Focal Plane Array Testing and Applications for Astronomy

November 5, 2003
Brookhaven National Laboratory
Outline

1. Astronomy and Instrumentation
2. Future Missions
3. Detector Testing for JWST
Galactic Center Research

- Although it occupies < 0.1% of the Galactic volume, the GC contains 10% of Galactic star formation.
- It is an excellent testbed for stellar evolution models because it contains the highest volume density of stars at all ages, from protostars to the oldest giants.
- It contains a large fraction of the most massive stars, providing test points for massive stellar wind/structure models.
- The three most massive young clusters in the Galaxy have formed recently in the central 100 pc.
- Two of the young clusters are ideally suited for testing particle dynamics models.
- It’s the nearest galactic center!
The GC in NIR - Wide View

2MASS

350 pc
Why Near-infrared?

Digitized Sky Survey

Figer 1995

V band

K band

60 pc
Galactic Center Clusters

Quintuplet Cluster

Central Cluster

Arches Cluster

Quintuplet Cluster
Quintuplet Cluster

NICMOS/HST

Arches Cluster

Lick 3-m
Figer 1995, PhD Thesis
Arches Cluster

Keck I 10-m
Serabyn, Shupe, & Figer
Nature 1998, 394, 448
Arches Cluster

Arches Cluster

VLT NAOS/CONICA
NIRSPEC

- 0.9-5.3 μm cross-dispersed spectrometer for Keck
- R=25,000, R=2,500, imaging (1-2.5 μm)
- Start: October, 1995, Delivery: April, 1999
NIRSPEC: Echelle Grating
NIRSPEC: Case Closed!
NIRSPEC Enpixelled Energy Center of SCAM
A NIRSPEC Raw Frame

$R = \frac{\lambda}{\Delta \lambda} \sim 23,000$

Array defects

Keck II 10-m
Figer et al. 2000

OH lines

CO$_2$ absorption lines
GC in the Slit-viewing Camera

[Image of a diagram showing a map of the Galactic Center region with labels for IRS10E, Sgr A*, IRS7, IRS16NW, IRS13, IRS1W, with a scale of 1.6 pc and orientation markers N and E.]
The Central Sources (Velocities)
Genzel et al. 2001
Massive Stars in Central arcsecond

16NW
16C
16SWW

seeing ≈ 0.3"

No CO!
Young stars!

CO
Slit Positioning for GC Slit Scans
Gas in Central Parsec: Brackett-$\gamma$
Gas in Central Parsec: Brackett-γ
Velocity Bubble Plot
Pistol Star: Mass

JHKLMN + D.M. + spectrum \rightarrow Lum.
Lum. + model \rightarrow Mass

tracks by Langer

Figer et al. 1998
Technology feeds discovery
STOKES on the KAO

- FIR array polarimeter
- Designed motion-control and sensing hardware
- Camera used on the KAO
- Measured polarization of dust ring in the Galactic Center
GRIM Cameras

- NIR cameras for CARA/APO
- Built motion-control and thermometry systems
- Cameras stationed on SPIREX at the South Pole and APO
- Used to characterize the South Pole observing site
Gemini Camera

- Dual-beam NIR camera for Lick 3-m: InSb, HgCdTe, imaging, spectroscopy (R = 525), polarimetry
- Designed the analog electronics for NIR arrays
- Conducted the UCLA Galactic Center Survey
NIRSPEC on Keck II

• NIR spectrometer for Keck II
• Local Project Scientist and Principal Optical Designer
• Wrote proposal, designed, constructed, tested, and commissioned instrument
• Delivered to Keck II in March, 1999

- High-z galaxies
- Galactic Center
- Hot stars
- Star formation
- Brown dwarfs
FLITECAM on SOFIA

- Served as PI
- Developed requirements and initial designs
- Will be delivered at observatory commissioning in 2001

- Telescope testing
- Solar system
- E/PO
The James Webb Space Telescope will address the following questions:

1. What is the shape of the Universe?
2. How do galaxies evolve?
3. How do stars and planetary systems form and interact?
4. How did the Universe build up its present elemental/chemical composition?
5. What is dark matter?
JWST Detector Testing Project Goals

“We will measure first-order detector properties (read noise, dark current, persistence, quantum efficiency, etc.) as functions of environmental parameters (radiation exposure, thermal conditions, operating modes) for both detector types, using the same procedures, setups, dewars, light sources, targets, electronics, acquisition software, analysis software, and staff.”

