Limits on Reciprocity Failure in 1.7μm cut-off NIR astronomical detectors

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The Need for Precision Photometry

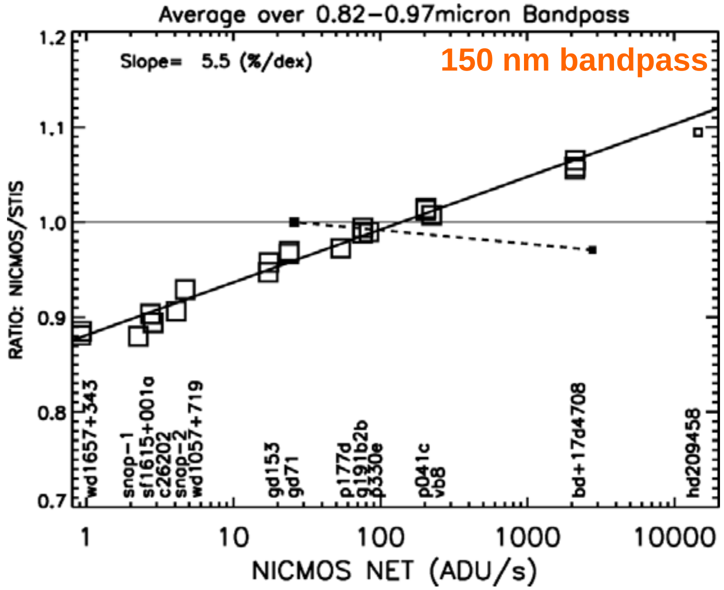
- Recent discovery of accelerated expansion of universe has started revolution in cosmology
  - evidence from SNe, galaxies, galaxy clusters and CMB
  - implication: ~70% of universe is made of "Dark Energy"
  - very little is known about nature of Dark Energy:
    - Λ, quintessence, GR break down, higher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

  $\rightarrow$ rely on precise photometry (1%-2% level)
- Photometric calibrations require observations of many standardized stars over a wide range of magnitude

  $\rightarrow$ rely on complete understanding of the linearity of the detectors

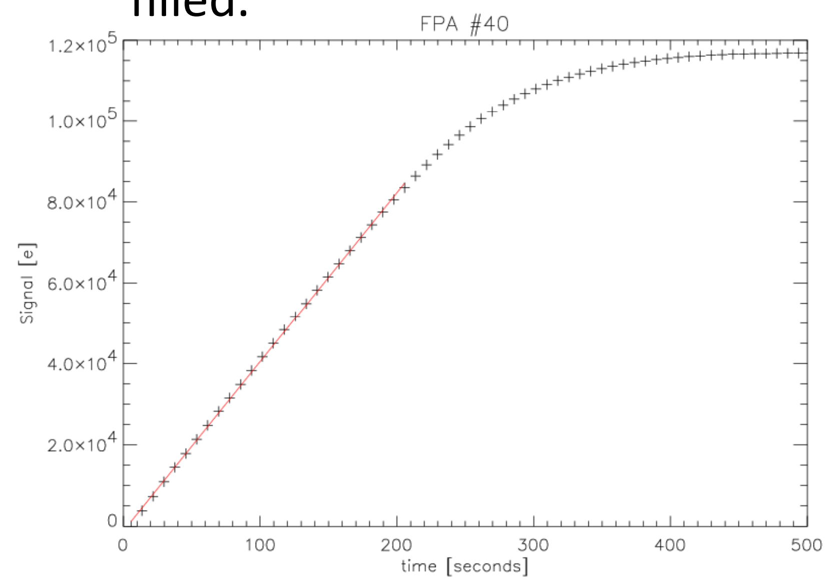
Reciprocity vs Saturation

- NICMOS arrays (2.5 μm cut-off HgCdTe) on HST exhibit a 5-6%\dex flux 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).

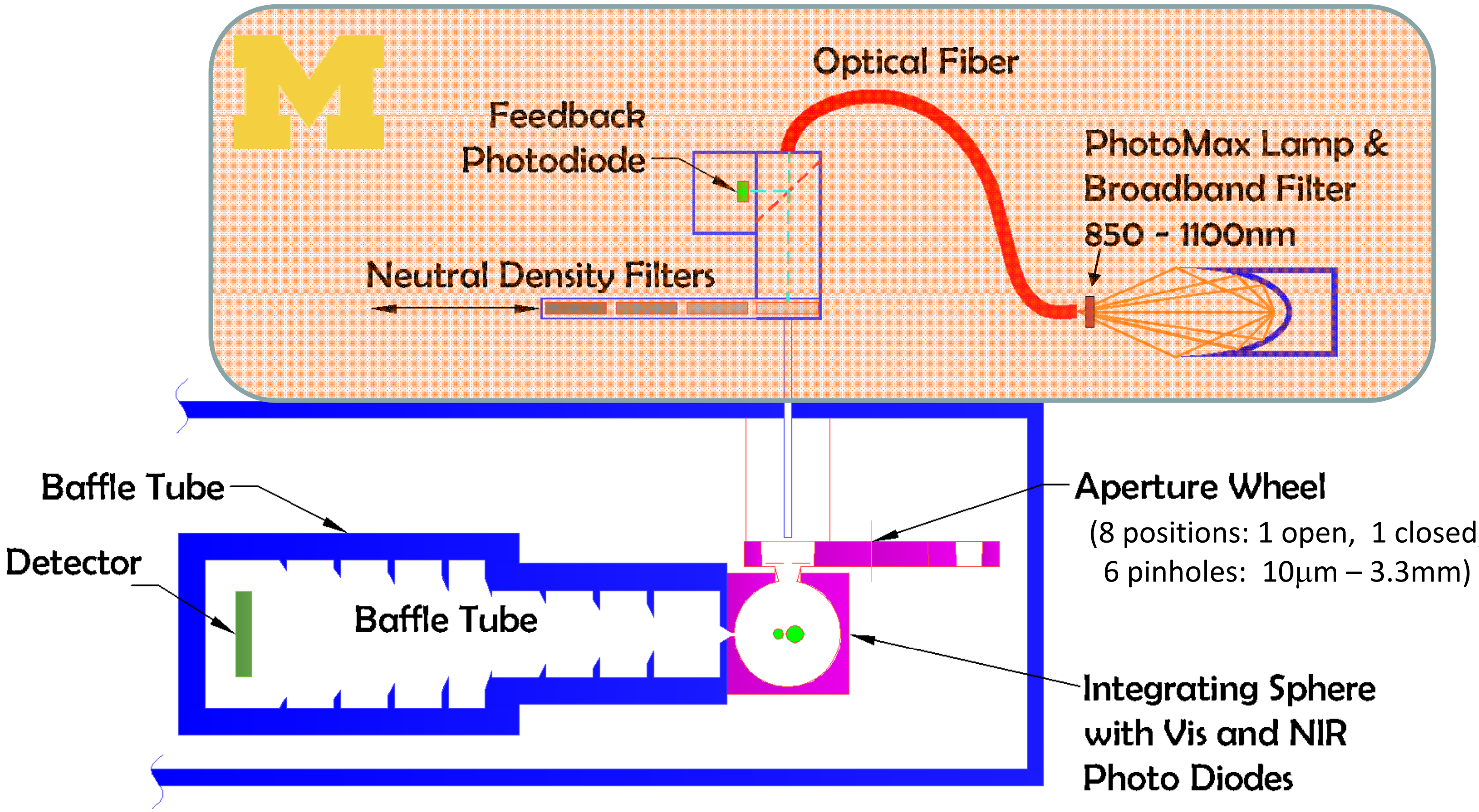
- distinctly different from well-known total count dependent non-linearity for NIR detectors that is due to saturation as well is filled.



