Progress on NIR Precision Photometry

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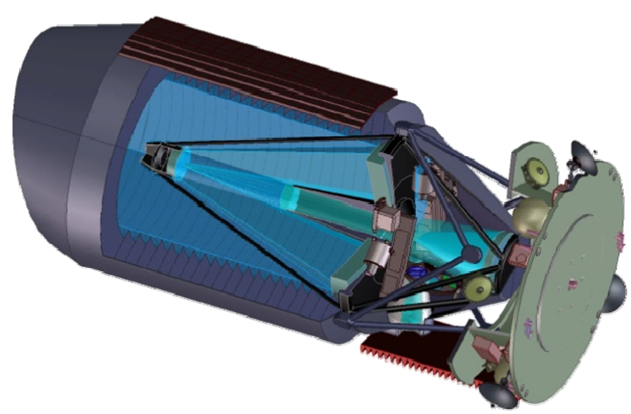
(Michigan)

SNAP Collaboration Meeting
FNAL, 16-May-2008



Outline

- What is needed to close the chapter on NIR precision photometry?
- NIR photometry error budget
  - Combined effort from detector, calibration and simulation groups
  - Modifications to SNAPSim (Chris Stoughton)
  - Input from Calibration Group (Susana Deustua)
- Absolute QE
  - Uniform illumination (challenge at 1% level)
- New universal NIR test dewar
  - Gain, DC, RN, QE, reciprocity: all measured in one dewar (UM)

NIR Precision Photometry

- Precision photometry is essential to the science goals of SNAP and will require low noise, high QE detectors with a high degree of sub-pixel uniformity and stability.

- Precision photometry at the 1% level presents new challenges for an undersampled survey telescope.

  – Intra-pixel variation (studied at UM with Spot-o-Matic)

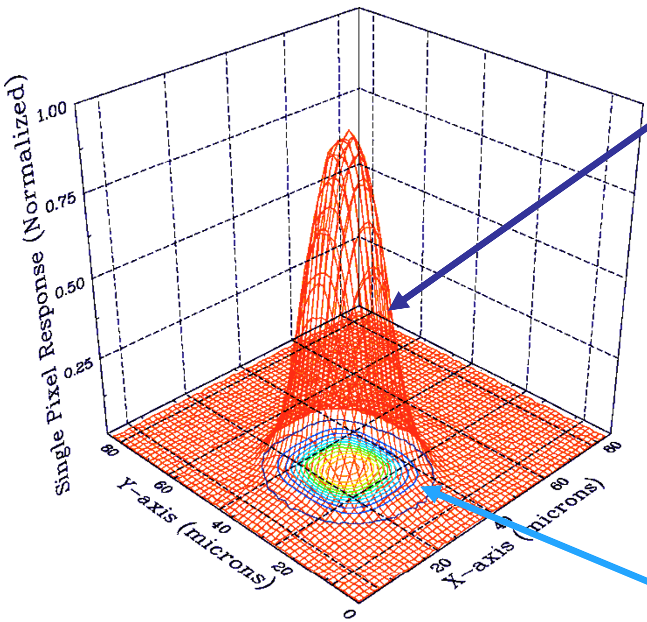
  – Pixel size variation and flat-fielding (studies at UM w/ Spot-o-Matic & QE data under way)

  – Intensity vs. time reciprocity (dewar extension to arrive by late May at UM)

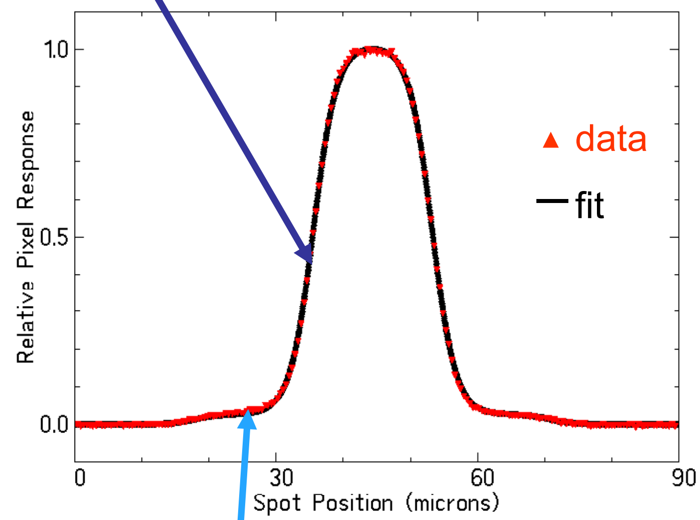
  – Persistence (studied at Caltech)

