAMP ANALYSIS, SATURATION AND RADIOACTIVE-LIKE EVENTS

The acquisition system of GIANO saves all the multiple non-destructive read-outs in the local data archive. The ramp analysis is performed off-line, after the integration is terminated. With this approach we can conveniently handle and correct

- pixels which are exposed to strong fluxes (saturation correction)
- pixels whose integration ramps are affected by jumps (radioactive-like events)

The saturation correction is performed by considering only the part of the ramp below the saturation level, and extrapolate the flux level. The first read-reset frame is used when saturation is already approached in the first two non-destructive read-outs.

The radioactive-like events are characterized by a sudden jump whose typical amplitude ranges from \( \sim 1000 \) to \( \sim 10,000 \) e\(^-\). These events may be produced by soft radioactive events or X-rays which, given the energy conversion factor for HgCdTe of \( \sim 330 \text{ e}^-/\text{KeV} \), would imply energies of 3-30 keV. Another possible explanation could be related to burst noise generated in the multiplexer.

The stronger events also affect the neighbouring pixels. An example of a quite strong jump (\( \sim 8,000 \text{ e}^- \)) is shown in Fig. 5. These events are identified and filtered by the ramp analysis routine, which only considers the read-outs before the jump and extrapolates their values.

5. RECOMMENDED ON-CHIP INTEGRATION TIMES

Given the measured values of read-out noise and dark-current, and taking into account the duty-cycle and the frequency of radioactive-like events, we recommend to adopt on-chip integration of at most 600 seconds. Integration times of 300 sec are most probably adequate for most circumstances.
6. PERSISTENCE

Persistence is a recurrent and annoying problem which affects all the arrays of this type. It is particularly evident with saturated signals, whose “ghost-signal” could still appear after hours.

We found that the best strategy to minimize persistence is to continuously reset the array when it is not integrating (idle phase). With this technique the persistence image fades to below 0.01% of the original flux after about 5 minutes the saturating source is turned off.

We also experimented a more drastic approach, namely switching off/on the array after it has been exposed to strong signals. This completely cancels any persistence residual, but generates an extra-dark pattern (see Fig. 6) which decades on time scales similar to the fading of the persistence residuals. The limited tests performed so far indicate that the shape, level and time variation of this pattern are always the same. Therefore, it could be measured with great accuracy and subtracted from the science frames. However, the pattern effectively acts as an extra dark-current and deteriorates the noise performances in the first few minutes.

Further tests are needed to verify if the off/on technique could be a valid alternative to just wait ~5 minutes for the the persistence to fade.

REFERENCES

8. Oliva, E.; Origlia, L.; Maiolino, R.; et al., SPIE, 8846, 146 (2012), this conference
Figure 1. Bottom panel: measured noise of the GIANO detector (dots) and predicted values (curves) for multiple non-destructive readout (Fowler sampling) and Poisson noise from the array dark current and instrumental internal background. Upper panel: duty cycle of the exposure, i.e. ratio between effective and total integration times.

Figure 2. Left panel: bad pixels mask of the GIANO detector. Right-hand panel: zoom view of a flat exposure.
Figure 3. Dark exposure of GIANO with 300sec integration.

Figure 4. Central region of double correlated GIANO frames showing the effects of reset anomaly for various reset times.
Figure 5. Right hand panel: plot of the ramp signal of a pixel affected by a radioactive-like event. Top left panel: portion of the dark frame reduced using the standard multi non-destructive procedure. Bottom left panel: same as above reduced using the filtering procedure described in the test.

Figure 6. Time variation of the extra-dark generated after the array is switched off/on.