Count rate dependent nonlinearity in 1.7μm cut-off NIR detectors

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SPIE Astronomical Instrumentation Conference
Marseille, 24-June, 2008

The Need for Precision Photometry

- Recent discovery of accelerated expansion of universe has started revolution in cosmology
  - evidence from SNe, galaxies, galaxy clusters and CMB
  - implication: ~70% of universe is made of "Dark Energy"
  - very little is known about nature of Dark Energy:
    - Λ, quintessence, GR break down, higher dim, axions, etc
    - any option has profound implications
- To determine nature of Dark Energy is difficult task
  - dark energy programs measure w(a) and its evolution with time
  - combination of several observational techniques are needed:
    - SNe (standard candles), weak lensing, galaxy clusters, BAO
- Must rely of accurate distance measurements over cosmic scales

  → rely on precise photometry (1%-2% level)
- An example:
  - failure to measure peak brightness of type-Ia SNe at % level would not allow to constrain cosmological parameters at required levels!

NIR Precision Photometry

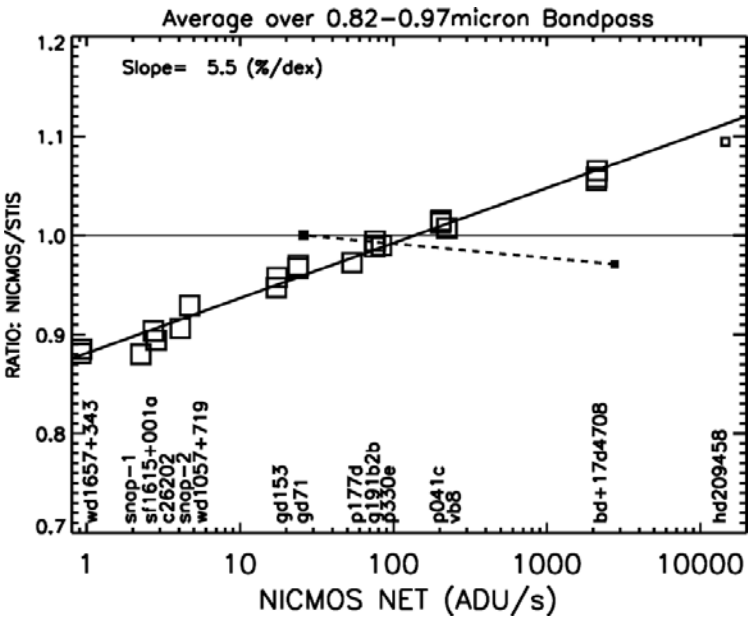
- Precision photometry is essential to the science goals of any Dark Energy mission and will require low noise, high QE detectors with a high degree of sub-pixel uniformity and stability.

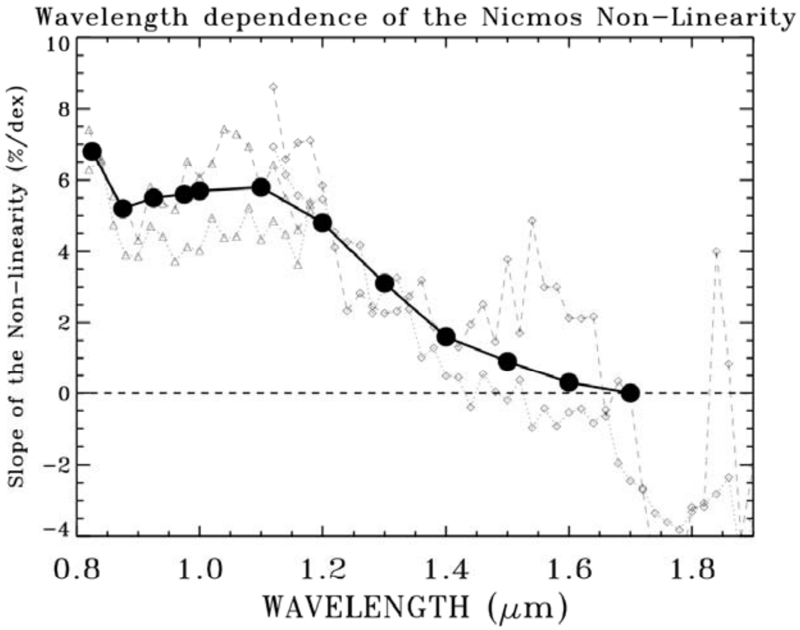
- Precision photometry at the 1% level presents new challenges for an undersampled survey telescope:
  - Intra-pixel variation (Spot-o-Matic: <2% for any PSF)
  - Pixel size variation and flat-fielding (<1% in HgCdTe)
  - Reciprocity failure (count rate non-linearity: ~5%/dex)

- What is needed to close the chapter on NIR precision photometry?
  - Potentially large count rate non-linearity in 1.7 μm cut-off HgCdTe detectors
    - Not observed in CCDs (<1% ?)
  - Determine pixel size variation and effect from flat-fielding

Count Rate Non-linearity

- Photometry calibration for DE missions requires observation of many standardized stars (and internal ref. syst.) 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

