Characterizing the Robert Stobie Spectrograph’s Near Infrared Detector

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ABSTRACT

We report on the detector testing status for the Robert Stobie Spectrograph’s near-infrared arm. The instrument utilizes a Teledyne HAWAII-2RG HgCdTe detector array with a 1.7 µm cut-off wavelength. We have selected an operating temperature of 120 K. The characterization effort will take place in our detector-testing laboratory at the University of Wisconsin-Madison. The laboratory is equipped with a test dewar, vacuum system, temperature controller, monochromator, and warm detector test enclosure. We will measure detector performance characteristics such as readout noise, gain, dark current, linearity, quantum efficiency, and persistence, and develop calibration strategies. Persistence could have a substantial impact on the spectrograph’s science data, and therefore, the development of mitigation techniques for this effect will be emphasized.

Keywords: Near infrared, HAWAII-2RG, HgCdTe, 1.7 µm cutoff, persistence, SALT

1. INTRODUCTION

The near infrared (NIR) upgrade to the Robert Stobie Spectrograph (RSS) will be commissioned on the Southern African Large Telescope (SALT) in 2012. SALT is a fixed-elevation, segmented-mirror-array telescope 11 meters in diameter. It is the largest single-aperture telescope in the world and is similar in design to the Hobby-Eberly Telescope. The RSS-NIR will provide high throughput, low- to medium-resolution long-slit and multi-object spectroscopy with broadband, spectropolarimetric, and Fabry-Perot imaging modes from 0.85 to 1.7 µm over an 8' x 8' field of view. It is being developed as a complementary instrument to the existing visible spectrograph (RSS-VIS)1. The design includes an articulated camera, Volume Phase Holographic (VPH) gratings, a polarizing beamsplitter and a single etalon Fabry-Perot system. The RSS-NIR is semi-warm, sharing a common slit plane and partial collimator with RSS-VIS. A pre-dewar, cooled to -40 °C, contains the final RSS-NIR collimator optic, VPH gratings, Fabry-Perot etalon, Fabry-Perot order blocking filters, polarizing beamsplitter, and the first five camera optics. The final two camera optics, long-wavelength blocking filters, and the detector are housed in a cryogenically cooled dewar. An RSS-NIR cross-section is shown in Figure 1. The combined RSS will provide simultaneous visible and NIR (320 nm – 1.7 µm) observations, a rare instrumentation capability among 8–11 m class telescopes.

A Teledyne Imaging Sensors (TIS) 2048 x 2048 pixel HAWAII-2RG (H2RG) HgCdTe array with a 1.7 µm cutoff wavelength has been selected as the near-infrared (NIR) detector for RSS-NIR. The array has an 18 µm pixel pitch and consists of 2040 x 2040 sensitive pixels plus four rows and columns of reference pixels on each side. It has had the CdZnTe substrate removed and includes an anti-reflection (AR) coating for improved performance. The H2RG offers 1-, 4-, and 32-channel readout modes. A guide mode capability is available in which a window can be read out at up to a 5 MHz pixel rate for telescope guiding while the full field collects science data. H2RG NIR detector arrays with 2.5 and 5 µm cutoff wavelengths will be used for the Near-Infrared Camera (NIRCam), Near-Infrared Spectrograph (NIRSpec), and Fine Guidance Sensor Tunable Filter Imager (FGS-TFI) on board the James Webb Space Telescope (JWST), and several have been previously fielded in instruments at ground-based telescopes (e.g., Gemini, CFHT, Magellan, VLT, University of Hawaii).

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Figure 1. RSS-NIR cross-section with optical path shown. Light from the prime focus of the SALT telescope passes through the slit, field lens, polarizing optics and then the RSS collimator. From there, the dichroic splits it between RSS-VIS (on right) and RSS-NIR (on left). As the light enters the RSS-NIR pre-dewar enclosure, it passes through a collimator doublet. The pre-dewar provides a cold (−40 °C), dry environment at atmospheric pressure. From the doublet, the light is redirected via a fold mirror through the gratings, order blocking filters, Fabry-Perot etalon, and/or polarizing beamsplitter. The dispersed light is collected by an all-spherical, 7-element refracting camera. Five elements are in the pre-dewar, the 6th forms the window to the dewar. The field flattener and detector (HAWAII-2RG) are in the dewar. The dewar contains a series of low-pass filters.