- IDTL proposal to NASA NRA
Detectors Are Important for JWST

![Graph showing signal vs. wavelength for different requirements and goals.]

- **Sunshield**
- **Zodiacal Light**
- **JWST requirement**
- **JWST goal**

**Wavelength [µm]**

**Signal [e-/sec/pix]**

- **R=5**
- **R=1000**

**Read noise per exposure [electrons]**

- **Dark current**
  - 0.126 e⁻/sec
  - 0.020 e⁻/sec
  - 0.003 e⁻/sec

**Duration of DRM NIR Observations [yrs]**

- **Images**
- **Spectra**
# University of Arizona Requirements Table

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCA Format</td>
<td>Minimum of 2048x2048 pixels, with reference pixels located within or outside of the 2048x2048 field.</td>
<td></td>
</tr>
<tr>
<td>SCA Imaging Surface Flatness</td>
<td>( \leq 15 \text{ mm peak-to-valley} )</td>
<td></td>
</tr>
<tr>
<td>Pixel Pitch</td>
<td>18 – 25 ( \mu \text{m} )</td>
<td></td>
</tr>
<tr>
<td>Pixel-to-Pixel relative location knowledge</td>
<td>(&lt; 1/20^\text{th} \text{ pixel} )</td>
<td></td>
</tr>
<tr>
<td>Fill Factor</td>
<td>( \geq 95% )</td>
<td>100%</td>
</tr>
<tr>
<td>Bad Columns/Rows</td>
<td>(&lt; 5 \text{ columns/rows containing } &gt;1000 \text{ contiguous out of spec pixels.} )</td>
<td></td>
</tr>
<tr>
<td>Bad Pixel Clustering</td>
<td>(&lt; 20 \text{ clusters containing up to } 20 \text{ contiguous out of spec pixels.} )</td>
<td></td>
</tr>
<tr>
<td>Pixel Operability (while simultaneously meeting all requirements)</td>
<td>( &gt; 98% )</td>
<td></td>
</tr>
<tr>
<td>Total Noise (Quadrature sum of all sources) per pixel in 1000 s*</td>
<td>( \leq 9 \text{ e}^{-}\text{rms} )</td>
<td>( \leq 2.5 \text{ e}^{-}\text{rms} )</td>
</tr>
<tr>
<td>Read noise for a single read</td>
<td>( \leq 15 \text{ e}^{-}\text{rms} )</td>
<td>( \leq 7 \text{ e}^{-}\text{rms} )</td>
</tr>
<tr>
<td>Dark current</td>
<td>(&lt; 0.01 \text{ e/sec} )</td>
<td></td>
</tr>
<tr>
<td>Minimum Detecte Quantum Efficiency</td>
<td>( \geq 70% \text{ for } 0.6 &lt; l &lt; 1.0 \text{ ( \mu \text{m} );} ) ( \geq 80% \text{ for } 1.0 \leq l &lt; 5.0 \text{ ( \mu \text{m} );} ) ( \geq 90% \text{ for } 0.6 &lt; l &lt; 1.0 \text{ ( \mu \text{m} );} ) ( \geq 95% \text{ for } 1 \leq l &lt; 5 \text{ ( \mu \text{m} );} )</td>
<td>( \geq 90% \text{ for } 0.6 &lt; l &lt; 1.0 \text{ ( \mu \text{m} );} ) ( \geq 95% \text{ for } 1 \leq l &lt; 5 \text{ ( \mu \text{m} );} )</td>
</tr>
<tr>
<td>Well Capacity</td>
<td>( 6 \times 10^4 \text{ e}^{-} )</td>
<td>( 2 \times 10^5 \text{ e}^{-} )</td>
</tr>
<tr>
<td>Electrical crosstalk between adjacent pixels</td>
<td>( \leq 5% )</td>
<td>( \leq 2% )</td>
</tr>
<tr>
<td>Radiometric Stability</td>
<td>( 1% \text{ over } 1000\text{s} )</td>
<td>( &lt; 1% \text{ over } 1000\text{s} )</td>
</tr>
<tr>
<td>Latent or Residual Images, when measured at the same integration time as was used for the near saturation image.</td>
<td>( &lt; 0.1% \text{ after the } 2^{\text{nd}} \text{ read following an exposure of } 80% \text{ of full well} )</td>
<td>( &lt; 0.01% \text{ after the } 2^{\text{nd}} \text{ read following an exposure of } 80% \text{ of full well} )</td>
</tr>
<tr>
<td>Radiation Immunity after exposure to 6Krad TID (Si)</td>
<td>(&lt; 4% \text{ pixels out of spec at } 6\text{Krad TID Si} )</td>
<td>(&lt; 0.5% \text{ pixels out of spec at } 6\text{Krad TID Si} )</td>
</tr>
<tr>
<td>Cosmic Ray Pixel Upsets in 1000s and cosmic ray flux of 5 s(^{-1})cm(^{-2}).</td>
<td>(&lt; 10% \text{ pixels above noise requirement} )</td>
<td>(&lt; 2% \text{ pixels above noise requirement} )</td>
</tr>
<tr>
<td>Frame Read-out Time</td>
<td>12 s</td>
<td>(&lt; 12 \text{ s} )</td>
</tr>
<tr>
<td>SCA pixel readout rate</td>
<td>100kHz rate, 10ms/ pixel</td>
<td>( &gt; 100\text{kHz} \text{ rate} )</td>
</tr>
<tr>
<td>Sub-array Size</td>
<td>As large as 128 x 128 pixels</td>
<td>( &gt; 100 \text{ pixels} )</td>
</tr>
<tr>
<td>Sub-array exposure time</td>
<td>0.2 sec for 128 pixels x 128 pixels, shorter for fewer pixels</td>
<td>(&lt; 0.2 \text{ secs for } 128 \text{ pixels x } 128 \text{ pixels} )</td>
</tr>
</tbody>
</table>
IR Arrays are “Hybrid” Sensors