Intra-pixel Variation

RSC H2RG #102



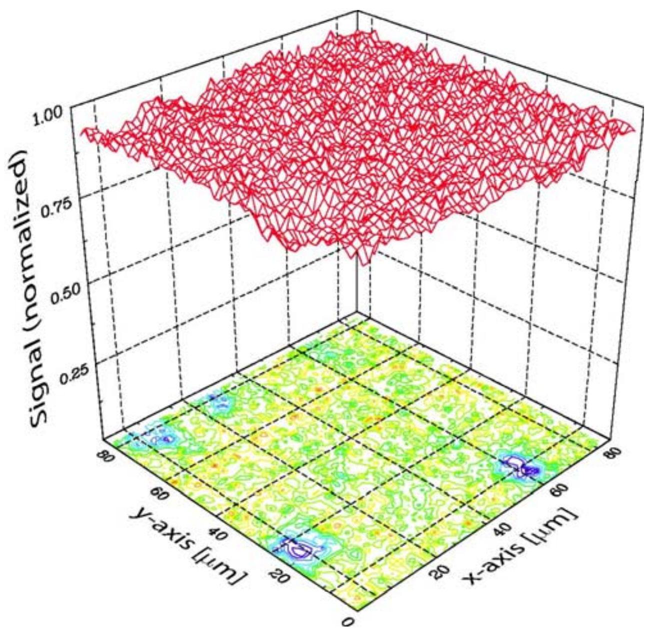
lateral charge diffusion
random, occurring prior to charge collection

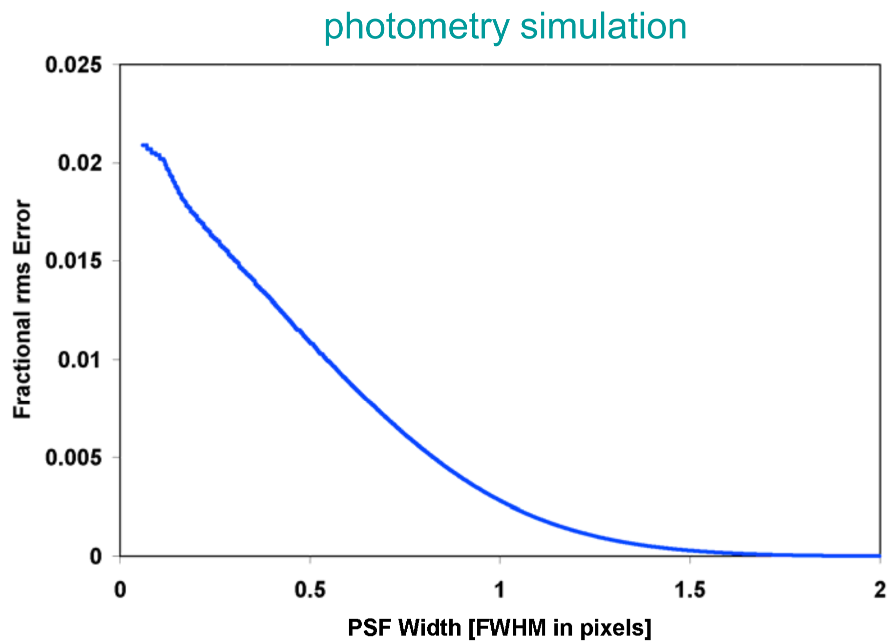


capacitive coupling
deterministically moves charge after charge collection

- 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)

Photometry in Undersampled Images

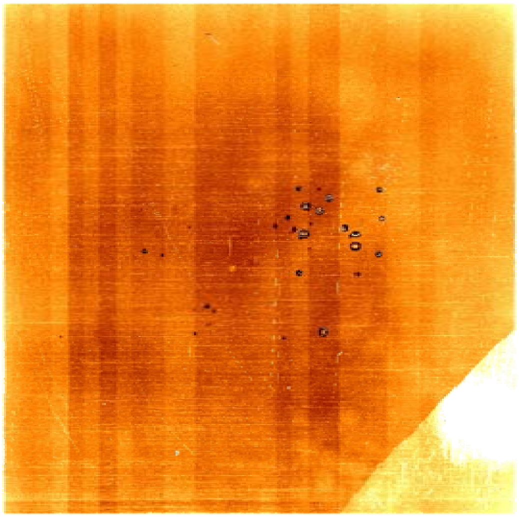




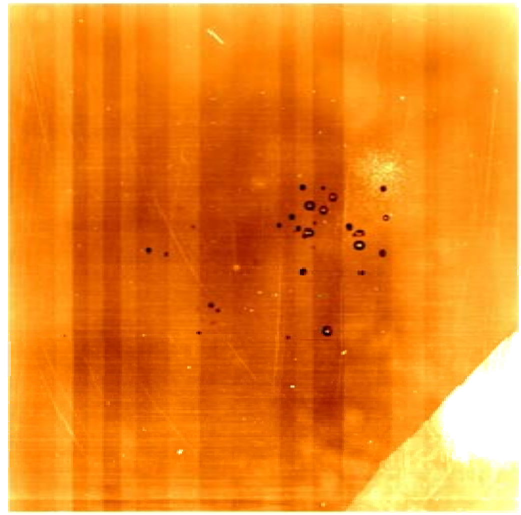
- 2-dim pixel response map scan gives a smooth response (σ ~1.9%)
- Thermal noise contribution ~ 1%

- Larger SNAP PSF (undersampled by factor 3) will yield photometric errors of <0.7%
- For critically or oversampled PSF: photometric errors negligible (<0.1%)