- linearity is maintained within ±3% up to 80% of the full integration capacity

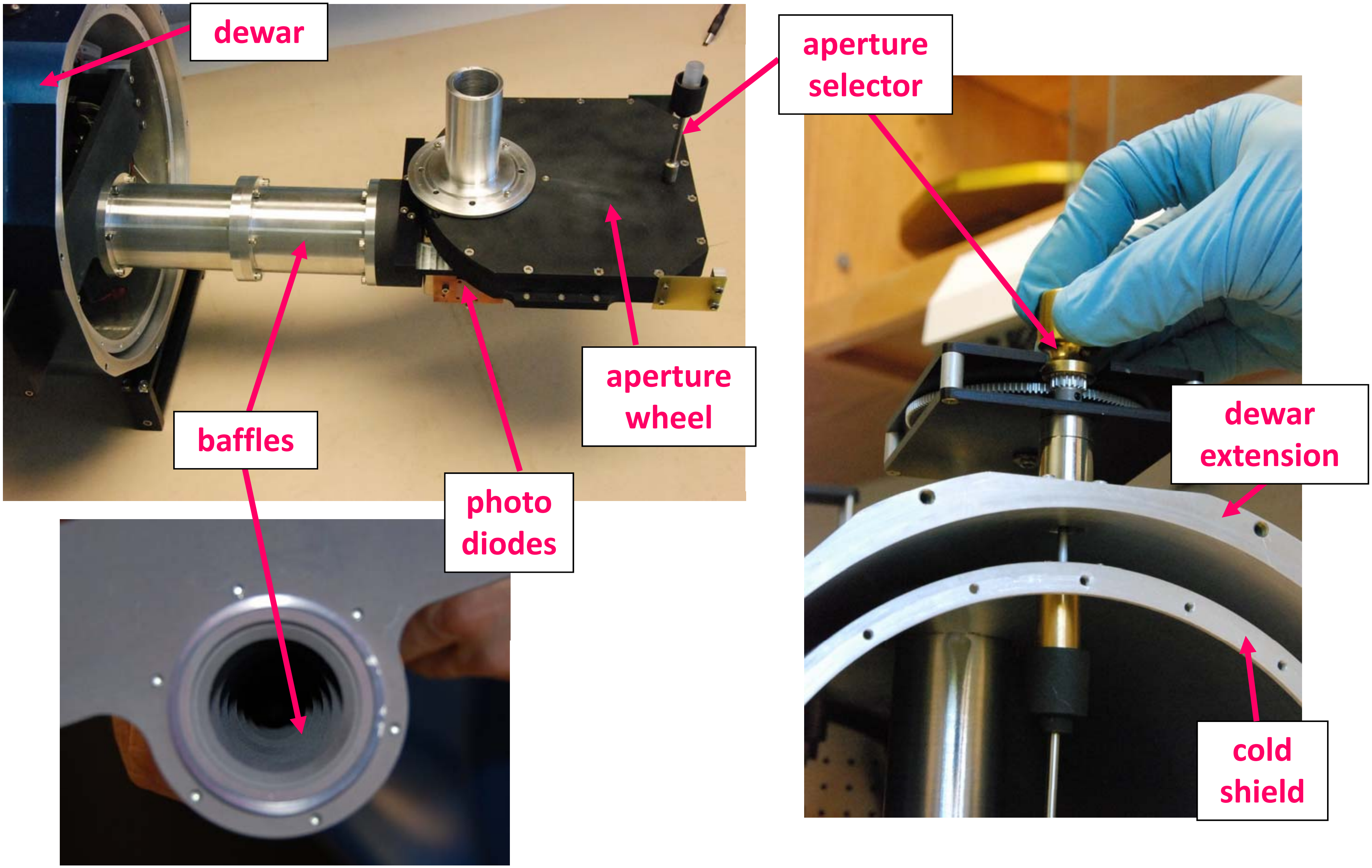
UM Reciprocity Setup

- Dewar extension attaches to existing IRLabs dewar



- no shutter required for HgCdTe (for CCDs shutter is important)

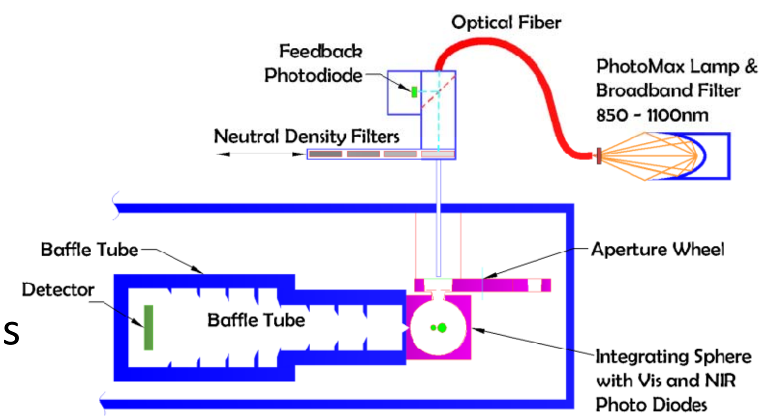
UM Reciprocity Setup



Reciprocity Measurement Scheme

Reciprocity measurement:

- use fixed geometry for detector and monitoring diodes
- sequence of calibrated fluxes
  - using photodiode (PD): independently shown to be linear
- Up-The-Ramp (UTR) images
  - take separate bias frame in dark and subtract that from the UTR images
- adjust exposure time to keep total count in detector constant
  - avoid standard detector non-linearity
- take ratio of average detector flux / PD current (normalized detector flux) and plot vs PD current (count rate)
- look for a ~5%/dex effect



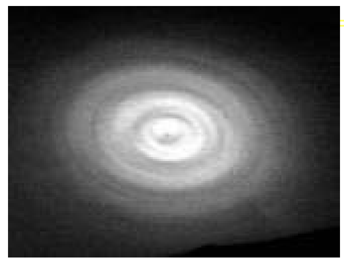
Calibrations and studies:

- PD linearity with dynamic range: 10^5 w/ six pinholes
- PD stability: temp. stabilized at ~120 K
- detector stability: temp. stabilized at 140 K (±10mK)
- Illumination stability: temp. controlled feedback diode → lamp output stable <0.1%
- persistence, timing, bias drifts, noise, frame-to-frame variations, long term drifts

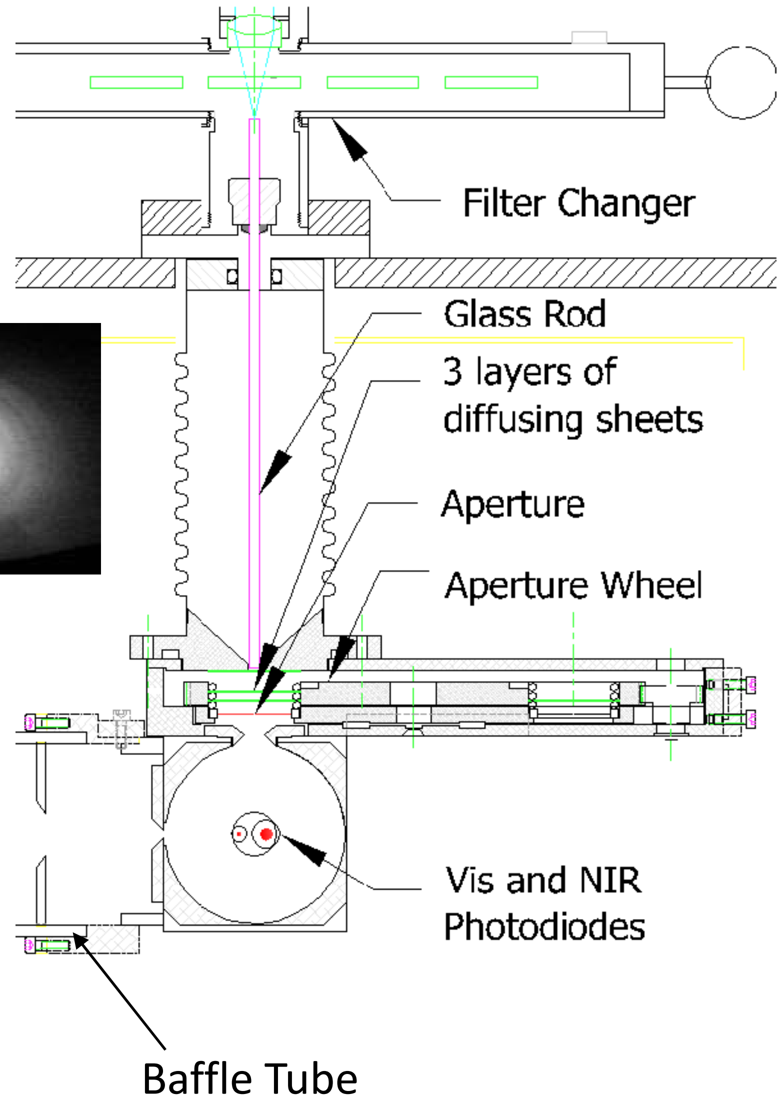
Challenges to reach good Repeatability

Illumination instabilities

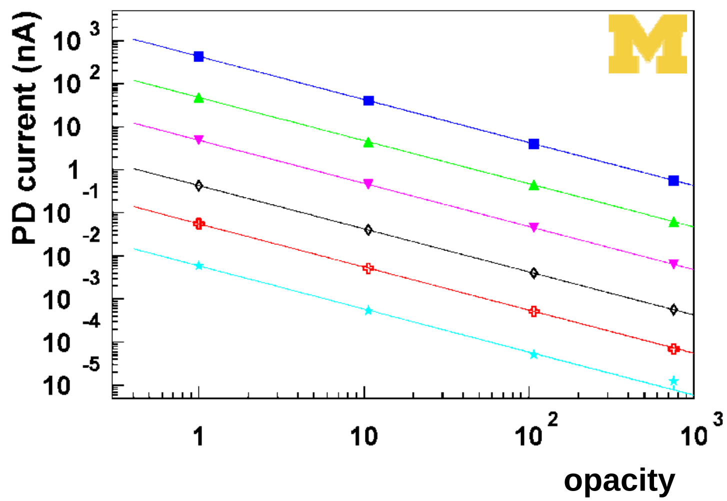
- New bellows
  - containment of stray light
  - reproducibly position glass rod directly above pinhole
  - But, glass rod produces illumination pattern on pinholes
  - repeatability only at 5% level
    - tighten pinholes in changer
    - added diffusing sheets between rod and pinhole



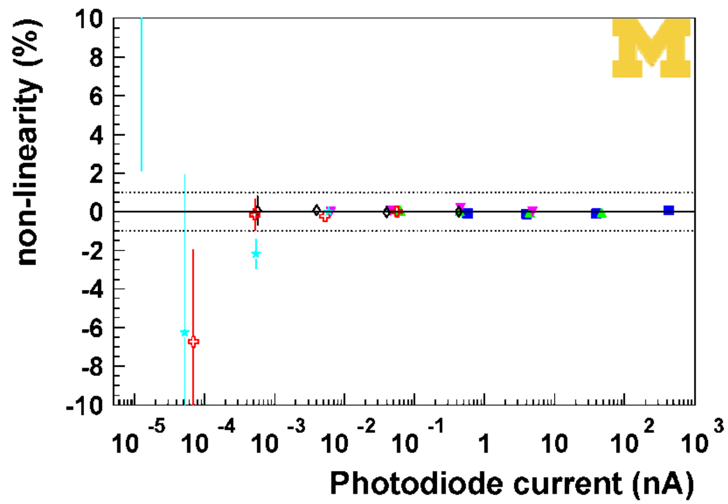
- Baffle tube
  - Baffle tube bigger & close to detector
  - Light tight box around detector
- ND filter changer
  - repeatability only at 7% level
    - filter changer was clamped tightly
- Lamp stabilization
  - Temp controlled feed back diode keeps lamp output stable <0.1%