• PN junctions are “bump bonded” to a silicon readout multiplexer (MUX).

• Silicon technology is more advanced than other semiconductor electronics technology.

• The “bump bonds” are made of indium.
Competitors
NIR Detector Characteristics

- Dark current
- Read noise
- Linearity
- Latent charge (persistence)
- Quantum efficiency (QE)
- Intra-pixel sensitivity
- Thermal stability
- Radiation immunity
NIR Detector Effects

- Dark current
- Bias drifts
- QE variations
- Amplifier glow
NIR Detector Effects

- Persistence

Latent Images ("persistence")

Cosmic Ray Persistence

negligible  significant  severe
NIR Detector Effects

- DC bias level drift

- Ghosts
### IDTL Planned Measurements

<table>
<thead>
<tr>
<th>parameter</th>
<th>variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>dark current</td>
<td>T</td>
</tr>
<tr>
<td>read noise</td>
<td>read mode, T</td>
</tr>
<tr>
<td>persistence</td>
<td>fluence, reset mode, wavelength</td>
</tr>
<tr>
<td>gain</td>
<td>wavelength</td>
</tr>
<tr>
<td>linearity, full well</td>
<td>wavelength, bias voltage</td>
</tr>
<tr>
<td>QE</td>
<td>wavelength, pixel, T</td>
</tr>
<tr>
<td>intra-pixel sensitivity</td>
<td>location</td>
</tr>
<tr>
<td>cross-talk (diffusion)</td>
<td>T</td>
</tr>
</tbody>
</table>
IDTL System
IDTL Test System

Leach II Controller Electronics

Dewar (6Kx6K capacity)

Entrance Window

Vacuum Hose

He Lines

Entrance Window
Dewar Cross Section

Figure 3.3. Mechanical drawing of cross section of IDTL dewar assembly. The optics with ray trace are also shown.