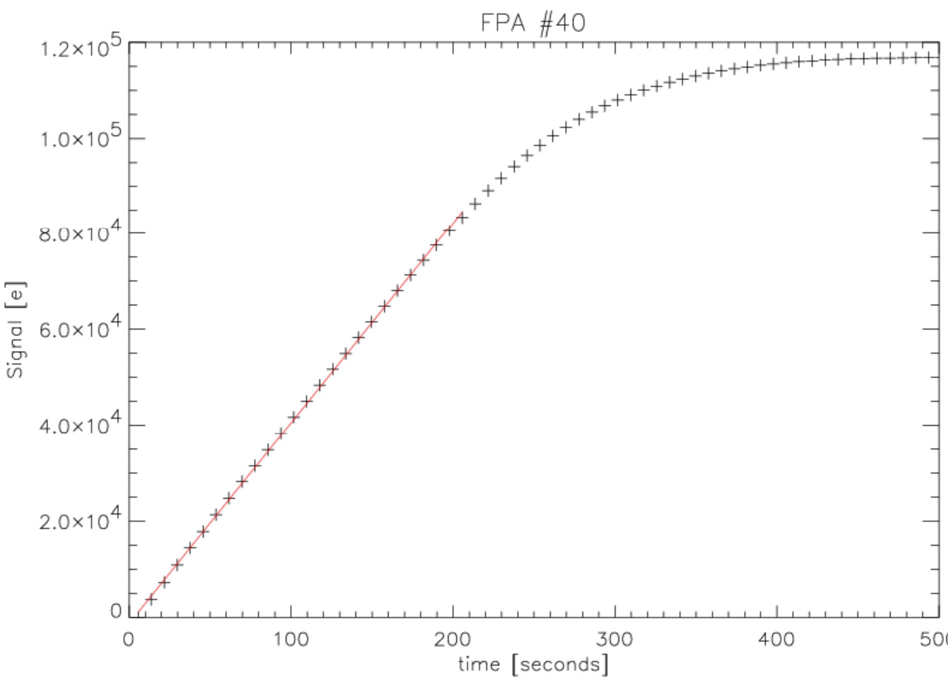


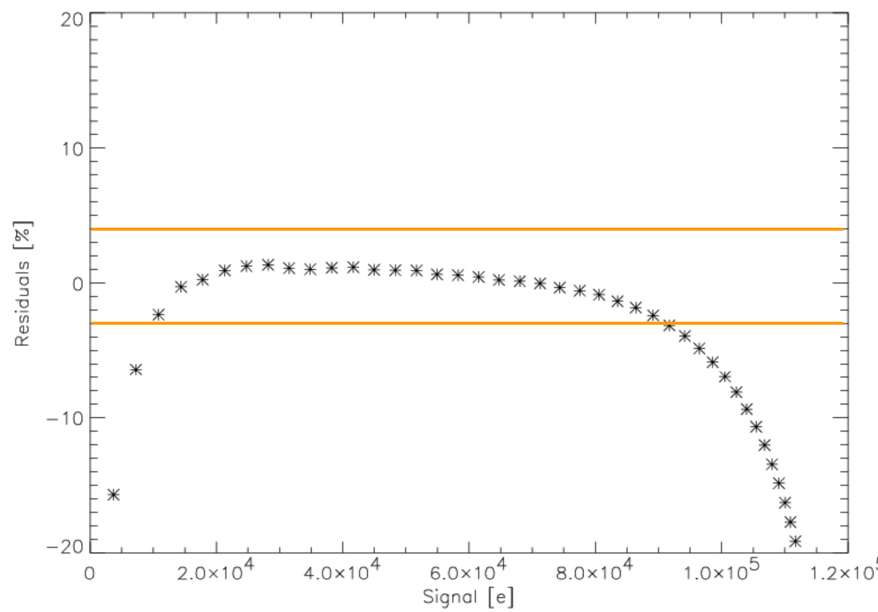


- exhibits power law behavior, with pixels with high count rates detecting slightly more flux than expected for a linear system (and vice-versa)
- effect strongly reduced at higher wave lengths

Classic Well Depth Nonlinearity

- NICMOS nonlinearity distinctly different from well-known total count dependent nonlinearity for NIR detectors (due to saturation as well is filled)





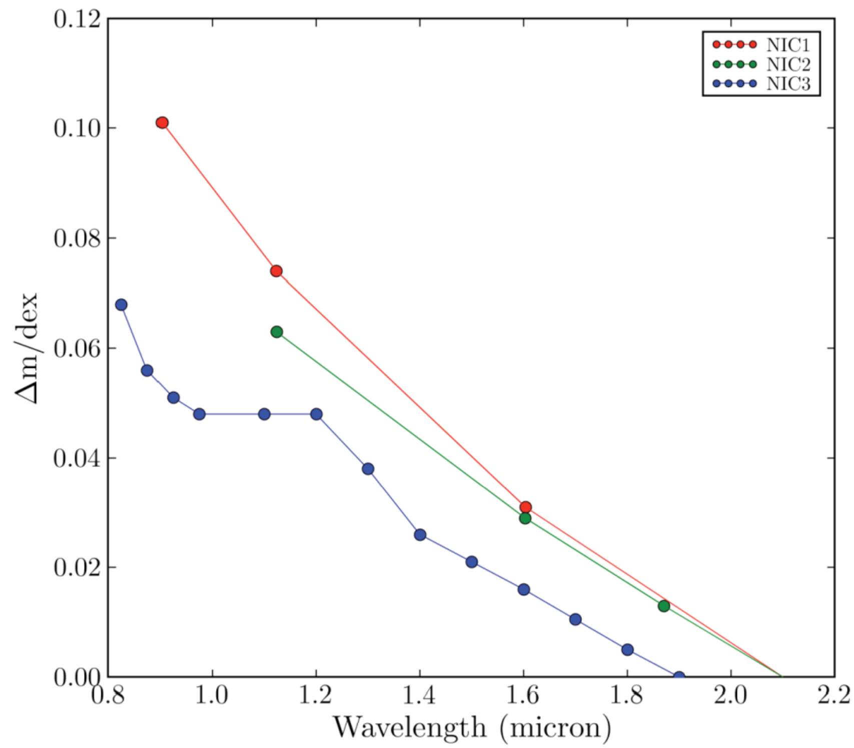
- full integration capacity (RSC FPA H2RG-32-040) is $1.17 \cdot 10^5$ e^-
- linearity is maintained within ±3% up to 80% of the full integration capacity

NICMOS Reciprocity Failure

- NICMOS is known to have a flux dependent non-linearity (15-25% effect) (ISR 2005-002)
- This is correctable assuming power law