Photodiode Linearity Calibration



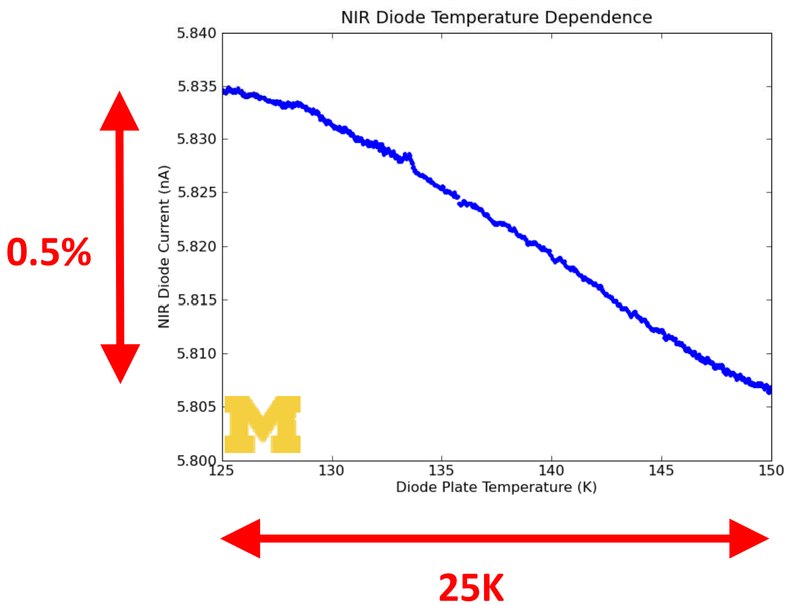
- Pinholes used: 3.3mm, 1.0mm, 333μm, 100μm, 33μm, 10μm
- Same slope fits data over ~10^6
- Lowest light levels have largest error; dominated by read noise in PD



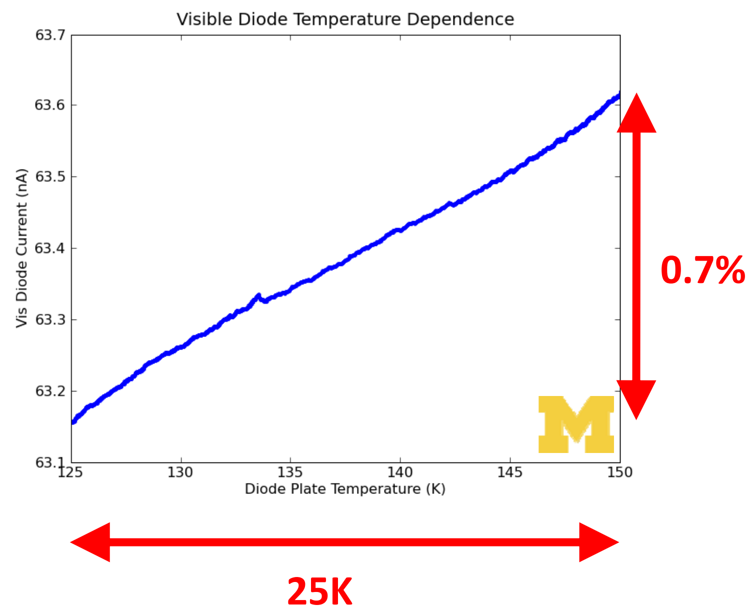
Deviation from linearity is better than **±0.5%** over ~10^5 in light flux

Photodiode Stability

InGaAs (NIR) diode: G10899



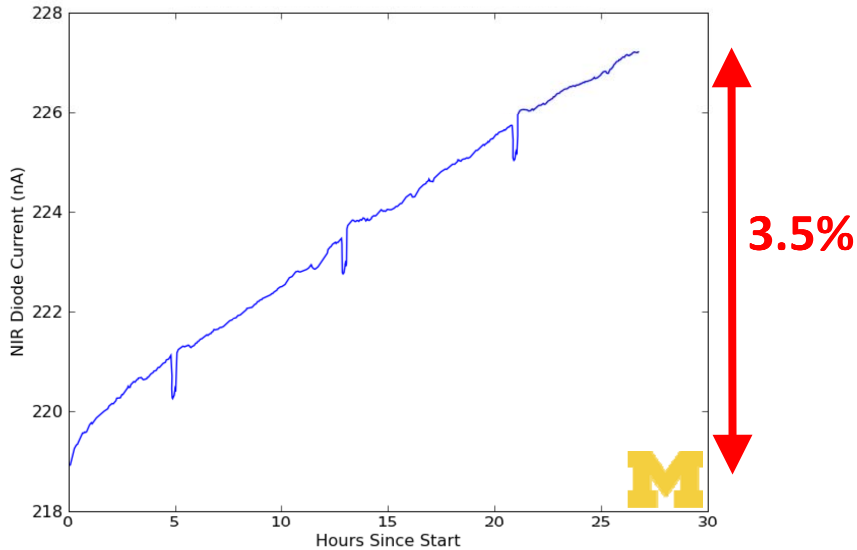
Silicon (visible) diode: NT53-371



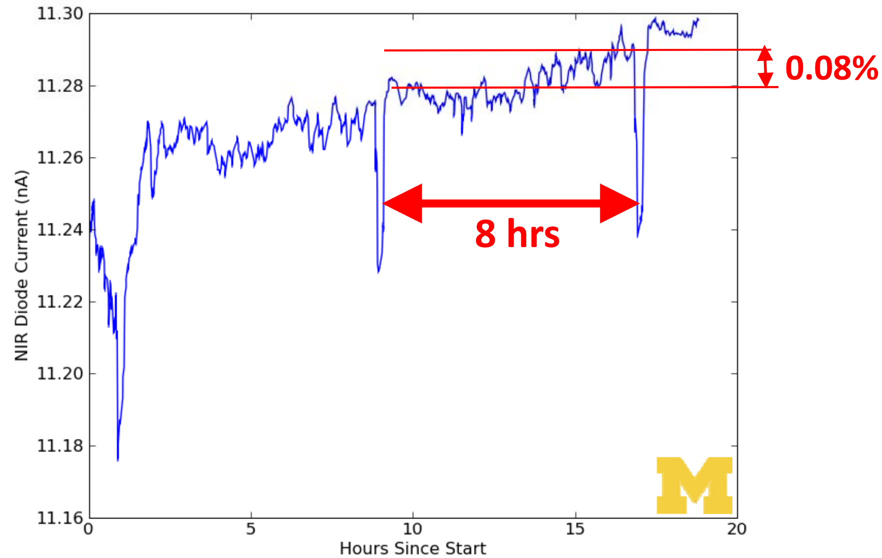
- Data taken simultaneously
- The PDs display a temperature dependence of < 0.1%/K
  - InGaAs and Silicon PDs: opposite behavior
- PDs temperature controlled to <1K