Figer et al. 2002, SPIE, 4850, 981
Detector Housing

Figure 5. Solid model rendering of IDTL detector mounting structure and light-tight enclosure.

Figer et al. 2002, SPIE, 4850, 981
Cryoharness and Detector Customization Circuit

Figure 6. IDTL cable harness (left) and detector customization circuit (right).
Figer et al. 2002, SPIE, 4850, 981
## System Design - Software

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control modes</strong></td>
<td>Interactive, batch (script)</td>
</tr>
<tr>
<td><strong>User interfaces</strong></td>
<td>GUI (graphical user interface), CLI (command line interface), script</td>
</tr>
<tr>
<td><strong>Level of automation</strong></td>
<td>Capability to obtain all data associated with complete test suite by pressing one key</td>
</tr>
<tr>
<td><strong>Displays</strong></td>
<td>Image, instrument status</td>
</tr>
</tbody>
</table>
Past and present personnel

Eddie Bergeron  
Data Analyst

Tom Reeves  
Lab Technician

Robert Barkhouser  
Optical Engineer

Mike Telewicz  
Intern

Bernie Rauscher  
Project Scientist

Utkarsh Sharma  
Graduate Student

Gretchen Greene  
Mechanical Engineer

Steve McCandliss  
JHU Lead

Ernie Morse  
Data Analyst

Monica Rivera  
Intern

Scott Fels  
Intern

Don Figer  
Director

Russ Pelton  
Technician

Sito Balleza  
Systems Engineer

Mike Regan  
System Scientist
IDTL First Light Images

Raytheon ALADDIN
Jan. ‘01 (MUX)

Rockwell HAWAII-1R
Feb. ‘02 (MUX) Apr. ‘02 (SCA)

Rockwell HAWAII-1RG
Jun. ‘02 (MUX) Jul. ‘02 (SCA)

Raytheon SB-304

Rockwell HAWAII-2RG
Jan. ‘03 (MUX)

Raytheon SB-304

Rockwell HAWAII-2RG
Mar. ‘03 (SCA) Mar. ‘03 (SCA)
Results: Conversion/Electronic Gain
Gains and $C_{\text{cell}}$ Summary

<table>
<thead>
<tr>
<th>Part</th>
<th>ext. gain $\mu$V/ADU</th>
<th>int. gain $\mu$V/ADU</th>
<th>MUX gain</th>
<th>conv. gain $\text{e}^{-}/\text{ADU}$</th>
<th>conv. gain $\text{e}^{-}/\mu\text{V}$</th>
<th>$C_{\text{cell}}$ fF</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2RG-015-5.0mu</td>
<td>3.81</td>
<td>4.31</td>
<td>0.89</td>
<td>1.30</td>
<td>0.30</td>
<td>48</td>
</tr>
<tr>
<td>SB304-008-5.0mu</td>
<td>3.81</td>
<td>4.83</td>
<td>0.79</td>
<td>2.20</td>
<td>0.46</td>
<td>73</td>
</tr>
</tbody>
</table>
Electronic Gain Experiment

• Definition: gain from unit cell to MUX output
• NIRCam Requirement: NA
• IDTL Measurement Goal: NA
• Experiment Description: measure change in output versus change in reset voltage
• Experiment Variations: none
Electronic Gain of SCA H2RG-015-5.0mu

Electronic gain = 4.305 μV/ADU
Sigma = 0.069 μV/ADU
Skipped first = 0 points
DATE = 05/09/2003
TIME = 13:07:36
Electronic Gain of SCA SB304–008–5.0mu

- Electronic gain = 4.827 μV/ADU
- Sigma = 0.029 μV/ADU
- Skipped first = 0 points
- DATE = 04/16/2003
- TIME = 22:16:53

VRESET Voltage (Volts)

Signal in First Read (ADU)
Photon Transfer Experiment

- Goal is to get conversion from ADU to electrons
- Two versions of test
  - Classic – Vary exposure time and look at variance on the whole detector.
  - Gray Scale – Take 10 exposures of a gray scale target and get the mean flux and variance for each pixel.
- Both then perform a least squares fit of variance and ADU. Both methods give consistent results.
Photon Transfer Results Summary