$$\text{count rate} \propto \text{flux}_{\text{tot}}^{\alpha(\lambda)}$$

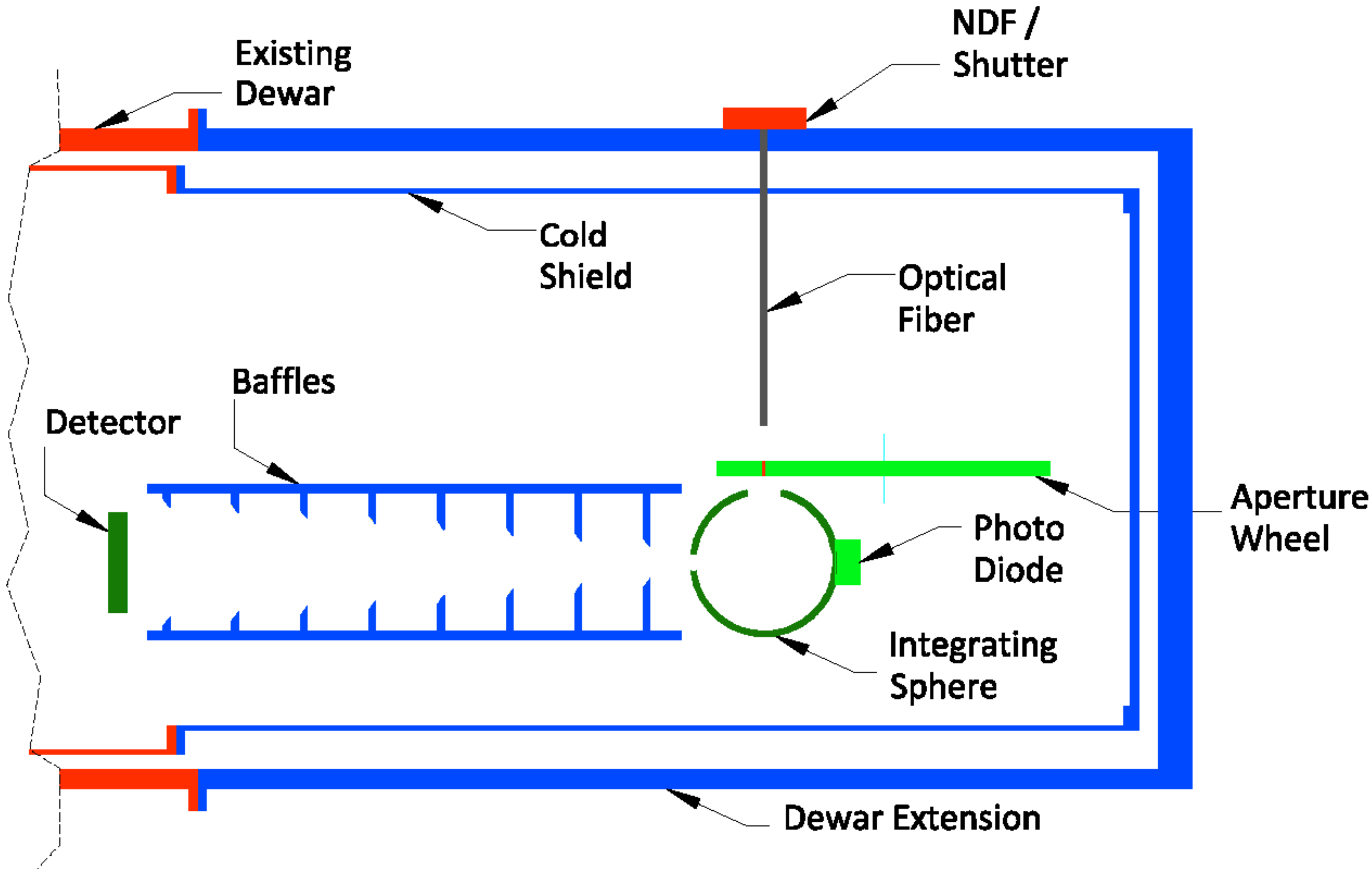
- for non-linearity ~5%/dex :
  α=1.02 → Δm=2.5(α-1)/dex



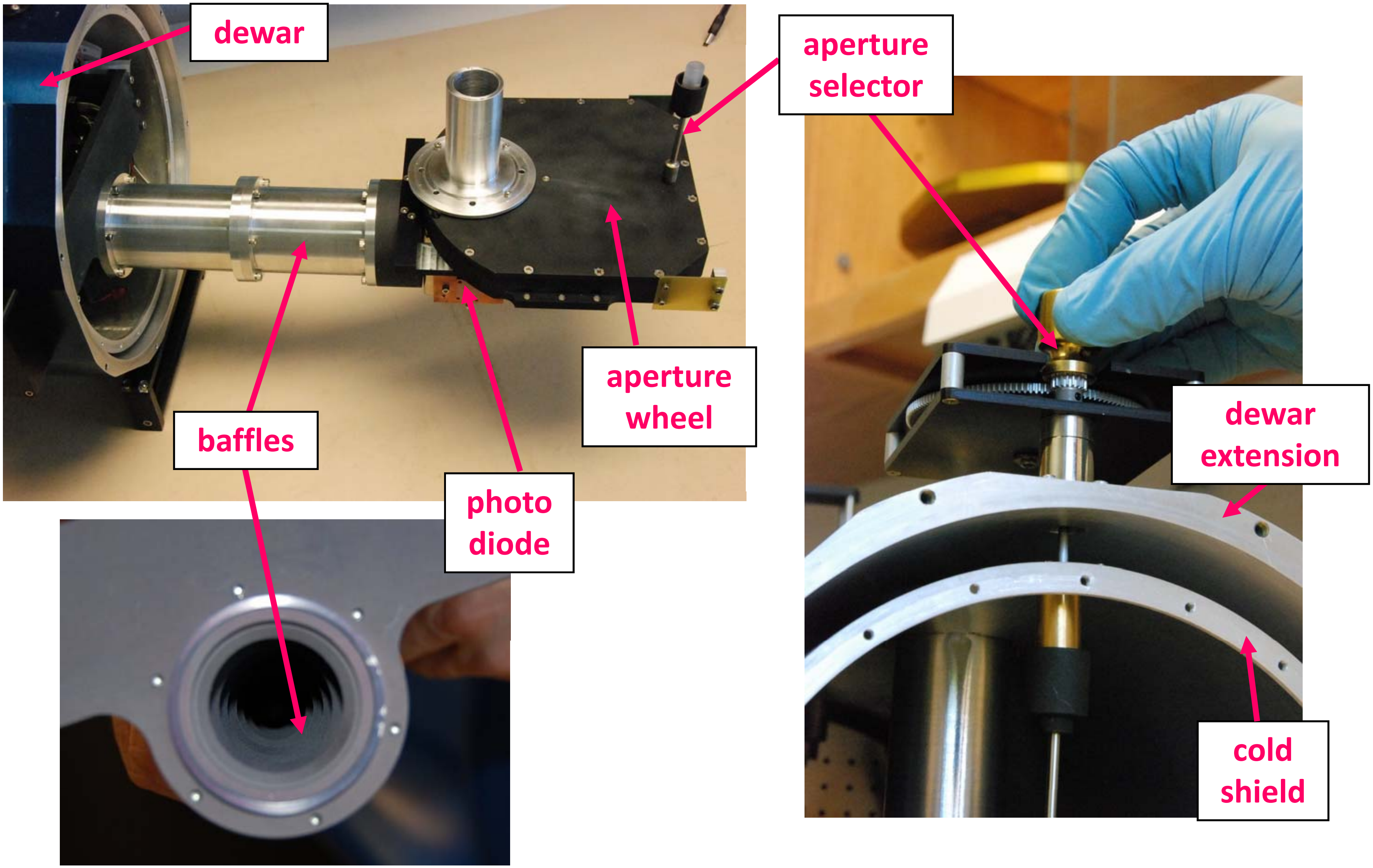
- Corrections known to within 10% (ISR 2006-003)
- Further efforts to reduce from 10% → 5% (ISR 2007-004)
- These pixel level uncertainties impact photometry, as they directly propagate into estimated uncertainties on derived magnitudes