2. DETECTOR OPERATION

2.1 Focal plane electronics and instrument dewar

The RSS-NIR H2RG’s bias levels, clock signals, and output digitization will be controlled with the TIS SIDECAR Application Specific Integrated Circuit (ASIC). The TIS JADE2 card provides the interface between the ASIC and a PC via USB 2.0. The JADE2 card will be available for our detector testing, but we plan to use a FPGA card being developed by the Inter-University Centre for Astronomy and Astrophysics (IUCAA) in RSS-NIR to interface between the ASIC and PC. The use of the SIDECAR and the IUCAA card with the H2RG instead of other available controllers minimizes the volume, mass, and power needed for the instrument’s detector subsystem.

Both the detector and SIDECAR are housed in a dewar and are connected by a TIS 4-inch flex cable. The dewar will be cryogenically cooled to 120 K. This detector operating temperature was chosen in order to optimize detector performance (e.g., dark current, persistence) and give us a wider selection of crycoolers. The semi-warm design of RSS-NIR forces us to block long wavelengths with filters inside the dewar to decrease the thermal background. Therefore, the dewar also includes a 5-position filter wheel in which three positions are reserved for long-wavelength cutoff filters.
2.2 Operational parameters

The RSS-NIR H2RG will be read out in the 32-output mode at a 200 kHz pixel rate. Sampling methods will include correlated double sampling (CDS), Fowler-N, and up-the-ramp, depending on the observing mode. The RSS-NIR H2RG’s basic properties, operational parameters, and required performance are summarized in Table 1.

Table 1. RSS-NIR H2RG properties, operational parameters, and required performance.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR material</td>
<td>HgCdTe</td>
</tr>
<tr>
<td>Substrate</td>
<td>CdZnTe (Removed)</td>
</tr>
<tr>
<td>Array configuration</td>
<td>2048 x 2048 pixels</td>
</tr>
<tr>
<td>Pixel pitch</td>
<td>18 µm</td>
</tr>
<tr>
<td>Outputs</td>
<td>32</td>
</tr>
<tr>
<td>Pixel rate</td>
<td>200 kHz</td>
</tr>
<tr>
<td>Sampling</td>
<td>CDS, Fowler, Up-the-ramp</td>
</tr>
<tr>
<td>Median read noise (single CDS)</td>
<td>≤ 30 e^-</td>
</tr>
<tr>
<td>Median read noise (Fowler-64)</td>
<td>≤ 6 e^-</td>
</tr>
<tr>
<td>Median dark current</td>
<td>≤ 0.1 e^- s^-</td>
</tr>
<tr>
<td>Quantum efficiency at 1.0 µm</td>
<td>≥ 50%</td>
</tr>
<tr>
<td>Quantum efficiency at 1.5 µm</td>
<td>≥ 70%</td>
</tr>
<tr>
<td>Well Capacity</td>
<td>≥ 65,000 e^-</td>
</tr>
<tr>
<td>Power dissipation</td>
<td>≤ 16 mW</td>
</tr>
<tr>
<td>Temperature</td>
<td>120 K</td>
</tr>
</tbody>
</table>

3. DETECTOR CHARACTERIZATION

We have received from TIS a science-grade H2RG detector, an engineering-grade array, a bare multiplexer (mux), room-temperature and cryogenic SIDECAR ASIC kits, and two JADE2 interface cards. In addition, we have acquired a controller from Astronomical Research Cameras that will be used to carry out the initial phase of detector testing. Our system consists of a 250 MHz fiber optic timing board, a clock driver board, one utility board, two 8-channel IR video boards, and a 250 MHz PCI board (Figure 2). The second video board is currently being used to supply two of the DC biases required by the H2RG. We anticipate 4-channel testing with the ARC controller, though if it becomes necessary, 32-channel testing could be accomplished by installing two additional video boards. A frame from our ARC controller obtained with open inputs is shown in Figure 3.

