Developing a (NIR) Photometry Error Budget for SNAP

Wolfgang Lorenzon
(Michigan)
SNAP Collaboration Meeting
How to assemble a Photometry Error Budget?

High precision photometry requires detailed understanding of all photometric errors

Sources of light

Sources of signal

Sources of noise

Sources of syst. errors

Photometry Error

Framework to assemble an error budget

How to subtract SN from background sources (variable)?
Sources of Light

Estimate the magnitude of each contribution to estimate the photon noise (based on $\sqrt{N}$ photon statistics)

1. Host galaxy
   – magnitude of galaxy is affected by SN, measure before SN goes off
   – noise of galaxy
2. Zodiacal (from plane of solar system)
   – changes with time (with position of Earth)
   – is smooth with low brightness
3. Cirrus (galactic dust)
   – lumpy on degree scale, but dimmer than zodiacal
4. Potential glowing intergalactic dust (warm or cold): negligible
5. Telescope optics: depends on temperature (300K ?)
6. Reflectivity of optics
   – <100% due to micro ripples and roughness of mirrors → broad halo around objects, but drops as $R^{-(2-3)}$ → part of PSF around bright objects
Time variation of Zodiacal Light

- Time variation
  - where is sun wrt dust
  - what light path are we looking through?

- smooth with low brightness
  - spatial uniformity unpredictable
  - ≤5% (with episodic changes)
Reflectivity of Optics

- Tails in signal due to micro ripples and mirror roughness extend over arc minutes → usually 2-4 orders below peak
- Note: $R^{-2}$ is really bad, with $R^{-3}$ more typical

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Sources of Noise

Well known in our detectors / electronics

1. Dark current (DC)
   - for 1.7 μm cut-off HgCdTe, bulk limited dark current should be ~ 0.01 e⁻/pix/s at 140K.
   - very low DC device (RSC H2RG-32-039) had peak DC of 0.01 e⁻/pix/s at 140K.
   - for all HgCdTe devices from RSC, dark currents < 0.2 e⁻/pix/s pixel (< 0.05 e⁻/pix/s for nearly all tested devices) are consistently measured.

2. Read noise (RN)
   - ~ 6.5 e⁻ for 300 s exposures
   - can combine DC and RN into a total noise spec

3. Shot noise on signal (photon counting statistics)
   - bright sources are better
Dark Current

Dark current histogram

Dark current map

(Data are for Rockwell H2RG)
Read Noise Reduction through Multiple Sampling

Ideal Fowler-N sampling reduces read noise by \( \sqrt{N} \)

2k x 2k RVS detector at 130K

Increase in noise floor at longer sampling times is likely dominated by the shot noise in the dark current.
Estimate contributions with simulations

1. Capacitive coupling
   - deterministically moves charge after charge collection

2. Lateral charge diffusion
   - random, occurring prior to charge collection

3. Persistence
   - effect of dithering

sub-pixel non-uniformity
Intra-pixel Variation

2D scan at best focus.

single pixel response is generally very uniform

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

σ = 1.4%
Diffusion and Capacitive Coupling

Pixel Profile Reconstruction

- Start with square PRF (17.8 ± 0.1 μm)
- Convolve with spot PSF (1.4 μm)
- Add charge diffusion (1.7 ± 0.02 μm)
- Add capacitive coupling (2.4 ± 1%)
- Compare to data

(correlated noise result: 2.2 ± 0.1%)
Persistence

Persistence is the release of charge following illumination of HgCdTe arrays.

- Appears to be both flux and intensity dependent

Currently working to simulate persistence using VLT VMOS galaxy data and USNO-B stars in the SNAP north field.

- Combine SNAP frames with measured data to simulate persistence frames and develop persistence specification

Grade ‘B’ persistence from Rockwell: 
~ 0.2% persistence in next frame
Sources of syst. Errors

Estimate contributions due to calibration errors

1. Non-linearity
   - well: saturation (<1%)  
   - reciprocity (under investigation at UM)  
2. Drift
   - temperature
   - bias voltage (whole detector is affected)  
     • fluctuations in the baseline signal of detector can easily be traced with ‘real’ detector pixels (but not with the reference pixels).
3. Filter transmission
4. Telescope throughput
5. Aging
   - QE
6. Cosmic ray damage
Well Depth (RSC FPA H2RG-32-040)

We obtain image data by thermal illumination, i.e. the dewar window is optically dark but at room temperature. After reset the device is read continuously. Full integration capacity of the array is $1.17 \times 10^5$ e and the linearity is maintained within ±3% up to 80% of the full integration capacity, above which the count deviates below the regression line.
Intensity vs. Time Reciprocity

Calibration of SNAP photometry requires observation of many standardized stars over a wide range of magnitude.

ACS has had problems with reciprocity failure - long exposures on dim stars do not give the same signal as equivalent short exposures on bright stars.

At UM we will study detector reciprocity with a specially constructed device.
SECTION A-A
Linearity and Stability (bias voltage)

We see fluctuations in the mean detector (dark) signal that are NOT caused by read-noise but rather reflect fluctuations in the biases.

The fluctuations can be traced with a small subset of (random) pixels (but NOT reference pixels).
SNAP Photometry Error Budget

High precision photometry requires detailed understanding of all photometric errors

Sources of light
SN, galactic dust, zodiacal, telescope optics, reflectivity of optics

Sources of noise (det.)
[dark current, read noise], shot noise in signal

Sources of signal
capacitive coupling, persistence, diffusion

Sources of syst. errors
non-linearity, drift, filter transmission, telescope throughput

Need combined efforts from detector, simulation and calibration groups