UM Reciprocity Setup

Dewar extension attaches to existing IRLabs dewar



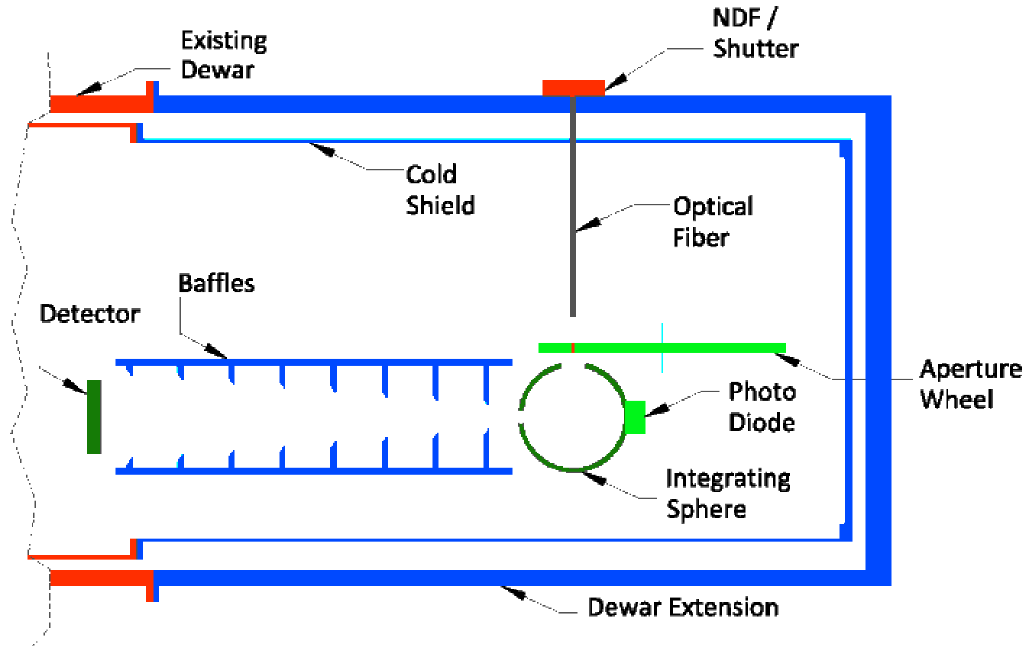
UM Reciprocity Setup



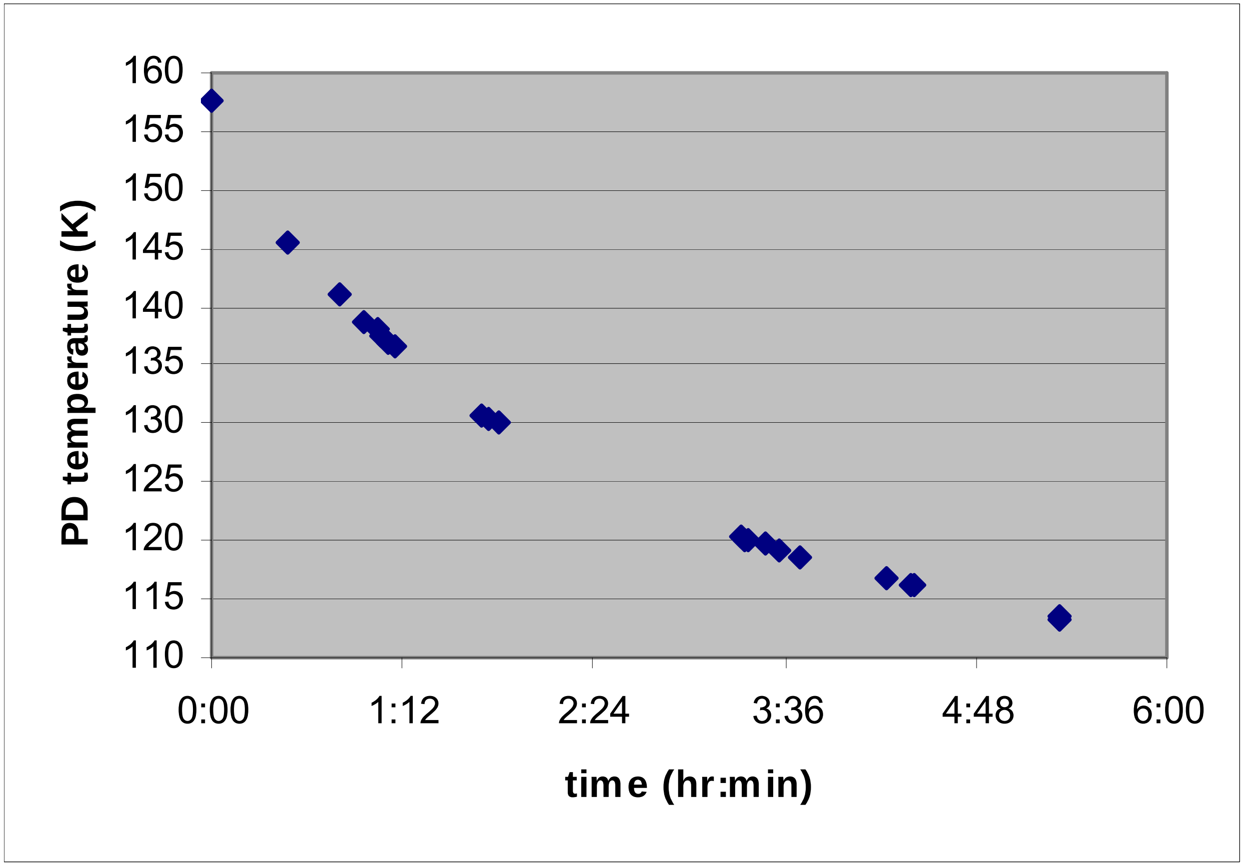
Reciprocity Measurement Scheme

- use fixed geometry
- dynamic range: 10^5 w/ six pinholes (10μm – 3.3mm)
- aperture calibration at ~120 K (not temperature stabilized)
- 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:
  - keep detector at 140 K
  - cycle through pin holes
  - adjust exposure time to keep N_γ constant
  - no shutter needed for HgCdTe
  - for CCDs shutter is important