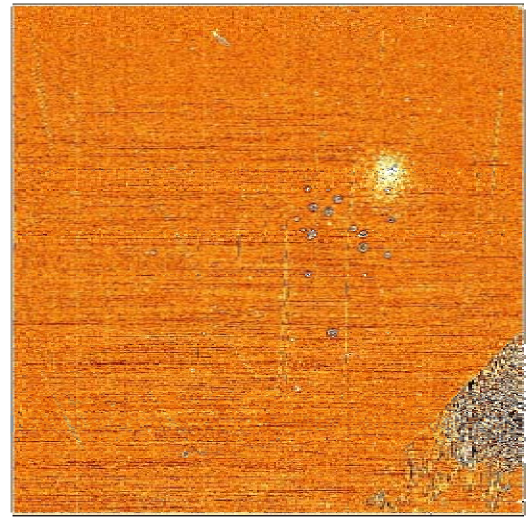
Pixel Size Variation and Flat-fielding



‘Raw’



Smoothed



Raw / Smoothed

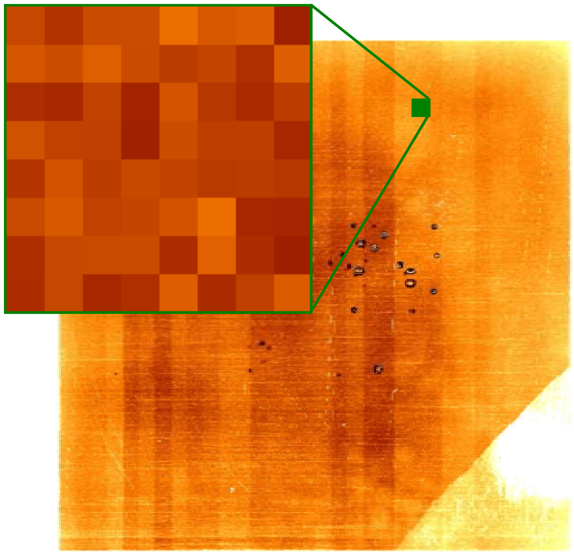
Are percent level variations on pixel scale seen in QE data caused by pixel area variations or pixel sensitivity variations?

If due to pixel area variations standard flat-fielding will degrade photometry precision for point sources in an undersampled telescope.

Low pass spatial filter preserves large scale sensitivity variations while eliminating small scale variations.

Combine QE and Spot-o-Matic data to resolve this issue.

Pixel Size Variation and Flat-fielding



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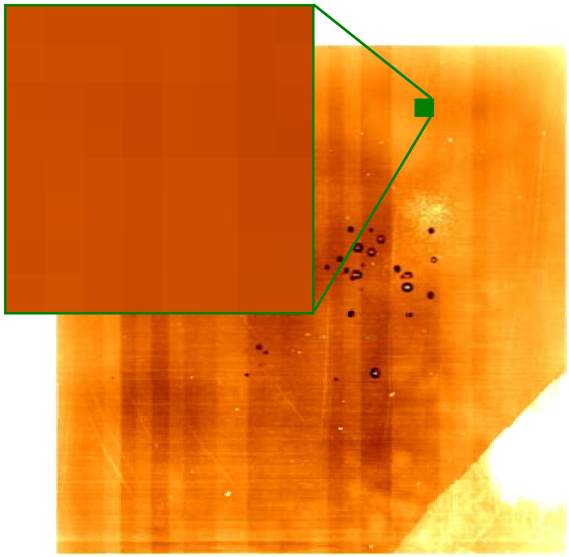

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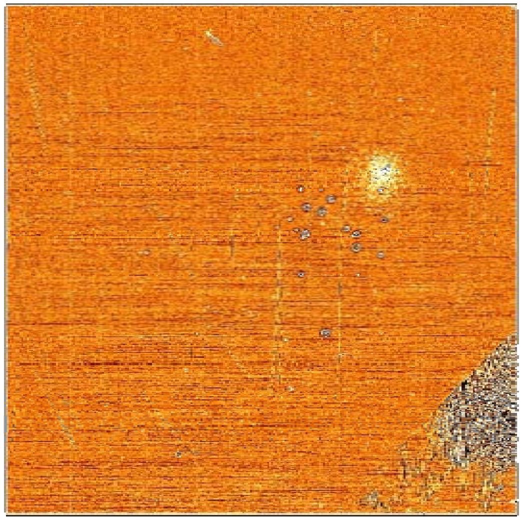