Lamp Stability

no feedback



with feedback

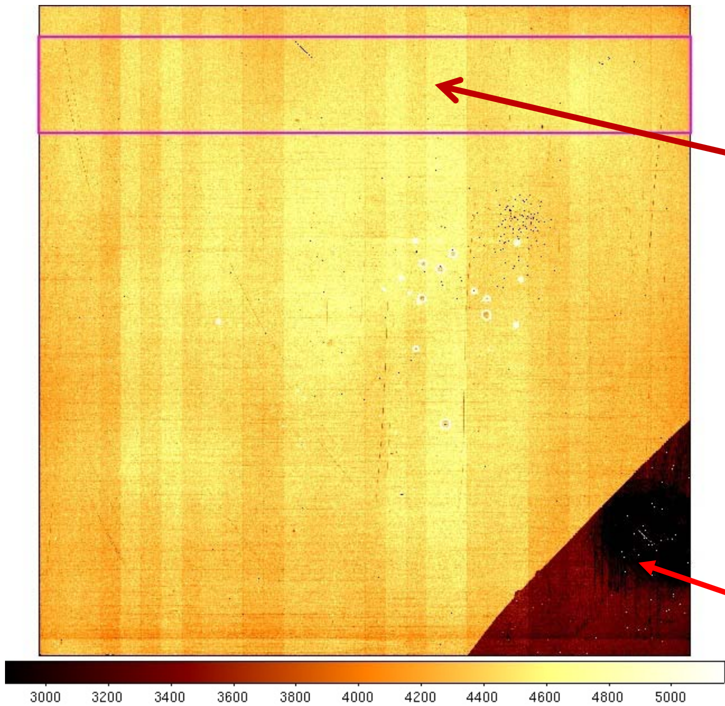


- quartz tungsten halogen lamp shows instabilities of ~3.5% over a 25 hr time interval (in constant current mode)
  ⟶ can be reduced to <0.1% with active feedback over 8 hour period

Other Systematic Studies

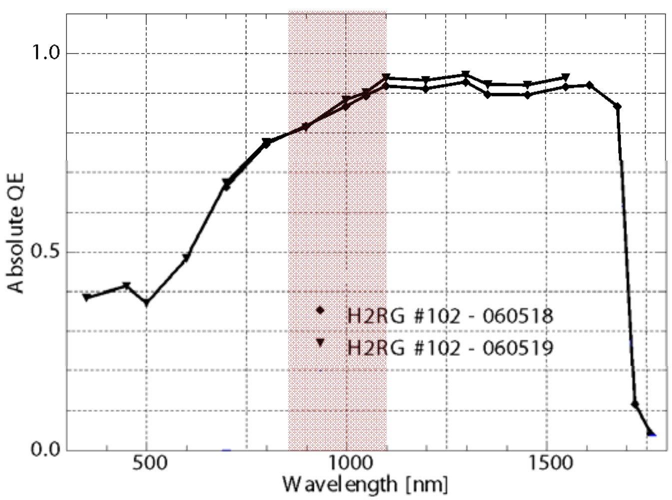
- Light Leaks
  - signal ports shielded
  - detector shielded → only 'sees' light from Integrating Sphere (IS)
- Persistence
  - go from low to high illumination (varying pin holes)
  - wait 30 min between each exposure sequence
- Timing
  - read time set in Vodoo needed to be calibrated (to <0.1%)
  - calibration 10 μs (shortest read: 211 ms)
- Long term drifts (detector temp drift, electronics temp drift ?)
  - 'dark' reference diode tracks bias voltage drift
- PD noise
  - minimized by replacing cables (shorter and shielded)
- Frame-to-frame variations (probably bias voltage fluctuations)
  - tracked well by reference pixels
  - averaging many frames to reduce this noise
- Aperture heating
  - high light levels can heat up pin holes (glow in NIR PD detectable)
  - use gold coated pin holes (gold towards IS)
  - can be removed by using darks with light on

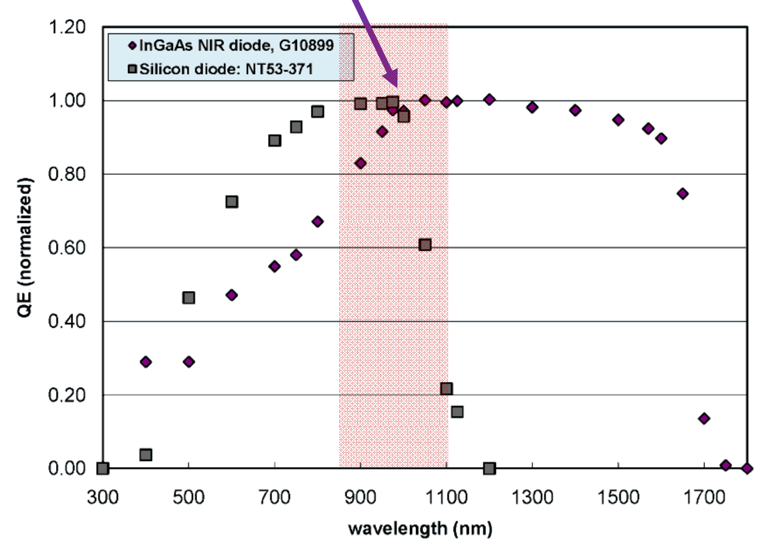
Detector Images (H2RG #102)



- fill well to about half of full well
- select region of
  - uniform QE
  - low on defects and hot pixels
- mask pixels that are 3σ above or below mean (4%)
  → 2% of pixels are clipped + adjacent pixels (2%)
- sum up all 'good' pixels
- divide by NIR PD signal
  (sensitivity well matched to detector)