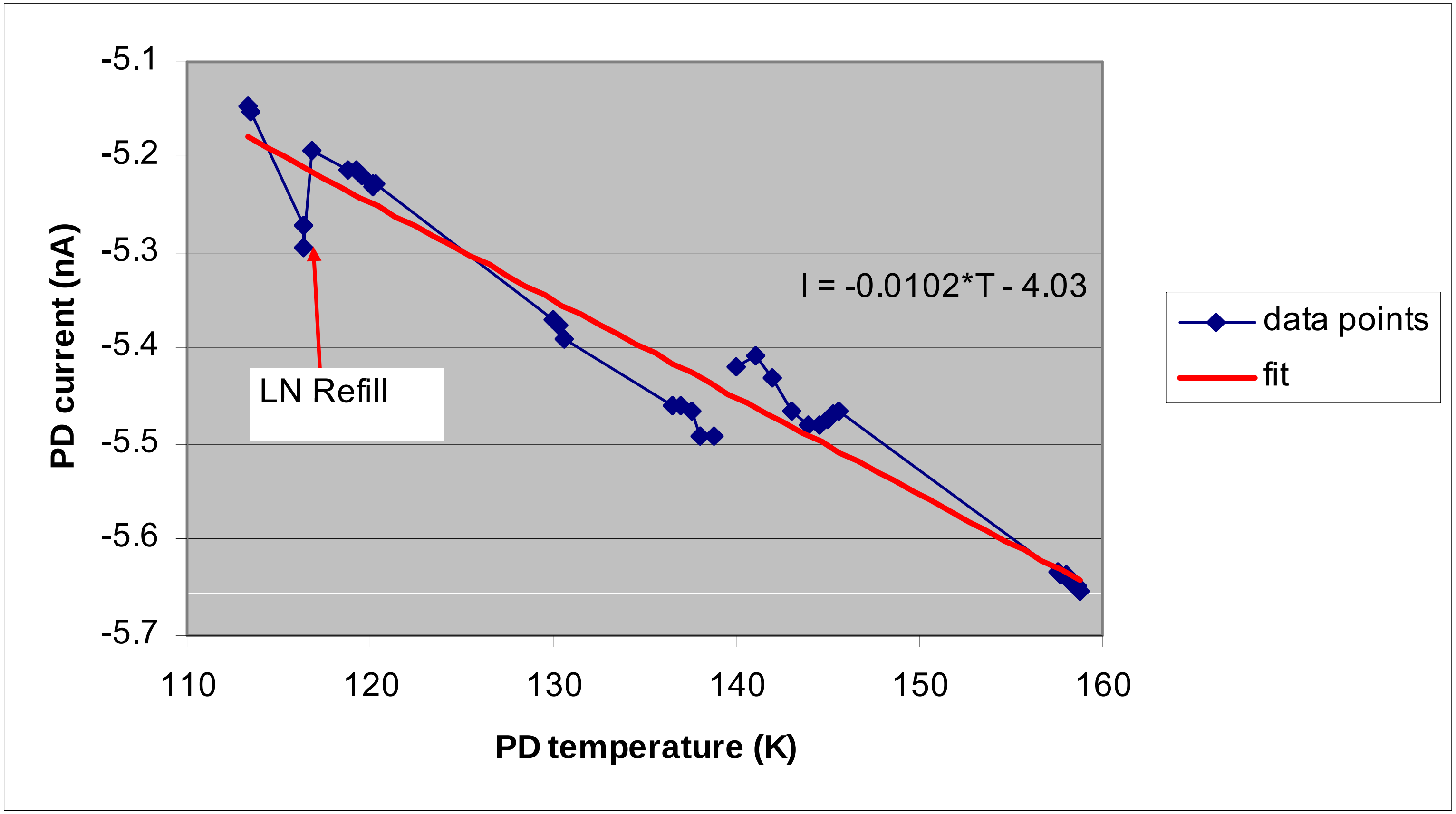


Dewar Extension Cool-down



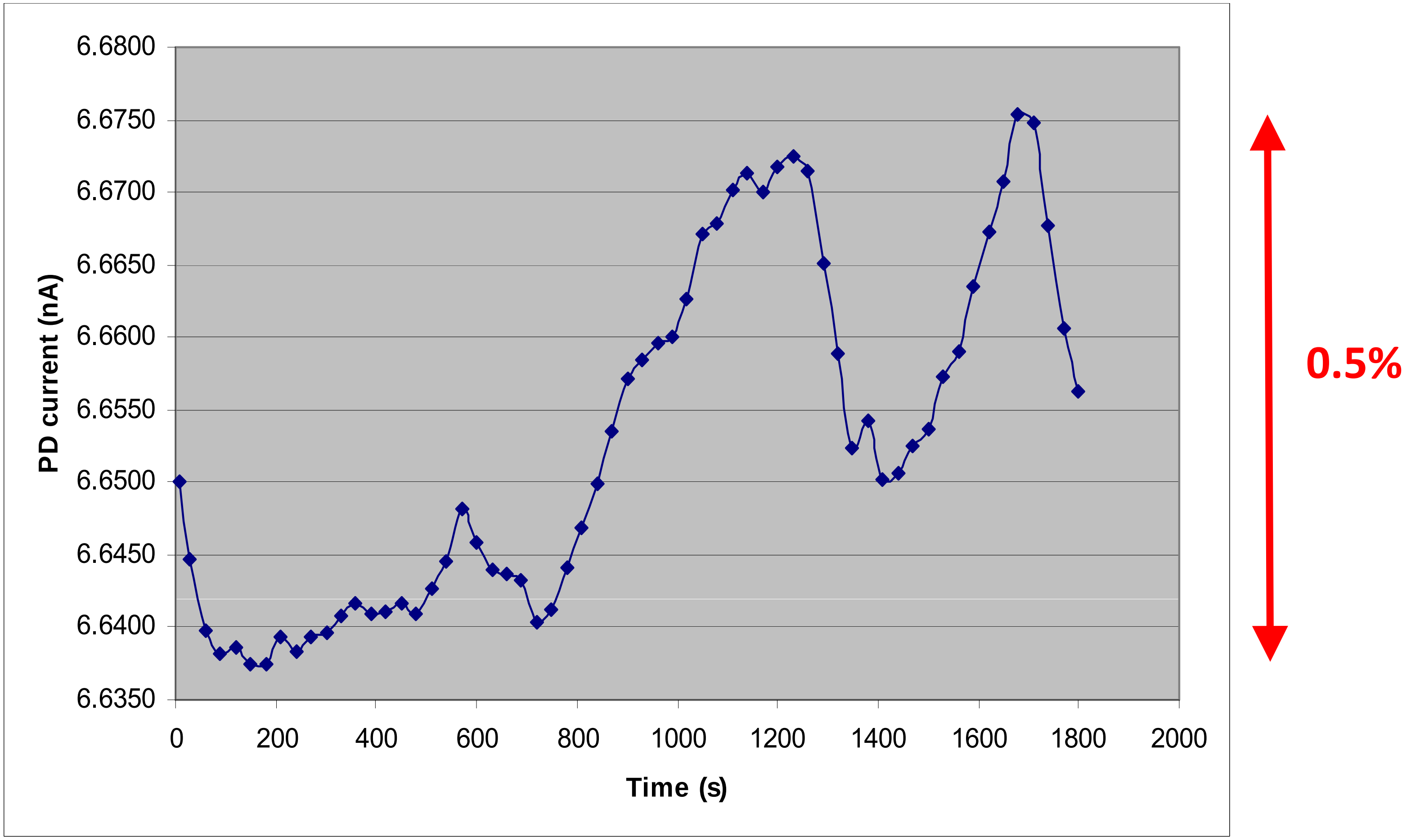
- Dewar extension temperature drops slowly with time

Photo Diode Stability



- The PD displays a temperature dependence of 0.2%/K
  → long exposures need to be corrected for change in PD temperatures
  → add temperature control to PD