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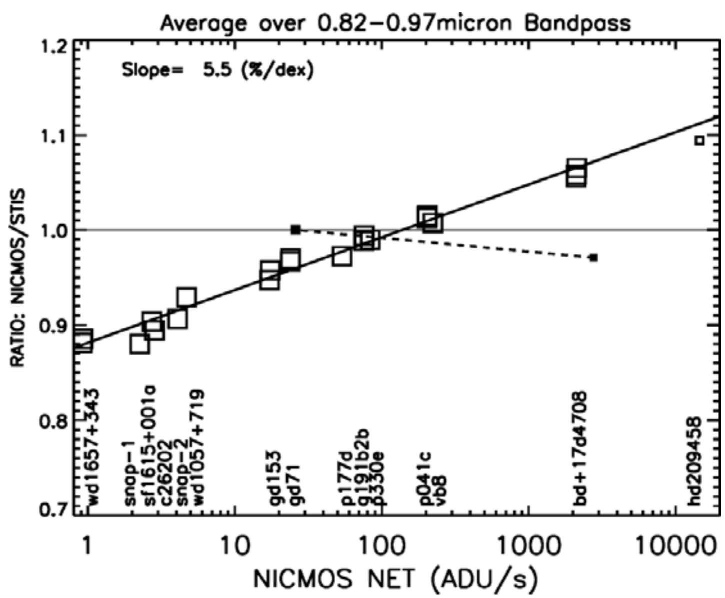
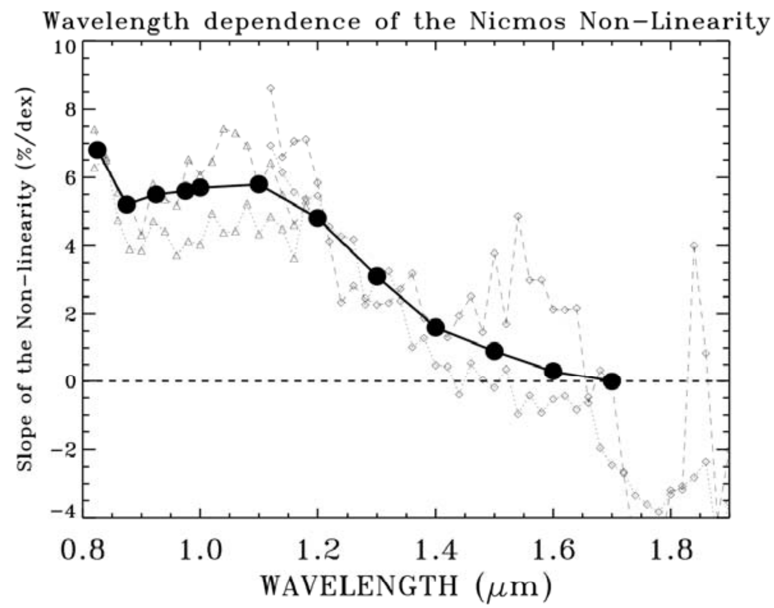
Intensity vs. Time Reciprocity

- Calibration of SNAP photometry requires observation of many standardized stars over a wide range of magnitude.
- NICMOS arrays (2.5 μm cut-off HgCdTe) on HST exhibit a 15%-25% flux- and wavelength-dependent non-linearity.