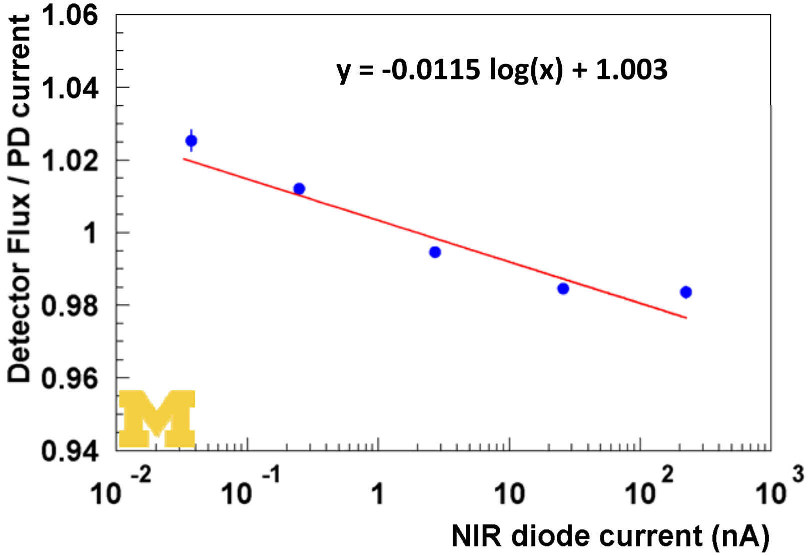
No AR coating



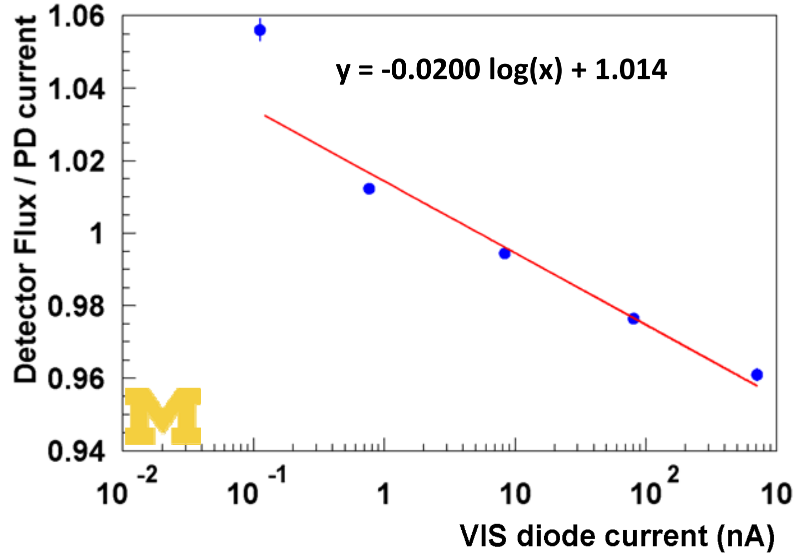


H2RG #102 Response

(NIR)



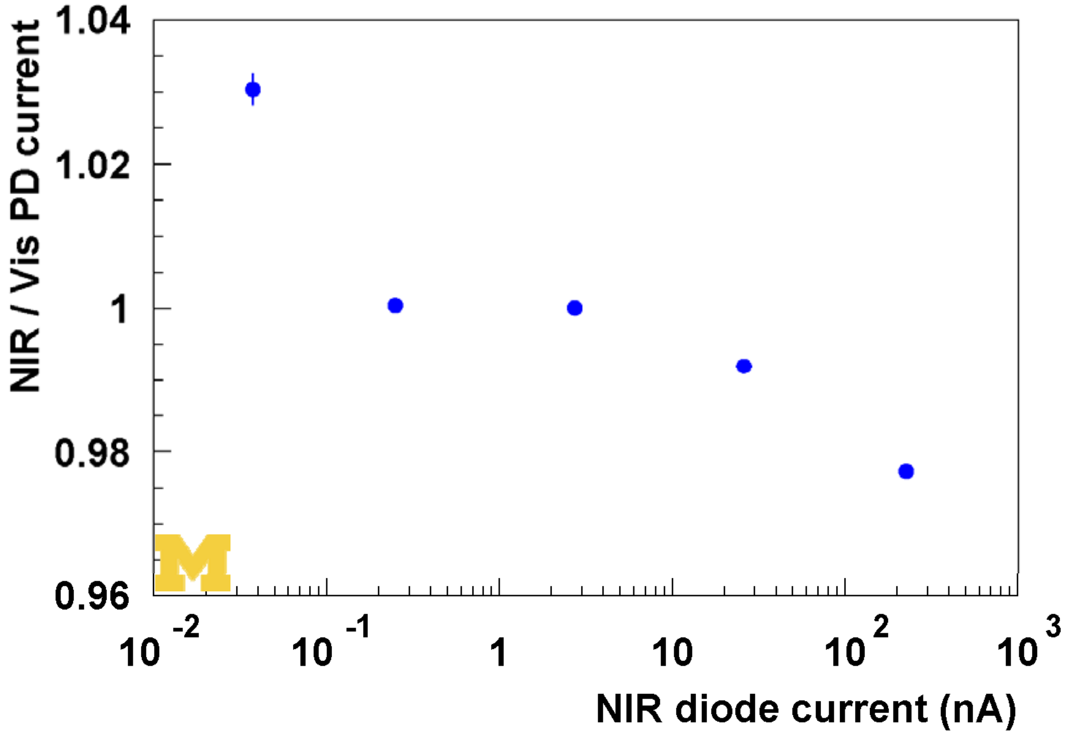
(VIS)

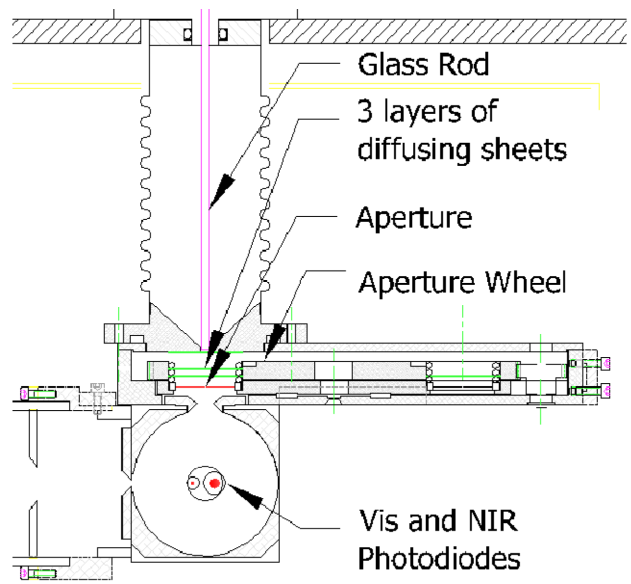


- The response of H2RG #102 (1.7 μm cut-off HgCdTe) **drops** by 1.2%/dex as input flux increases
  → opposite behavior to NICMOS 2.5 μm cut-off HgCdTe (5%\dex)
  → but much smaller effect

- When ratio taken vs visible PD → response drops by 2.0%/dex (twice as large!)
  → (NIR / Vis) PD signal must vary as input flux increases!