Lamp Stability



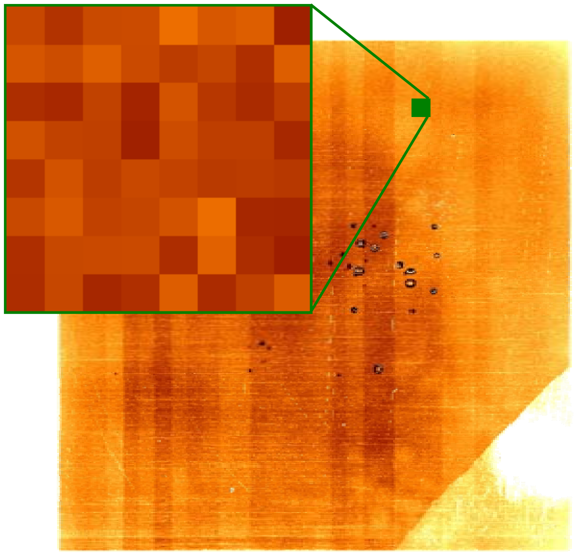
- quartz tungsten halogen lamp shows instabilities of ~0.5% over a 30 min time interval (constant current mode)
  → can be reduced to ~0.1% with active feedback

Reciprocity Measurements: To do

- Now that stability of the reciprocity setup is characterized, need to:
  - do aperture calibration
  - check PD linearity
  - do reciprocity measurements

- Can be preformed on HgCdTe, CCDs, …
  - a detector specific mounting plate needs to be machined
    → allow for fast turn around time if detectors available only for short time

Pixel Size Variation and Flat-fielding



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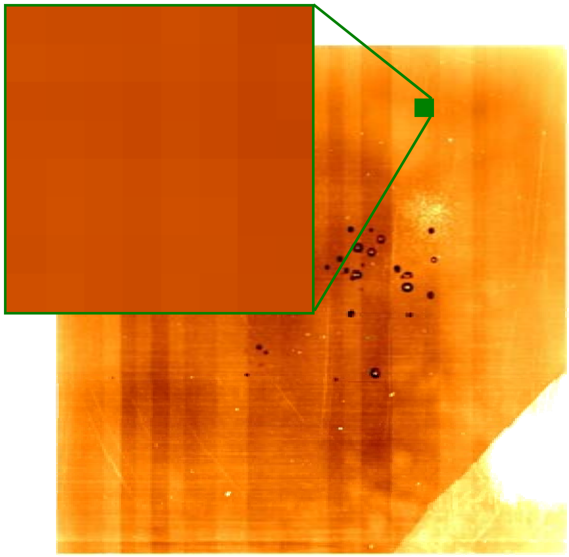
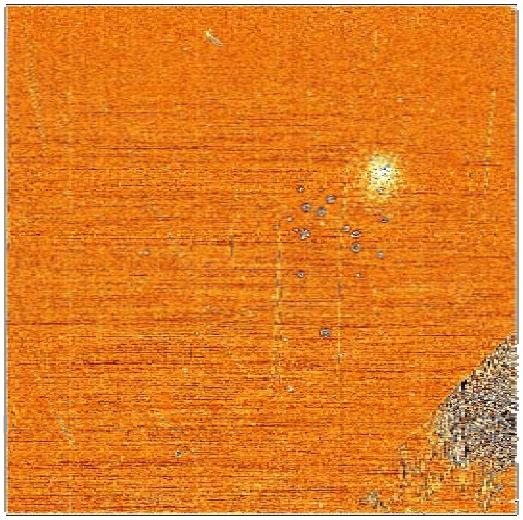


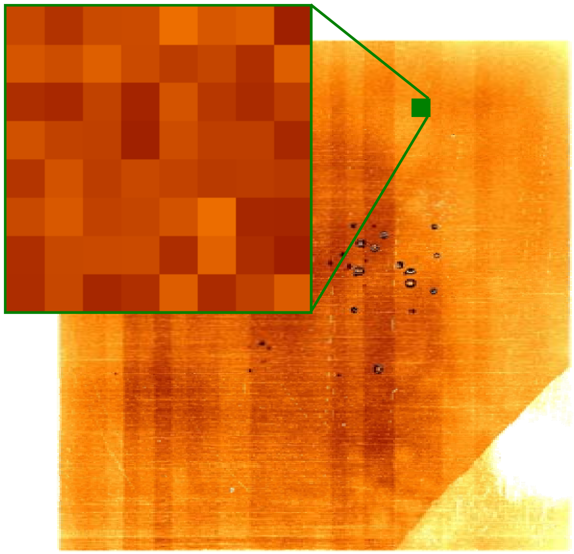
Smoothed



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 ?



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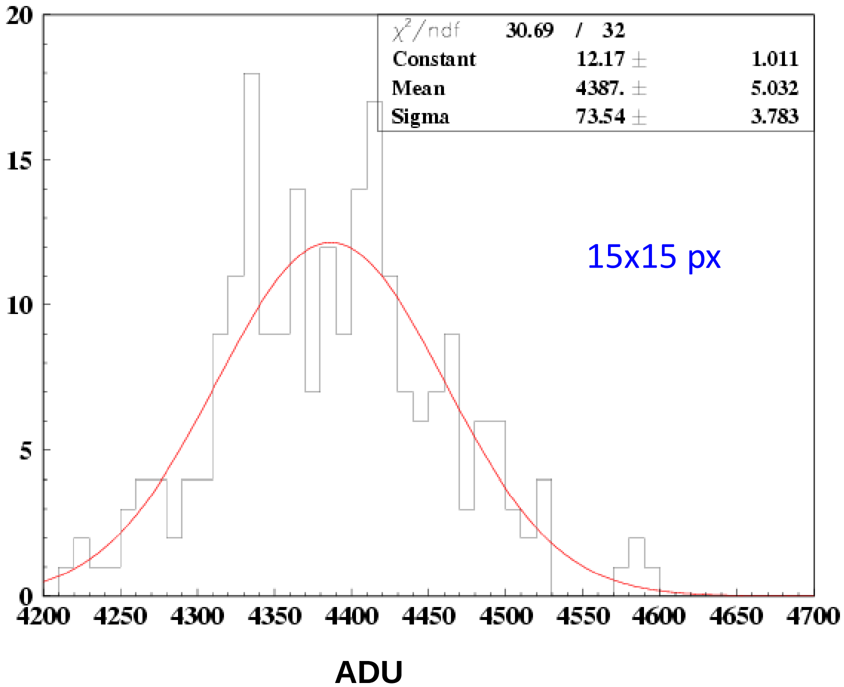
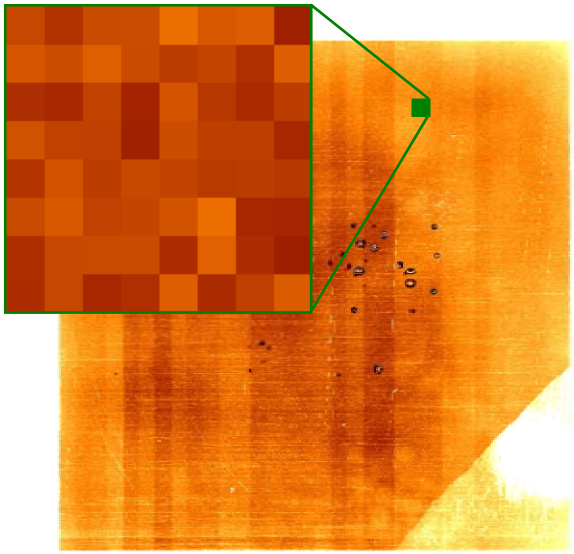


- single spectrum (15x15 px):
  pixel response: σ~1.8% (expected from Poisson stat: ~1.6%)
  → due to area variations?

