Final Performance Report (Award: DE-FG02-08ER41566) "Precision Photometry to Study the Nature of Dark Energy"

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The University of Michigan group has focused from August 2008 to May 2010 on investigating and characterizing 'reciprocity failure', the flux-dependent nonlinearity that has been observed in near-infrared detectors. This nonlinearity, referred to as "reciprocity failure", had to be carefully distinguished from the well-known nonlinearity of total signal, referred to as "classical nonlinearity", which is observed in near-infrared detectors that integrate charge on the junction capacitance of the pixels. Classical nonlinearity in NIR detectors is caused by dependence of diode capacitance on voltage and nonlinearity in the readout multiplexer, and is usually measured by integrating a constant flux for different exposure times. Reciprocity failure in turn can be measured by varying the flux for exposure times that produce a constant integrated signal.

Reciprocity failure impacts photometry as residual pixel-level uncertainties directly propagate to the estimated uncertainty on the derived magnitude. Detailed knowledge of the degree of reciprocity failure for a detector will affect the calibration strategy and the calibration devices needed. A profound understanding of the cause of this effect could influence the detector manufacturing process, possibly reducing or even eliminating this nonlinearity.

To investigate reciprocity failure, a dedicated test system was built. A sensitivity to reciprocity failure of approximately 0.1%/decade was achieved over up to five orders of magnitude in illumination intensity. Initial measurements were performed on a 1.7 μm HgCdTe detector (HR2G-102) between 700 nm and 1400 nm which yielded a nonlinearity due to reciprocity failure of about 0.35%/decade. We found no indication for wavelength dependence in the tested detector. This result contrasted considerably with the magnitude and strong wavelength dependence for reciprocity failure in measurements that were reported for the NICMOS detectors on the Hubble Space telescope. The results for the measurements has been submitted to PASP and will appear in print in the PASP February 2011 issue.

Armed with a highly sensitive setup, we extended these measurements to three more detectors. All four detectors we tested were produced as part of the SNAP/ JDEM research and development program during three successive production runs with modified growth recipes. To our surprise very large differences in reciprocity failure (from 0.35%/decade to 10.6%/decade) were observed in these detectors. We further investigated the spatial structure of reciprocity failure on these devices and discovered them to be quite strong for the devices that exhibited large reciprocity failure. Trying to find a correlation with other detector parameters such as persistence, dark current, QE, and conversion gain, however, no strong correlation was found. We then went on to investigate how reciprocity failure was affected by device temperature. A low and a high reciprocity device was tested at temperatures ranging from 100 K to 160 K. These tests revealed that reciprocity failure can be "frozen out" at sufficiently low temperature. The results from the two detectors suggested that this freeze-out depends on the magnitude of reciprocity failure in a particular detector and will therefore most likely vary for different detectors.

As a result of our measurements we want to stress that care must be taken when measuring quantum efficiency for detectors that exhibit reciprocity failure. Reciprocity failure will bias QE measurements towards higher values at high illumination levels and towards lower QE values at low illumination levels. In addition, spatial nonuniformity of reciprocity failure across a detector will alter the apparent device uniformity as a function of the illumination intensity. Reciprocity failure is not yet understood at a fundamental level and therefore QE has to be measured at sufficiently low temperature to suppress reciprocity failure in order to reveal the "true" QE. A second paper, detailing these new findings, will be submitted in the very near future for publication in PASP.

Since reciprocity failure from one detector to another can vary widely, reciprocity failure calibration presents a challenge. Furthermore, it is currently unknown if on-orbit radiation damage may alter it. Reciprocity failure is therefore best addressed by the selection of "good" devices and by cooling them sufficiently.

To summarize, the University of Michigan group has very successfully performed all the measurements that were proposed in our proposal and discovered properties of these devices that will have a very big impact on near-infrared detectors performance in space or on the ground.