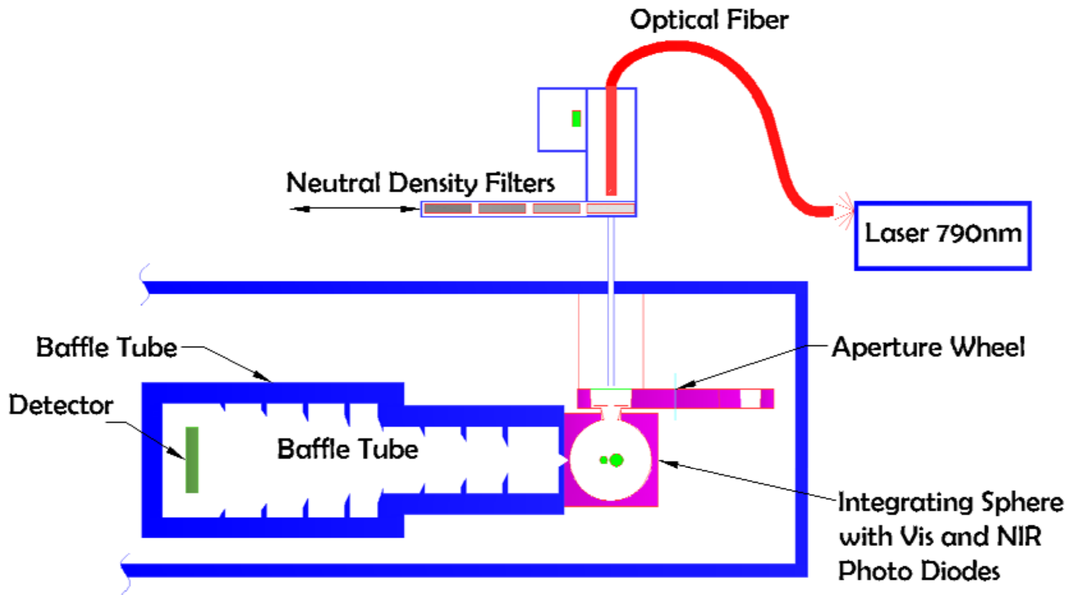
NIR / Vis PD Signal

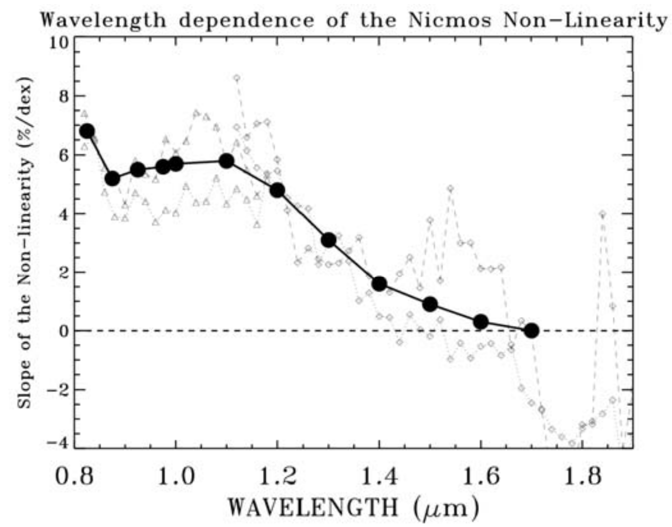


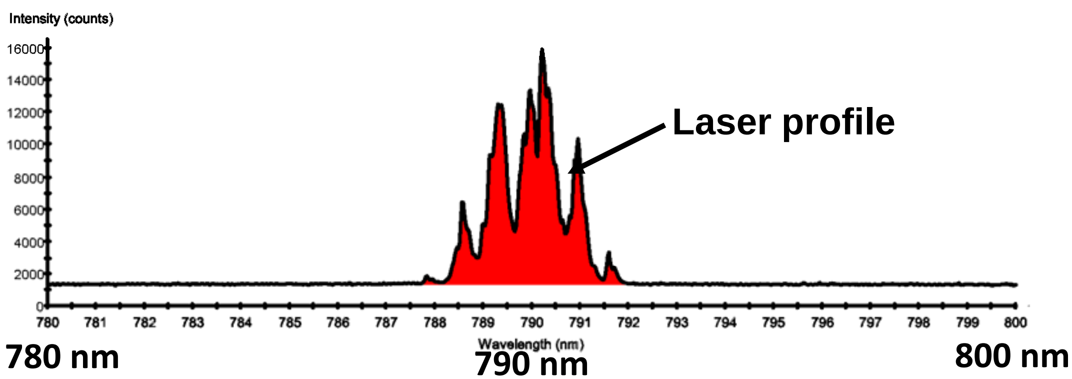


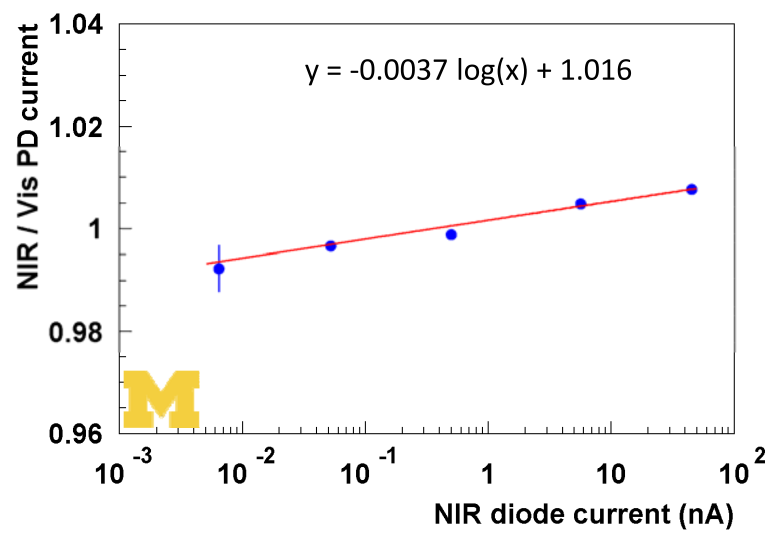
- (NIR / VIS) PD current varies with increasing light intensity (-1.3%/dex)
  - ⟶ flip Vis & NIR diodes (geometrical effect): unchanged
  - ⟶ replace Vis with 2nd NIR diode (spectral effect): improvement
  - ⟶ replace 250nm with 50nm bandpass (spectral effect): improvement
  - ⟶ replace lamp by narrow band laser