Pixel Size Variation ?



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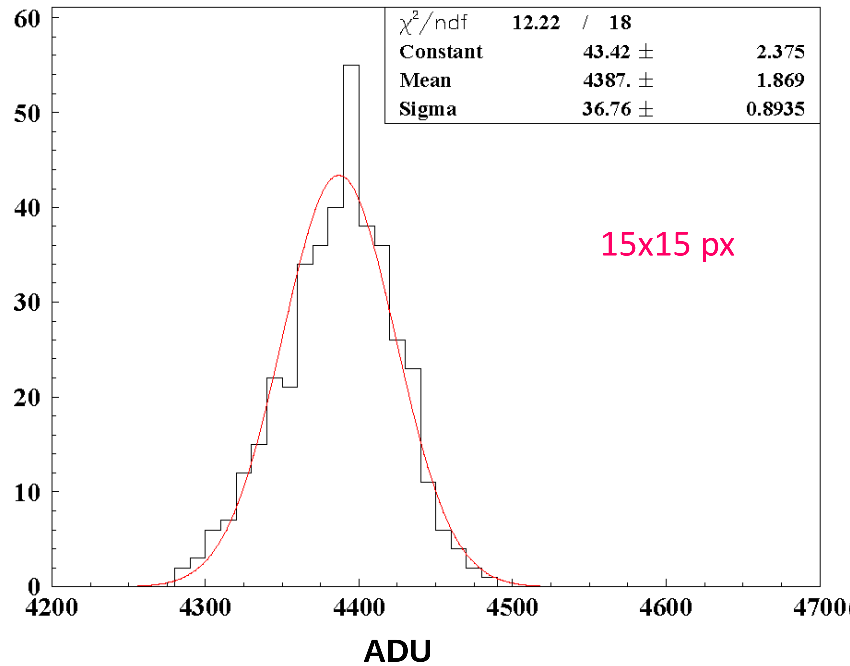
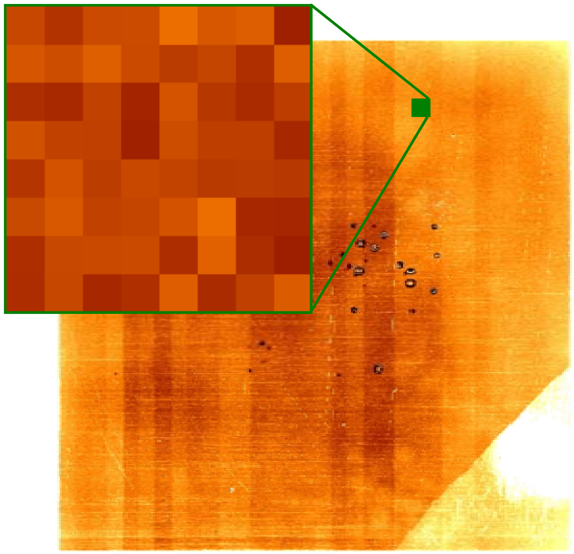


- single spectrum (15x15 px):
  pixel response: σ~1.8% (expected from Poisson stat: ~1.6%)
  → due to area variations?

- 100 spectra (15x15 px):
  pixel response: σ~0.8% (expected from 1/√N: 0.18%)

Pixel Size Variation ?



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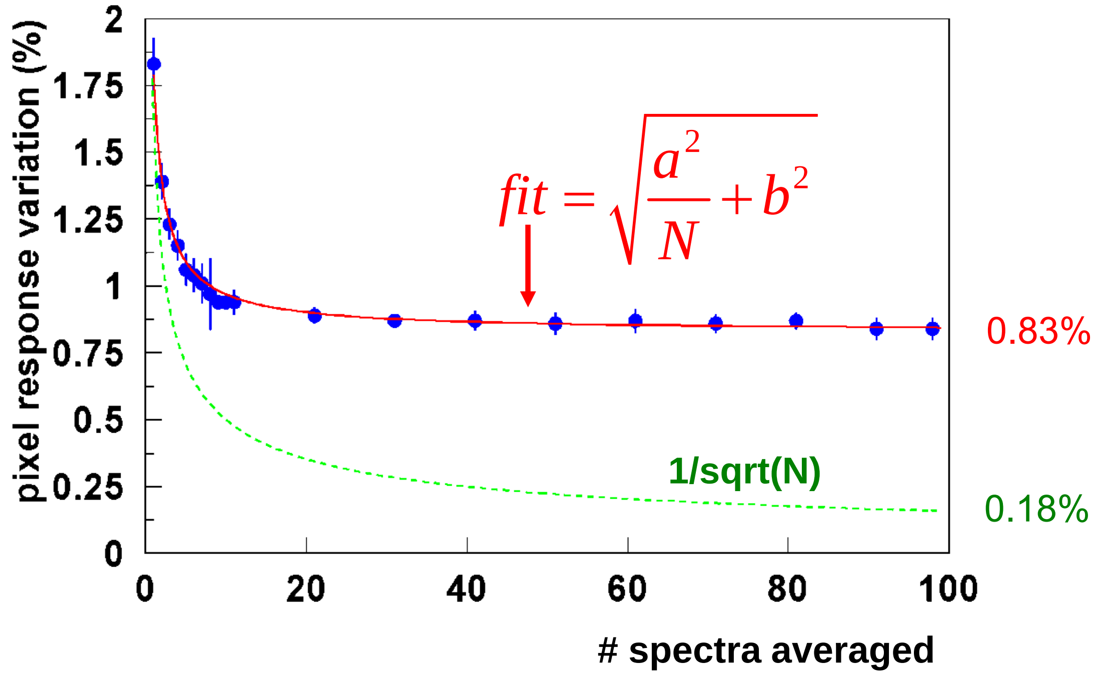

