Towards High Precision Photometry

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Towards High Precision Photometry

- Project μm-size NIR spots through dewar window onto detectors
- Measure intra-pixel sensitivity variation ⇒ demonstrate required photometric accuracy
- Measure lateral charge diffusion and confirm capacitive coupling measurements

micron-size spot projection system uncovers sub-pixel structure

List of NIR sensors

<table>
<thead>
<tr>
<th>NIR sensor</th>
<th>Manufacturer</th>
<th>Specifications</th>
<th>QE</th>
</tr>
</thead>
<tbody>
<tr>
<td>InGaAs</td>
<td>Raytheon</td>
<td>Virgo 1k</td>
<td>70-80%</td>
</tr>
<tr>
<td>HgCdTe</td>
<td>Raytheon</td>
<td>Virgo 598141</td>
<td>80%</td>
</tr>
<tr>
<td>HgCdTe</td>
<td>Rockwell</td>
<td>H2RG #102</td>
<td>90-95% w/AR coat</td>
</tr>
<tr>
<td>HgCdTe</td>
<td>Rockwell</td>
<td>H2RG #40</td>
<td>70%</td>
</tr>
<tr>
<td>HgCdTe</td>
<td>Rockwell</td>
<td>Banded Array #25</td>
<td>20-30%</td>
</tr>
</tbody>
</table>
SNAP Collaboration Meeting, June 2006

- **SNAP Collaboration Meeting, June 2006**

- **x-y-z stage**

- **objective lens**

- **dewar window**

- **light guide**

- **monitoring photodiode**

- **beam splitter**

- **tube lens**

- **filter**

- **pinhole**

- **linear encoder**

- **x-y-z stage**
Brief History

• Start
  – REU Summer 2003 project (M. Borysow)
  – base initial design on LBL pinhole projector (visible)
  – adapt for NIR and improve design (senior thesis project: W2004)

• Improvements
  – REU Summer 2004 project (N. Barron)
  – installed linear encoder on z-axis
  – improve motion control and analysis software (M. Borysow)

• Characterization of NIR devices
  – line-spread functions (LSF)
  – one and two dimensional pixel response functions (PRF)
  – multiple pixel scans (honors thesis project: W2005)

• Results for RVS and RSC devices
  – lateral charge diffusion (M. Brown)
  – capacitive coupling
  – photometry simulations (→ publication)
Characterizing beam spots

- A knife edge is placed ~3 mm above the detector surface
- Spot-O-Matic is scanned across knife edge in x-y while focusing in z to minimize the spot size and determine the line spread function (LSF)

![Diagram showing knife edge and Spot-O-Matic scanning]

- Best Focus:
  - RVS InGaAs 1k: \( \sigma < 1.40 \, \mu m \)
  - 1050 nm

- 1550 nm
  - \( \sigma < 2.10 \, \mu m \)

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Characterizing pixels

- Virtual knife edge scans (pixel boundary) used to focus Spot-o-Matic onto detector surface
- Intensity profile is a 1-dim convolution of Spot-o-Matic LSF with pixel response function
- Edge transition is increased from the $\sigma = 1.4 \ \mu m$ spot size obtained from the knife-edge scan

\[ \sigma = 2.7 \ \mu m \]
\[ 1050 \ nm \]
\[ \sigma = 2.6 \ \mu m \]
\[ 17.5 \ \mu m \]
Pixel Response Profile (RSC H2RG #102)

2D scan at best focus. Pixel scan is convolution of the PRF with the PSF of the spot

single pixel response is generally very uniform

summing pixels gives a smooth response, with dips tending to fall on pixel boundaries

$\sigma = 1.4\%$
Pixel Response Profile (RVS 141SR)

2D scan at best focus.

single pixel response is very uniform

summed pixels also gives a smooth response, with dips tending to fall close to pixel boundaries

$\sigma = 1.9\%$
Intra-Pixel Variation

H2RG #40 (RSC) with anomalous substructure

appeared to be perfectly fine detector:
- 70% QE, 35 e⁻ read noise, 0.05 e⁻/px/s DC

Scan through center of pixel

Effect on photometry under study!
Pixel Response

- PRF is uniform over pixel surface
- PRF extends beyond pixel boundary
  - lateral charge diffusion
  - capacitive coupling
  - higher order rings of Airy disk (~0.25% contribution)

lateral charge diffusion
random, occurring prior to charge collection

capacitive coupling
deterministically moves charge after charge collection

de-convolution necessary to determine PRF, charge diffusion, capacitive coupling
“De-convolution”

RSC H2RG #102

start with square PRF (18 μm)
convolve with PSF (1.4 μm)
add charge diffusion (1.7±.02 μm)
add capacitive coupling (2.2 ±.1%)
compare to data

let’s fit also the pixel width:

square PRF (17.8 ± .1 μm)
PSF (1.4 μm)
charge diffusion (1.7 ± .02 μm)
capacitive coupling (2.4 ± .1%)
published value: 2.2 ± .1%
## Comparison of NIR sensors

<table>
<thead>
<tr>
<th></th>
<th>RSC H2RG #102 (1050 nm)</th>
<th>RVS Virgo 598141SR (1550 nm)</th>
<th>RVS InGaAs (1050 nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Signal (normalized)</strong></td>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
<td><img src="image3.png" alt="Graph" /></td>
</tr>
<tr>
<td><strong>Spot Position (microns)</strong></td>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
<td><img src="image3.png" alt="Graph" /></td>
</tr>
<tr>
<td><strong>Pixel size</strong></td>
<td>18 μm (17.8±0.1 μm)</td>
<td>20 μm (20.3±0.1 μm)</td>
<td>20 μm (20.0±0.1 μm)</td>
</tr>
<tr>
<td><strong>LSF</strong></td>
<td>1.4 μm</td>
<td>2.1 μm</td>
<td>1.4 μm</td>
</tr>
<tr>
<td><strong>diffusion</strong></td>
<td>1.68±0.02 μm (1.71±0.02 μm)</td>
<td>1.69±0.05 μm (1.62±0.04 μm)</td>
<td>2.26±0.02 μm (2.3±0.02 μm)</td>
</tr>
<tr>
<td><strong>capacitive coupling</strong> (published)</td>
<td>2.24±0.1% (2.38±0.1%) 2.2±1%</td>
<td>2.09±0.1% (1.96±0.1%) 1.25±1%</td>
<td>0.7±0.1% (0.7±0.1%) 0.5±1%</td>
</tr>
</tbody>
</table>
Intra-Pixel Variation in 1D

scan over 7 adjacent pixels

summed response of inner 5 pixels

RSC H2RG #102 (1050 nm)

RMS of central region: 1.05%

RVS Virgo 598141SR (1550 nm)

RMS of central region: 1.56%

response of individual pixels

• simple addition of adjacent pixels restores photometry to better than 2%
• Spot-o-matic can detect sensitivity variations at percent level or below
Conclusions

- Spot-o-Matic has turned into a reliable tool
- Detailed comparison among two vendors now possible
- InGaAs and HgCdTe devices show a very flat pixel response with $\sim2-3\,\mu m$ edge effects dominated by diffusion
- A simple addition of adjacent pixels restores photometry to better than $\sim2\%$
- Will turn our attention to
  - effect of intra-pixel variations on photometry
  - publish Spot-o-Matic paper this summer