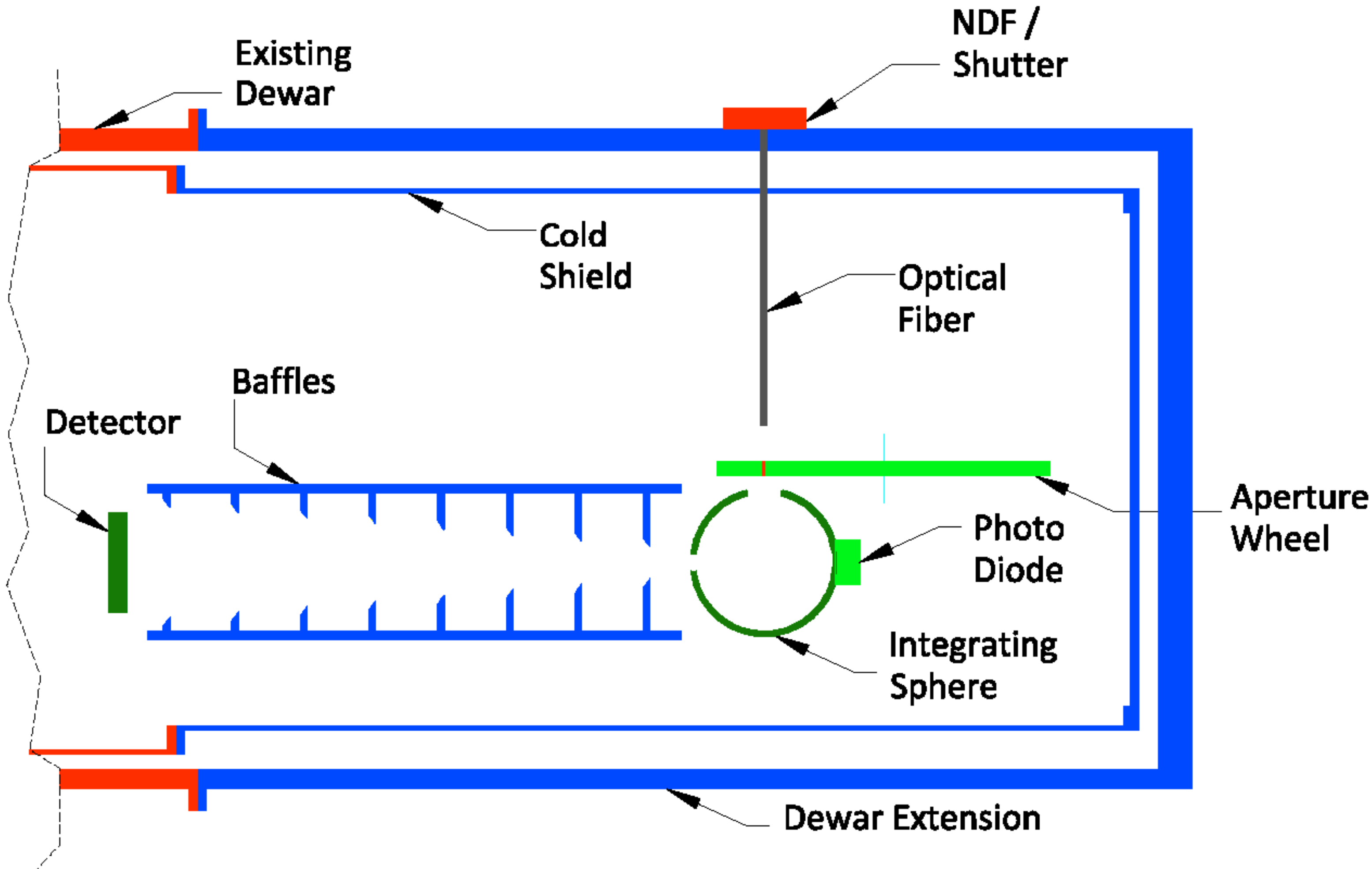




- distinctly different from well-known count-rate dependent non-linearity for NIR detectors that is due to saturation as well is filled.
- exhibits power law behavior, with pixels with high count rates detecting slightly more flux than expected for a linear system (and vice-versa).

Reciprocity Setup

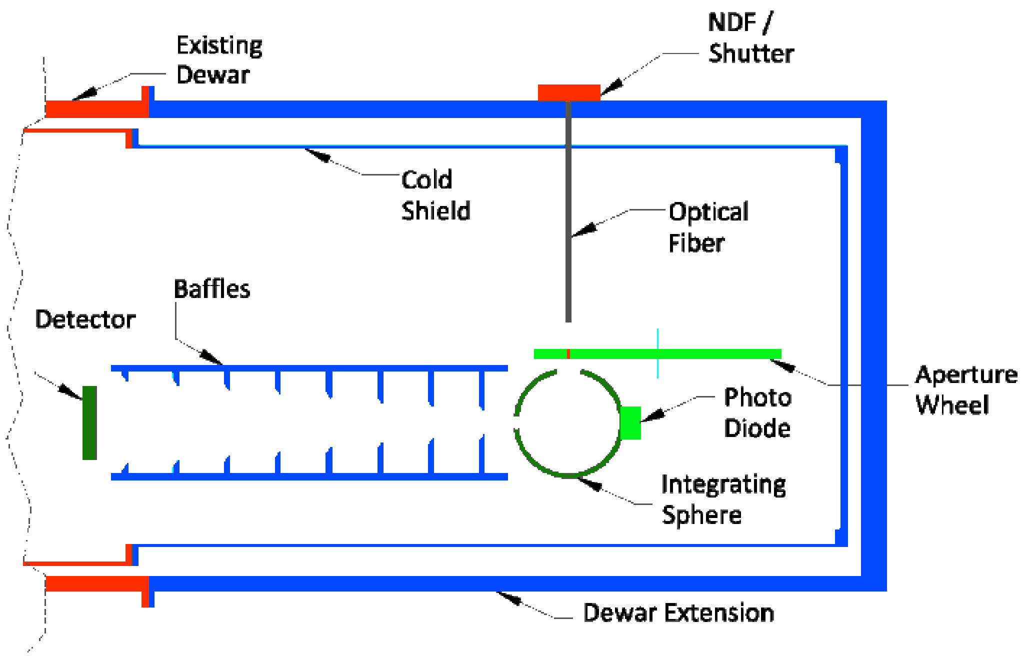
Dewar extension attaches to existing IRLabs dewar, scheduled to arrive at UM by end of May.