Reciprocity Setup with 790±1 nm Diode Laser



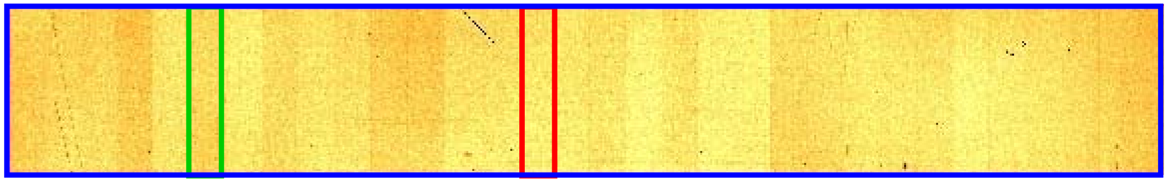


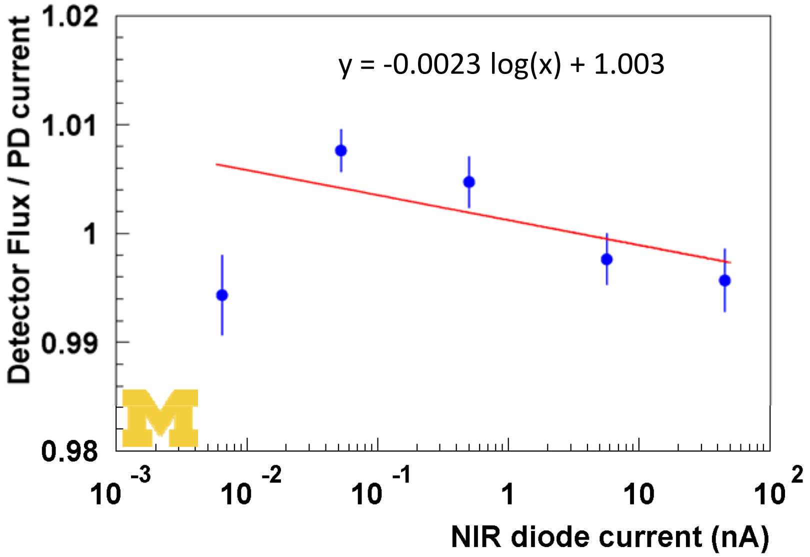


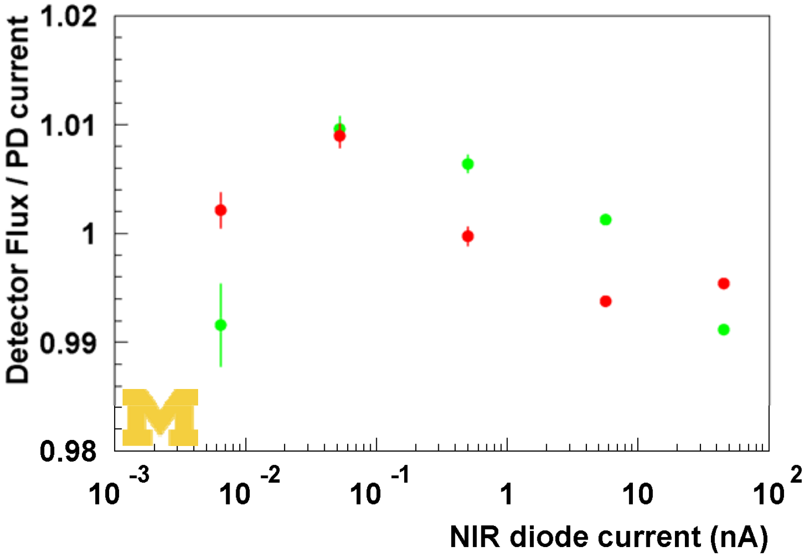


(NIR / VIS) PD current improves from -1.3%/dex → +0.4%/dex

H2RG #102 Response

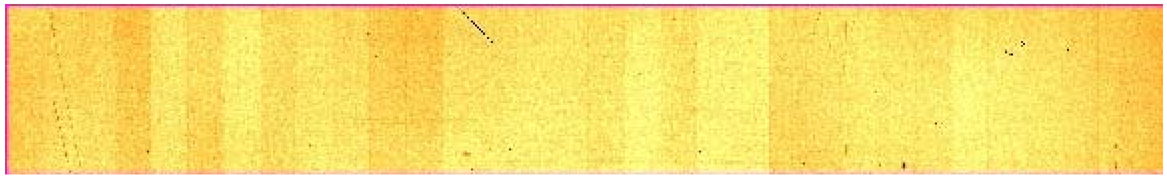




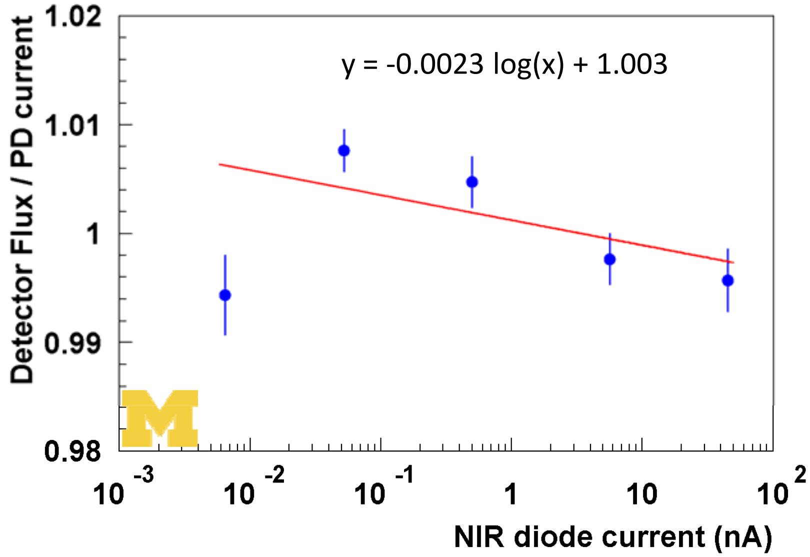


- The response of H2RG #102 (1.7 μm cut-off HgCdTe) exposed to narrow band laser light **drops** by (0.23±0.1)%/dex as input flux increases
  → but much smaller effect than with broad band (250 nm) filter
- Device shows some variations across the detector

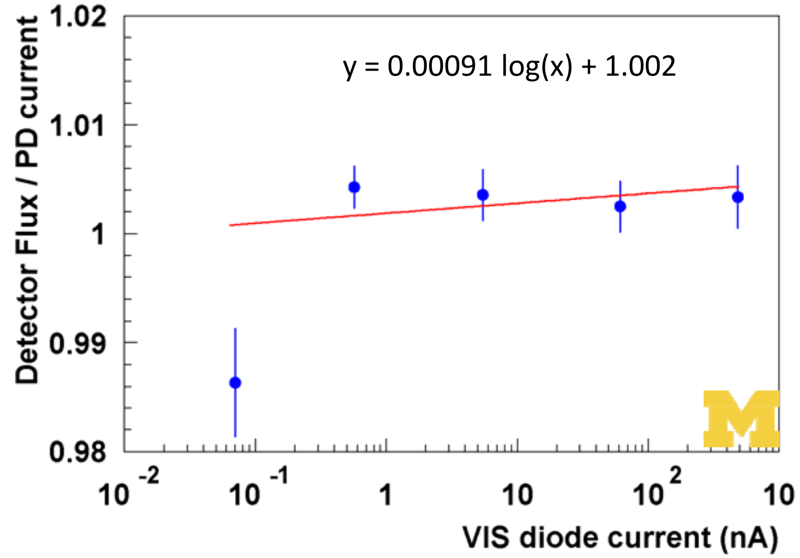
H2RG #102 Response



(NIR)



(VIS)



- The response of H2RG #102 (1.7 μm cut-off HgCdTe) is (-0.23±0.1)%/dex (NIR) and (0.091±0.097)%\dex (Vis) as input flux increases

  ⟶ slight difference between NIR and Vis PD calibrations

  ⟶ but overall smaller than 0.25%\dex

Summary and Outlook

- Reciprocity failure on a 1.7 μm HgCdTe detector appears < 0.25%/dex
  - much smaller effect than seen on NICMOS
  - consistent with zero within precision of our apparatus
  - many studies performed on effects that could mimic reciprocity failure

- Will measure additional 1.7 μm HgCdTe detectors for reciprocity failure
  - use narrow band light source to perform studies
  - use lasers at different wave lengths to study wave length dependence

- Can be performed on HgCdTe, CCDs, …
  - a detector specific mounting plate needs to be machined
    $\rightarrow$ allow for fast turn around time if detectors available
    only for short time
  - ready for cross checking devices from DCL at GSFC