• Results
  – H2RG-015 gain = 1.3 e^-/ADU
  – SB304-008 gain = 2.2 e^-/ADU

• These results will be used for all subsequent experiments.
Gray Scale Photon Transfer

Gain: 2.14 ± 0.00 e- / ADU
Read Noise: 36.4 ± 0.5 e- rms
Date: 04/17/2003
Time: 20:40:44 UT
SCA: SB304-008-5.0mu
Refsub Version: 1.5
Refsub Type: Spatial averaging
Full Frame Photon Transfer

![Graph showing photon transfer characteristics]

- SCA: H2RG-015-5.0mu
- Filters: BL1, J+PK50-2
- Read Noise: 21.4±0.0 e- rms
- Gain: 1.28±0.00 e-/ADU

Analysis region: [4:2043, 4:2043]
Rebsub version: 1.5
Rebsub type: Spatial averaging

Date: 05/08/2003
Start Time: 22:17:45 UT
Bias subtracted: Yes

File: \Rabbit\Rockwell\H2RG-015-5.0mu\cold\PhotonXfer_test.8May03\Results\BL1_J+PK50-2_photonxfer_data.jpg
Results: Linearity/Well Depth
Linearity Experiment

• Uses data from photon transfer experiment
  – Determine count rate as a function of ADU.
  – Solve for coefficients in equation:

\[ \text{countRate} = 1 - aDN - bDN^2 \]
Non-linearity/ Well Depth Results Summary

- Non-linearity in electrons

<table>
<thead>
<tr>
<th>Device</th>
<th>Linear term (e⁻)</th>
<th>Quadratic Term (e⁻)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB304-008</td>
<td>4.4 x 10⁻⁶</td>
<td>9.4 x 10⁻¹¹</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Device</th>
<th>Linear term (e⁻)</th>
<th>Quadratic Term (e⁻)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2RG-0015</td>
<td>9.3 x 10⁻⁷</td>
<td>9.0 x 10⁻¹²</td>
</tr>
</tbody>
</table>

- Well Depth
  - H2RG-015 = 130K e⁻
  - SB304-008 = 122K e⁻
Well Depth and Non-linearity

SB304-008-5.0mu Well Depth Histogram at 31 K (K+PK50-2 + BL2)

H2RG-015-5.0mu Well Depth Histogram at 37 K (K+PK50-2 + BL2)

SB304-008-5.0mu Linearity

H2RG-015-5.0mu Linearity

fit = 1 + (-2.03e-05 * DN) + (-1.94e-11 * DN^2)

- included in fit
- not included in fit

fit = 1 + (-7.13e-07 * DN) + (-5.32e-12 * DN^2)

- included in fit
- not included in fit
Dark Current Experiment
Dark Current Experiment

• Definition: portion of signal that accumulates in the absence of exposure to light
• NIRCam Requirement: <0.01 e⁻/sec/pixel
• IDTL Measurement Goal: <0.001 e⁻/sec/pixel
• Experiment Description: obtain series of SUTR-250 images with minimum exposure time with no light falling on detector and fit signal versus time with line
• Experiment Variations: T=26 K, 28 K, 30 K, 32 K, 35 K, 37 K, 40 K, 45 K, 50 K, 60 K, 70 K, 80 K
Results: Dark Current
# Dark Current Results Summary

(e⁻ per pixel per 1000 seconds from 2700 second frame using UTR-250)

<table>
<thead>
<tr>
<th>Part</th>
<th>Temperature (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>26</td>
</tr>
<tr>
<td><strong>H2RG-015-5.0mu</strong></td>
<td>NA</td>
</tr>
</tbody>
</table>

*1.5-2.4 e⁻ measured using UTR-8. We infer a "per read" contribution of ~0.01-0.03 e⁻/read.