Reciprocity Measurements

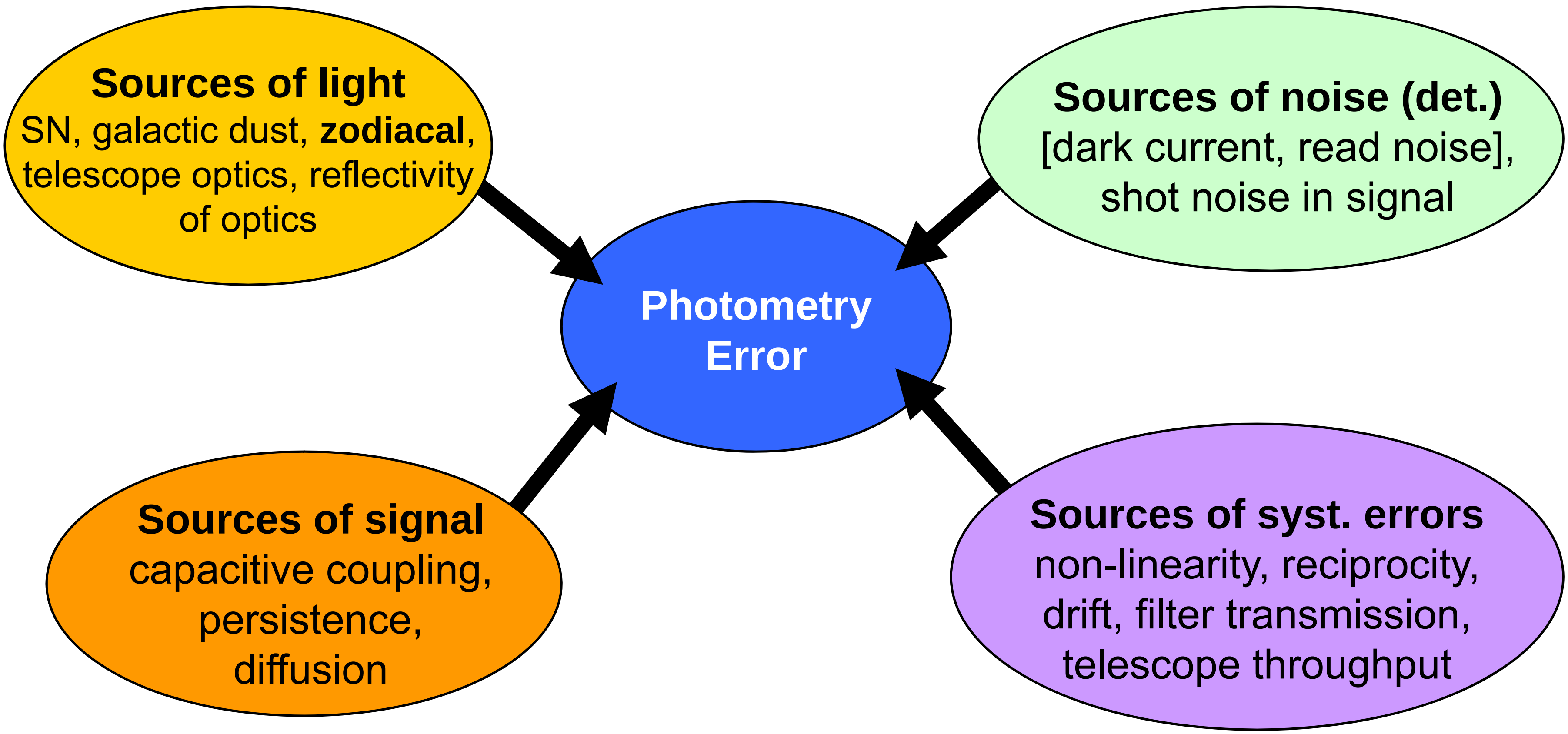
- use fixed geometry
- dynamic range: 10^5 w/ six pinholes (10μm – 3.3mm)
- aperture calibration at 140 K
- PD linearity: take ratios of aperture pairs vs light source intensity
- repeat for various band pass filters
- adjust light source intensity with ND filters to operational range of detector

- Reciprocity Measurement:
  - cycle through pin holes
  - adjust exposure time to keep N_γ constant
  - no shutter needed for HgCdTe
  - for CCDs shutter is important



SNAP NIR Photometry Error Budget

High precision photometry requires detailed understanding of all photometric errors



Need combined efforts from detector, simulation and calibration groups

Input from Calibration Group

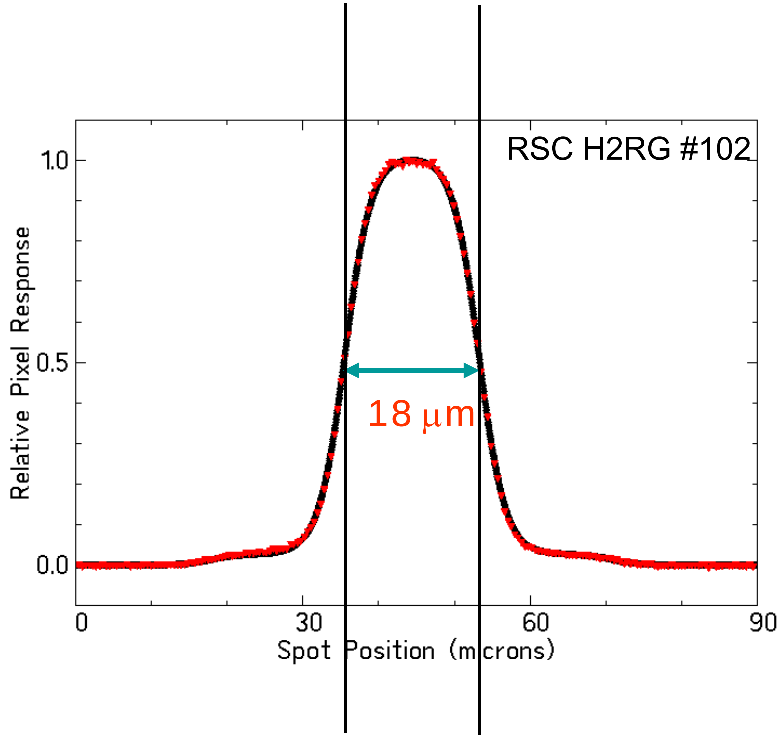
Errors in correcting for detector defects	Multiple	4 pixels in the object - root N of the pixels in the			0.0273	Source
bias + dark errors	Cal Process	Errors intrduced throught the Subtraction of Bias Frames (zero sec exposures) and of Dark Frames (same exposure time as science frames, shutter closed)			0.0025	JWST
Reference pixel correction errors	Cal Process	Track and remove drifts in the detector bias level			0.0025	JWST
non-linearity errors	Cal Process	Uncertainty is the linear response part of the detector	Characterization pre-launch		0.0050	Brown
intrapixel sensitivity	Cal Process	variation in the photometry depending on where in the pixel the centroid of the target lands	Spotomatic characterization pre launch		0.0200	Roger
reciprocity failure	Cal Process	non-linearity dur to the count rate (NOT the total count).	chareacterize in the lab, before launch		0.0500	Schubnell
IPC	Cal Process				0.0010	
persistence	Cal Process				0.0060	Brown
electronic ghosts and cross talk	Cal Process				0.0025	JWST