The goals of the detector testing effort are to measure performance characteristics such as readout noise, dark current, gain, linearity, quantum efficiency (QE), and persistence and develop calibration techniques for the science-grade array under operating conditions. The testing will be carried out in two phases. The first is a warm phase in which room-temperature tests will be carried out on the mux and engineering-grade array. The main purpose of the warm setup is to gain experience operating the detector subsystem components, verify bias levels and clock signals, test functionality, and develop readout and sampling strategies. The second phase of testing will take place under cryogenic conditions. The science-grade array will be characterized in this phase, though it will begin with tests on the mux and engineering-grade array. Initially, a test dewar will be used for the cryogenic tests, but we will be able to incorporate the instrument dewar into this phase when it becomes available. We note that warm and cryogenic testing can take place at the same time on two different arrays.
Figure 2. The ARC controller and its power supply. Also shown is the interior of the warm test enclosure.

Figure 3. Four-channel non-deinterlaced frame from the ARC controller obtained with open inputs.
3.1 Persistence

The top priority for the detector characterization effort is the development of persistence calibration and mitigation techniques. Persistence is remnant signal from prior illumination that is observed in the current frame. It is a complicated function of parameters such as readout timing, exposure cadence, and location on a given detector. The response differs considerably between detector arrays. Smith et al. have presented a persistence model in which charges that were trapped in the depletion region during signal accumulation are released in subsequent frames following a reset when the depletion width is restored\(^4\). The effect seems to have multiple time constants, and can impact several subsequent exposures. Persistence at levels of a few tenths of a percent to approximately half a percent were measured by Smith et al. in 1.7 \(\mu\)m cutoff, substrate-removed H2RGs for the SuperNova Acceleration Probe (SNAP)\(^5\). The authors suggest a number of mitigation techniques including selectively resetting pixels with high signals, inserting a time delay between reset and the first read, increasing the detrapping rate by illuminating the detector with photons that have a wavelength beyond the detector’s cutoff wavelength (“Night Light”), and illuminating the detector during reset with photons with energies above and below the band-gap energy (“Flashy Reset”).

Persistence, even at the level of a few tenths of a percent, could represent a substantial problem for queue-scheduled RSS-NIR science. This level of persistence from a bright source can introduce significant errors when observing a faint source in subsequent frames. Our persistence testing will begin with an approach similar to the Smith et al. method. However, unlike the SNAP survey, RSS-NIR will not have a constant set of exposure parameters. It will therefore be necessary for us to measure persistence under a wide range of observational conditions in order to develop a persistence model for our detector. Initially, persistence will be measured in dark frames following bright illumination in a previous frame. Following these tests, we will characterize the persistence in frames in which signal is accumulated following stimulus exposures. We are currently considering mitigation strategies that would have a minimal impact on observing efficiency (e.g., selective resetting, “Night Light”, “Flashy Reset”).

4. DETECTOR TESTING LABORATORY

The testing and integration of the RSS-NIR H2RG detector and focal plane electronics will be carried out in our facilities at the University of Wisconsin-Madison. Our NIR laboratory is composed of three adjoining rooms with a common air source that keeps the rooms positively pressurized with respect to the outside hall and adjacent air spaces. All three labs have HEPA filters on the air inlets, and the air source has a back-up fan to keep the rooms pressurized in case the main building air handler shuts down. The main lab is primarily used for mechanical assembly and overall system testing. It will have a cleanliness level of between Class 10,000 and 50,000 depending on activity. The optics lab is between Class 2,000 and 5,000 and will be used for optical assembly development and testing. The detector lab is our cleanest space, between Class 100 and 2,000 depending on activity and location in the room. All workbenches and chairs in this lab are clean room certified to \(\leq\) Class 100, and all equipment and parts are cleaned prior to, or immediately after, entering the room. The cleanliness of the labs are periodically monitored with a portable Met One particle counter, and the bench area is continuously monitored when working with the detector and other critical elements.

Electrostatic discharge (ESD) protection procedures have been implemented in all three labs to varying degrees. Both the detector and read-out electronics are ESD Class 0 parts that may be damaged by less than 500 V, and as such all critical operations are performed in the detector lab to prevent damage to these devices. The detector lab has benches, chairs, and a floor that are ESD certified. All bench surfaces have ESD monitors that check the bench connectivity and dual-conductor wrist strap monitors to ensure that personnel are properly grounded. Lab humidity is continuously measured and recorded. We have dual air ionizers for the workspace and an ESD field meter that we use during activities with the detector and associated electronics. All critical items are packaged inside a second ESD protection layer (generally a mechanical package or dewar) before removing them from the detector lab.