<table>
<thead>
<tr>
<th>Part</th>
<th>Temperature (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>26</td>
</tr>
<tr>
<td><strong>SB304-008-5.0mu</strong></td>
<td>NA</td>
</tr>
</tbody>
</table>

*6 e⁻ measured using UTR-8. We infer a "per read" contribution of ~0.17 e⁻/read.
Results: Dark Current
Rockwell
Dark Current for H2RG–015–5.0mu

Analysis Region: [4:2043, 4:2043]
Reflsub Version: 1.5
Reflsub Type: Spatial averaging
Start date: 5/20/2003

\rabbit\rockwell\H2RG–015–5.0mu\cold\dktest.20May03\SlopePlots\darkjumbo_H2RG–015–5.0mu_0.jpg
Dark Current for H2RG-015-5.0mu

Analysis Region: [4:2043, 4:2043]
Refsub Version: 1.5
Refsub Type: Spatial averaging
Start date: 5/16/2003

Time (hours)
Mode of Signal vs. Time: dark_37K_250_min_1_01.fits

Detector: H2RG-015-5.0mu
Detector Temperature: 36.999 K
Read Mode: SUTR-250,1

Analysis Region: [4:2043, 4:2043]
Rfsaub Version: 1.5
Rfsaub Type: Spatial averaging
Slope = 0.003 ADU/s

Date: 05/10/2003, Time: 15:08:35 UT

\Rabbit\Rockwell\H2RG-015-5.0mu\cold1\dktest.9May03\SlopePlots\dark_37K_250_min_1_01.jpg
Focal Plane Array Testing and Applications for Astronomy

Detector: H2RG-015-5.0mu
Analysis Region: [4:2043, 4:2043]
Resub Version: 1.5
Resub Type: Spatial Averaging
Date: 05/10/2003, 15:08:35 UT

$X_{\text{ave}} = 0.0028$
$\sigma = 0.0040$

\text{\textbackslash rabbit\textbackslash Rockwell\textbackslash H2RG-015-5.0mu\textbackslash cold\textbackslash dktest.9May03\textbackslash histograms\textbackslash dark_37K_250_min_1_01_slope_hist.jpg}
dark_37K_250_min_1_01_slope.fits

z = 0 – 0.006 ADU/s
Results: Dark Current
Raytheon
Mode of Signal vs. Time: dark_28K_250_min_1_02.fits

- Detector: SB304--008--5.0mu
- Detector Temperature: 27.999 K
- Read Mode: SUTR--250,1

Analysis Region: [4:2051, 0:2047]
- Refsub Version: 1.5
- Refsub Type: Spatial averaging
- Slope = 0.011 ADU/s

Date: 03/15/2003, Time: 23:03:01 UT

\Rabbit\Raytheon\SB304--008--5.0mu\cold1\dktest.15Mar03\SlopePlots\dark_28K_250_min_1_02.jpg
dark_28K_250_min_1_02_slope.fits

\[ z=0 - 0.02 \text{ ADU/s} \]
Persistence Experiment
Persistence Experiment

• Definition
  – The portion of the signal that is produced by sources in previous images. Anything that liberates charge into the conduction band can result in latent charge, i.e. a bright star or a cosmic ray.
  – Fraction of charge migrates to traps, where it is not liberated by pixel reset, but instead slowly escapes to PN junction according to exponential time profile

• JWST Requirement
  – <0.1% in 2nd read after exposure >= 80% of saturation

• IDTL Measurement Goal
  – N/A
Persistence Experiment

• Experiment Variations
  – Wavelength (J, K, M band-pass filters)
  – Fluence (30%, 100%, 1000% of full-well)
  – Number of resets between fluence and persistence exposure (1-reset, 3-reset and autoflush)
    • Autoflush consists of continuous row-by-row reset of detector
Persistence Experiment

- **Experiment Description**
  1. Obtain series of dark exposures
  2. Take illuminated test exposures to determine fluence times for 30%, 100%, 1000% fluence for each bandpass
  3. Put closed (unmachined) filter wheel position in place and wait 4000 seconds.
  4. Put pass-band filter in place
  5. Illuminate detector & take exposure to generate desired fluence
  6. Put closed filter position in place
  7. Perform specified # of row-by-row resets of detector
  8. Take 2000-second UTR-32 persistence exposure
  9. Repeat steps 3 – 8 for all filter-fluence combinations
Persistence Movie
Focal Plane Array Testing and Applications for Astronomy