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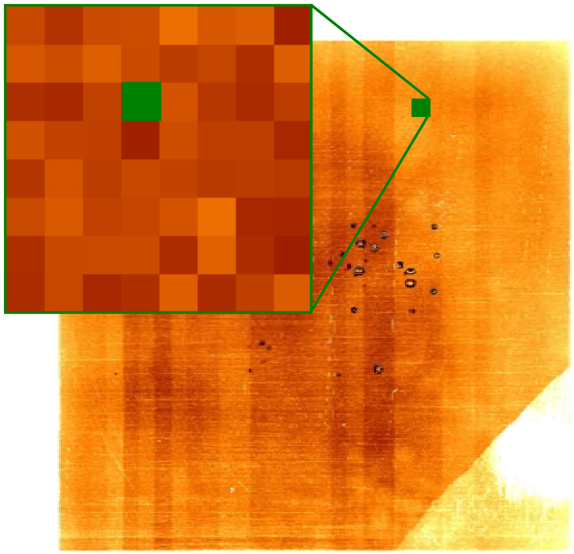

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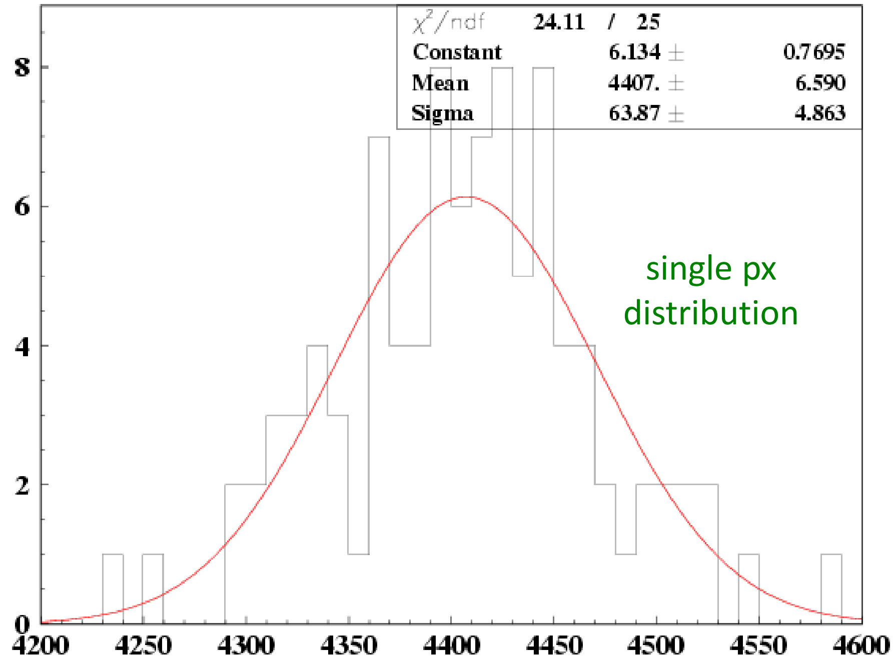
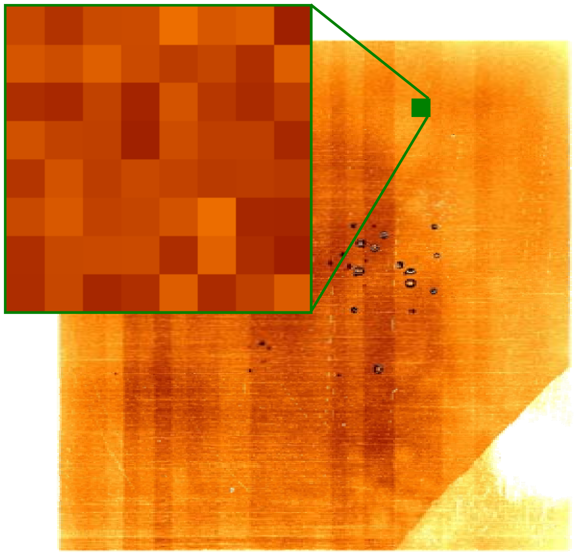


- single spectrum (15x15 px):
  pixel response: σ~1.8% (expected from Poisson stat: ~1.6%)
  → due to area variations?
- 100 spectra (15x15 px):
  pixel response: σ~0.8% (expected from 1/√N: 0.18%)
- 100 spectra (1 px):
  eliminate pixel area, QE, gain, … effects: σ~1.6% (as expected from stat)

Pixel Size Variation ?



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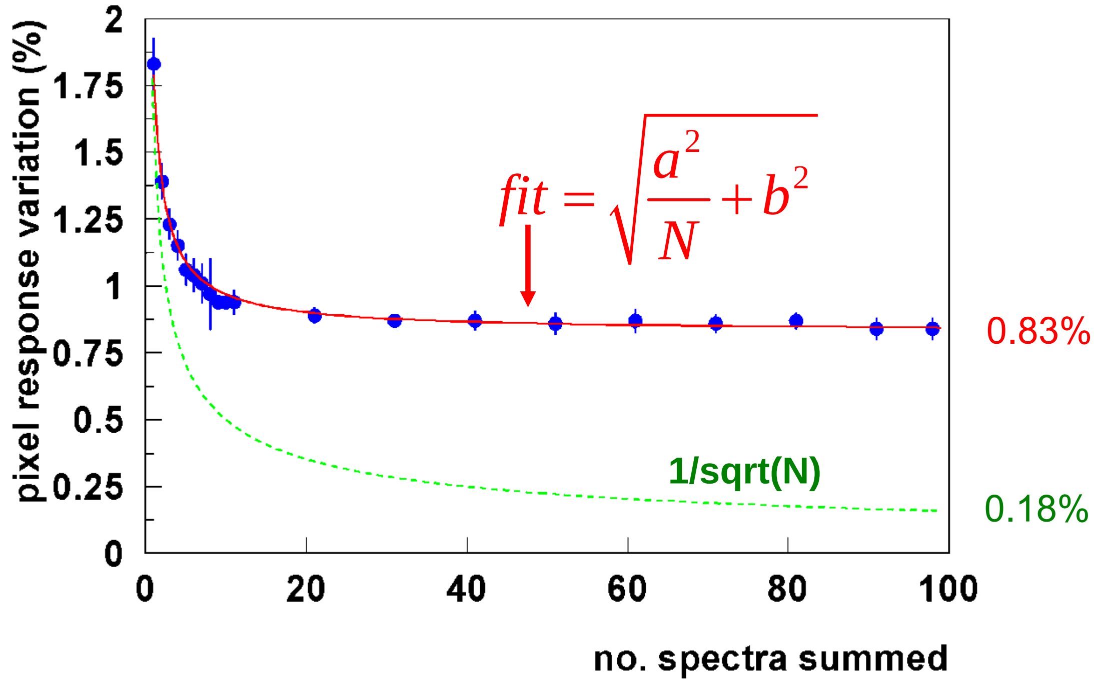

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  pixel response: σ~1.8% (expected from Poisson stat: ~1.6%)
  → due to area variations?
- 100 spectra (15x15 px):
  pixel response: σ~0.8% (expected from 1/√N: 0.18%)
- pixel response variations: pixel size, QE, gain, … variations ?
  → pixel area variations: σ<0.8% (~0.4% in linear dim)
  → effect on flat-fielding needs to be quantified