S. Deustua (SNAP-SLAC (Jan 2008)

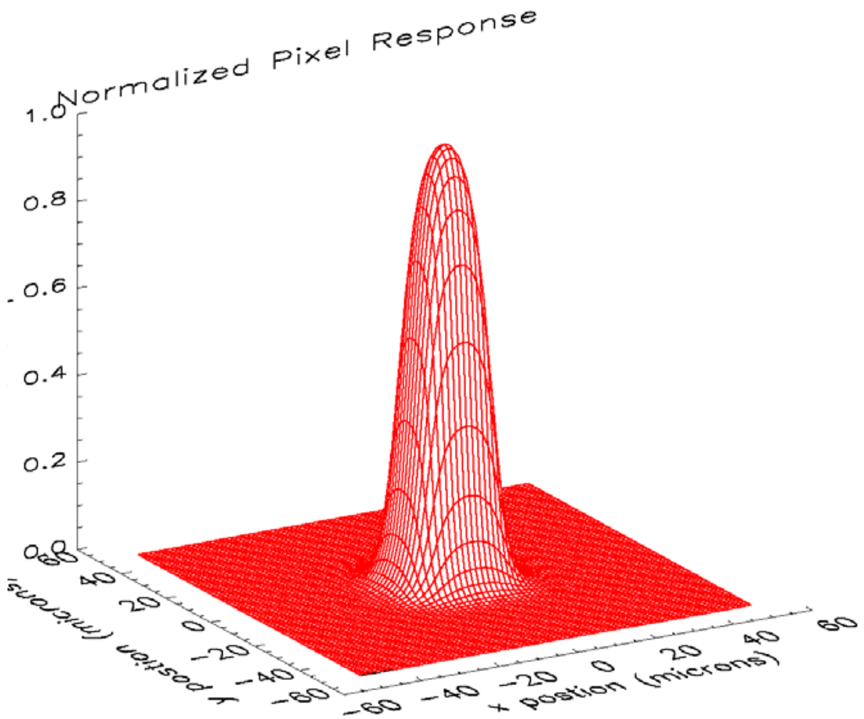
- detector contributions: 2.73% = Σ i^2 / sqrt(4)
  - receipe:
    - errors added in quadrature (best case scenario)
    - values obtained from experiments, literature or best estimates from experience
    - 0.1% assigned to uncertain/unknown quantities as “ceiling”
- reciprocity failure: largest contribution (5%)
  - if 1%: 2.73% → 1.20%
- effects of IPC & diffusion (→ intra-pixel variations) on photometry under study
- list is incomplete

Pixel level Simulations with SNAPSim

Pixel Profile Reconstruction
comparison with data



Boxcar + gaussian PSF + sech diffusion
no capacitive coupling yet

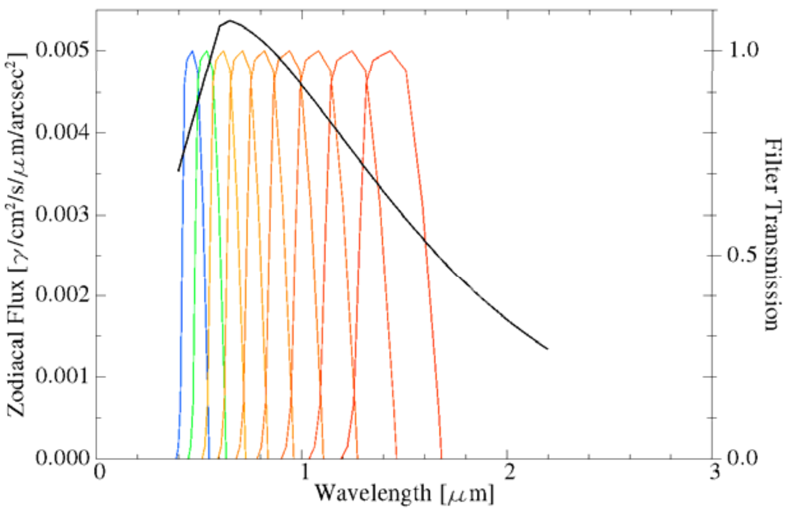


SNAPSim: 2-dim pixel profile

Limitations on Photometric Precision

Dominant noise source:

shot noise on source flux and zodiacal light, not detector RN and DC



- Zodiacal light is irreducible background
- sets scale for detector noise [<(0.5 ∗ zodi) for 300s exposure]
- noise on zodi rate/px: sqrt(0.75γ/s/px∗300s) = 15 γ/px → RN < 7 e^-/px