K+PK50–2+BL2 persistence, 977000 e– fluence

% of fluence liberated since previous read

Fast decay

Slow decay

Time (seconds)

Fluence Time: 348.0 seconds
Delay: 25.5 seconds
Source: Latent_reduced_K+PK50–2_BL2_977000...38.fits
1 ADU = 0.000102376%
Results: Persistence
### Persistence Results Summary

Cumulative Persistence after 2000 seconds

<table>
<thead>
<tr>
<th>Device</th>
<th>1 Reset</th>
<th>Filter-Fluence</th>
<th>Fluence Time (s)</th>
<th>Fluence (ADU)</th>
<th>Persistence (%)</th>
<th>Persistence (ADU)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>H2RG-015-5.0μm</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J-30%</td>
<td>1</td>
<td>60.9</td>
<td>23000</td>
<td>0.28</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>J-100%</td>
<td>1</td>
<td>245.8</td>
<td>94000</td>
<td>0.19</td>
<td>179</td>
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</tbody>
</table>

| **SB304-008-5.0μm** |         |                 |                  |              |                |                  |
| J-30%       | 1       | 57.5           | 16000            | 2.90         | 464            |                  |
| J-100%      | 1       | 222.8          | 62000            | 3.20         | 1984           |                  |
| J-1000%     | 1       | 2334.9         | 647000           | 0.38         | 2459           |                  |
| K-30%       | 1       | 63.1           | 18000            | 2.60         | 468            |                  |
| K-100%      | 1       | 228.0          | 64000            | 3.20         | 2048           |                  |
| K-1000%     | 1       | 2326.4         | 649000           | 0.38         | 2466           |                  |
| M-30%       | 1       | 47.1           | 17000            | 3.40         | 578            |                  |
| M-100%      | 1       | 178.2          | 63000            | 3.20         | 2016           |                  |
| M-1000%     | 1       | 1832.4         | 648000           | 0.39         | 2527           |                  |
## Persistence Results Summary

### Cumulative Persistence after 2000 seconds

<table>
<thead>
<tr>
<th>Device</th>
<th>Autoflush</th>
<th>Filter-Fluence</th>
<th>Fluence Time (s)</th>
<th>Fluence (ADU)</th>
<th>Persistence (%)</th>
<th>Persistence (ADU)</th>
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<tr>
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</tbody>
</table>
Persistence Plots
Rockwell
Persistence Plots
Raytheon
Crosstalk Experiment
Crosstalk Experiment

• Definition
  – Three effects are measured in this experiment:
    • Charge diffusion: Charge liberated by a normally incident cosmic ray hit on a single pixel migrating to neighboring pixels
    • Incomplete settling: Settling time insufficient for complete settling of signal after read of pixel hit by cosmic ray
    • Electronic crosstalk: Effect induced in one analog channel by signal in another channel
  • JWST Requirement: < 5% electronic crosstalk
  • IDTL Measurement Goal: N/A
Image of Cosmic Ray Hit

Stretch:
-40 – 100 ADU
Crosstalk Results

• Effects measured in results:
  – Rockwell H2RG results show effects of charge diffusion, incomplete settling and electronic crosstalk
  – Raytheon SB304 results show effects of charge diffusion and electronic crosstalk (incomplete settling not present because pixel read after hit pixel is non-adjacent)

• Results are shown as 3x3 grid representing pixel with cosmic ray hit and adjacent pixels

• Values in grid represent 25th percentile of all values for that pixel position relative to the cosmic ray hits expressed as a percentage of the signal in the central pixel
Crosstalk Results Summary

Comparison of Representative Results

Results are shown for each device at its optimum temperature

<table>
<thead>
<tr>
<th>Device</th>
<th>Detector Temp. (K)</th>
<th>Number of images</th>
<th>Number of Events</th>
<th>Crosstalk Results (%)</th>
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<tr>
<td>H2RG-015-5.0μm</td>
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