4.1 Warm setup

The warm testing will be carried out with the bare mux, engineering-grade array, and the ARC controller. The room-temperature SIDECAR and IUCAA interface card can be incorporated into this setup as well. We have also designed
and built a warm test enclosure that houses the mux or engineering-grade array, contains a transition board with the physical dimensions of the cryogenic SIDECAR ASIC and several test points, and permits a nitrogen purge. The warm test enclosure is shown in Figure 2.

4.2 Cryogenic setup

An IR Labs 8-inch dewar will be used for cold testing. We have a Varian TPS vacuum system consisting of a V81-M turbo pump and an oil-free IDP Dry Scroll backing pump. It also includes an FRG-700 full range Pirani and cold cathode combination vacuum gauge. An electromagnetic isolation valve in the pump line between the test dewar and the pumping system will close and prevent an uncontrolled vent to atmosphere in the event of a power failure. We will be using a Lakeshore Model 325 temperature controller with two control loops: one in close proximity to the detector and one on a cold plate that is an intermediate stage between the detector and the LN2 reservoir. In addition, a Lakeshore Model 218 temperature monitor will provide temperature information from eight other sensors located at various thermal points of interest in the dewar. All sensors are Lakeshore DT 670-CU silicon diodes mounted in small copper bobbins. The test dewar, turbo pump system, and temperature controller are shown in Figure 4.

Figure 4. IR Labs test dewar, Varian vacuum system, and Lakeshore temperature controller.

The transition board developed for the warm test enclosure will also be used in the dewar for cold testing with the ARC controller. After the IUCAA interface card is delivered, the SIDECAR ASIC can be used for 4- and 32-channel cold testing (it will take the place of the transition board in the dewar). The SIDECAR will be connected to the H2RG within the dewar via the 4-inch flex cable.

The RSS-NIR camera produces an F/1.45 telecentric beam emanating from a 329 mm diameter exit pupil located 477 mm in front of the detector. In order to simulate these camera features and duplicate the expected illumination seen by the detector in the delivered system, a simple non-color-corrected optical relay was designed (Figure 5). This relay uses
a pair of plano-convex ZnSe lenses to project a 24.2 mm diameter physical cold stop, located within the IR Labs test dewar, out to the same distance and diameter as that produced by the actual camera lens. The test dewar optics produce reasonable image quality, but require refocus at different wavelengths. This is not a concern for the QE and persistence measurements, as those tests will be carried out using broad illumination patterns. What is of primary concern is that these patterns reproduce the pupil illumination seen by the camera.

An Oriel monochromator system will be used with the cold setup. The system is dual source (QTH and Globar), and consists of a grating monochromator with multiple gratings that span the range from 350 nm to approximately 40 µm and a stabilized power supply. There is a computer-controlled drive unit for automated scans. The available fixed slits give bandpasses between 0.5 and 20 nm using a 1200 line mm\(^{-1}\) grating. In addition, we have two 200 mm integrating spheres that can be used with this system.

![Figure 5. Non-color-corrected optical relay. The relay uses a pair of plano-convex ZnSe lenses to project a 24.2 mm diameter physical cold stop out to the same distance and diameter as that produced by the actual camera lens.](image)

### 5. FUTURE WORK

The warm testing of the RSS-NIR bare mux and engineering-grade array will begin in July 2010. The cold testing with the IR Labs dewar is scheduled to begin in late summer 2010. The cold test setup will be modified to include the SIDECAR ASIC and IUCAA interface card when the latter component arrives, possibly in late 2010. Once the instrument dewar becomes available, we will be able to carry out cold tests on both the engineering- and science-grade arrays simultaneously. We anticipate spending a significant fraction of our NIR lab testing time on persistence measurements, and developing calibration and mitigation techniques for this effect. The detector characterization measurements will be repeated as part of the RSS-NIR commissioning process at SALT.
6. ACKNOWLEDGMENTS

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REFERENCES