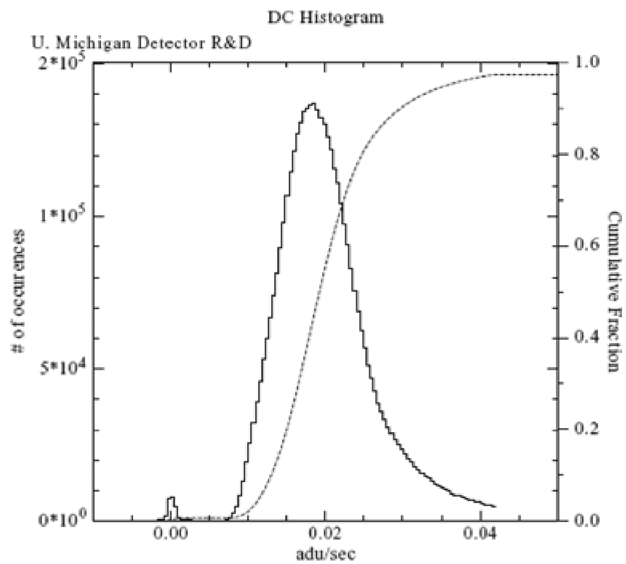
SNAP Filter	Central λ [nm]	Zodiacal Flux $\left[\frac{\gamma}{\mathrm{sr\,s}}\right]$	PSF Area [sr]	Zodiacal Rate $\left[\frac{\gamma}{\mathrm{s}}\right]$ *	N_{pix}
0	461.5	4.326×10^{11}	8.36×10^{-13}	0.362	3.62
1	530.8	5.927×10^{11}	9.16×10^{-13}	0.543	3.96
2	610.4	7.593×10^{11}	1.02×10^{-12}	0.776	4.42
3	701.9	8.853×10^{11}	1.16×10^{-12}	1.027	5.02
4	807.2	9.837×10^{11}	1.35×10^{-12}	1.328	5.84
5	928.3	8.306×10^{11}	1.59×10^{-12}	1.320	6.88
6	1067.5	1.112×10^{12}	2.25×10^{-12}	2.502	3.31
7	1227.7	1.118×10^{12}	2.68×10^{-12}	2.996	3.95
8	1411.8	1.080×10^{12}	3.25×10^{-12}	3.506	4.78

M. Brown thesis, p.87

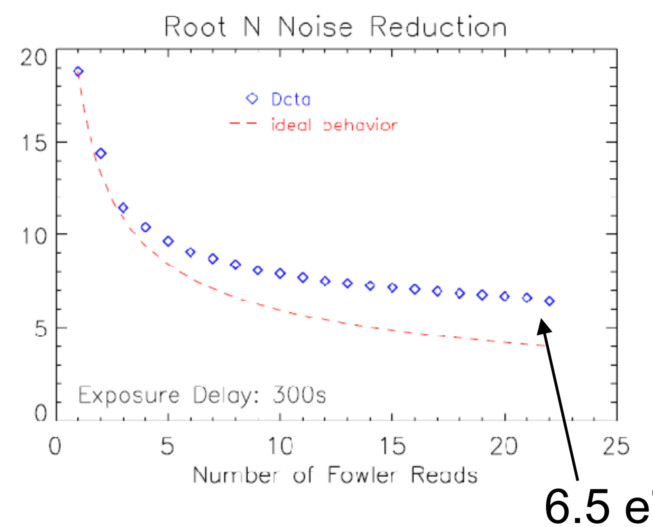
* per aperture

Sources of Detector Noise

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 *(< 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



NIR Error Budget

Detector properties	Description	Mitigation	Estimated	Measured	Source/ reference
capacitive coupling	deterministic, occurring after charge collection	Spotomatic pre-launch		?	
charge diffusion	random, occurring prior to charge collection	Spotomatic pre-launch		?	
intra-pixel variations	variations in photometry due to PSF location on pix	Spotomatic pre-launch		0.7%	Lorenzon SNAP PSF
persistence	memory of last light on pix	CIT, pre-launch	0.1%		Roger
DC + RN	combined noise spec	NIR lab, pre-launch	6.5 e^-		
shot noise	photon counting statistics				
zodiacal light	sun light scattered on dust	irreducible	15 e^-		Aldering 2001 Brown thesis, p. 87
well saturation	standard non-linearity (total count rate)	NIR lab, pre-launch		<0.1%	Schubnell
reciprocity failure	count-rate dependent non-linearity (non-standard)	NIR lab, pre-launch		?	
bias voltage drift	fluctuations in baseline signal (track with detector pix, NOT with reference pix)	NIR lab, pre-launch	0.1%?		Schubnell
Cosmic ray damage	Physical damage to pix			?	
flat field (p2p)	pix response variations due to area or QE variations	NIR lab, pre-launch		?	
dark errors	Subtraction of bias frames (0s exp) and dark frames (300s exp)	NIR lab, pre-launch		?	