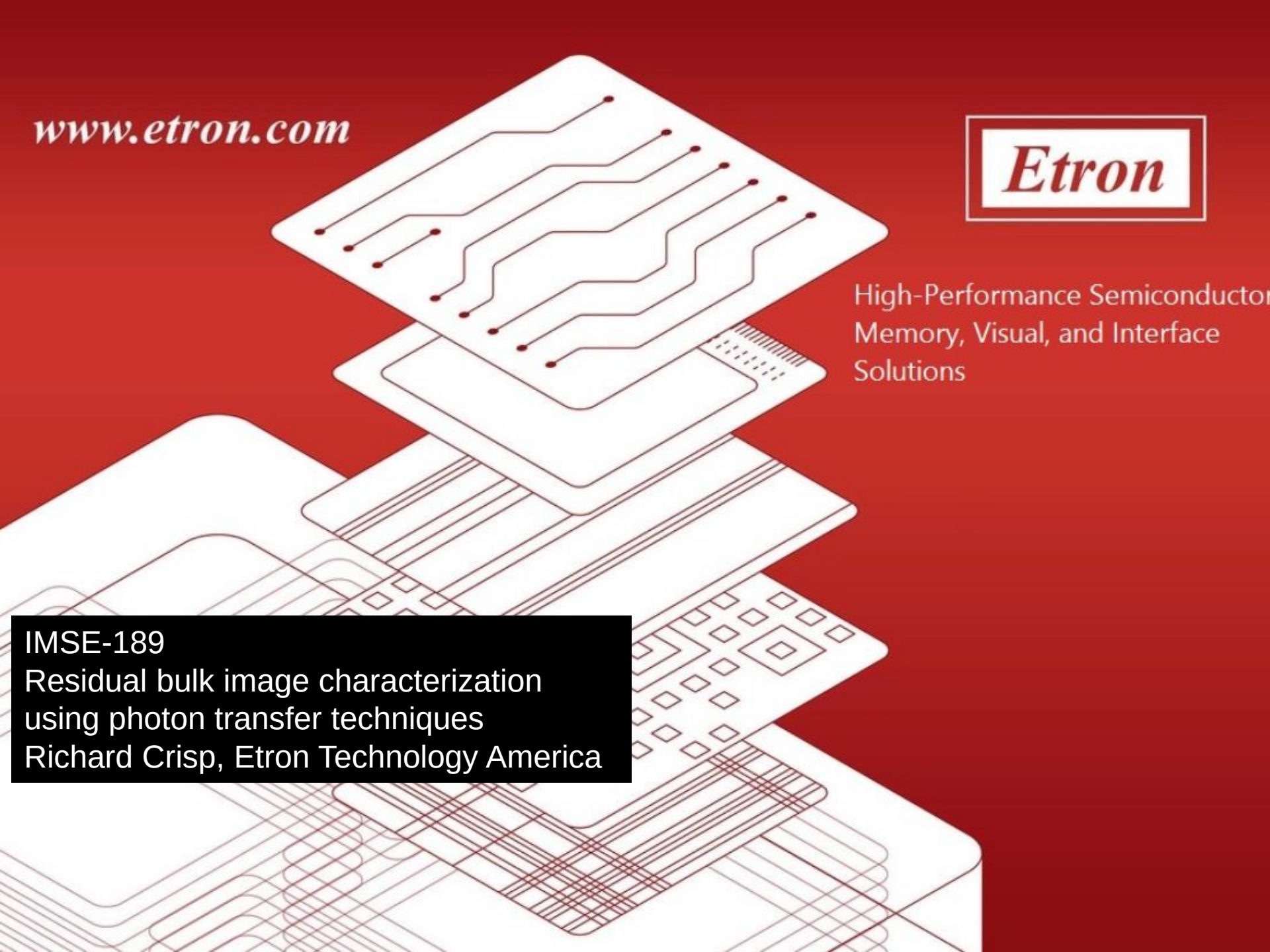


IMSE-189
Residual bulk image characterization using photon transfer techniques

Richard Crisp, Etron Technology America

Outline

- Company Overview
- R&D Workbench: Camera EO Characterization
- Trapped Charge Issues with PTC Characterization
- Using PTC methods for Charge Trapping Measurement
- Residual image management

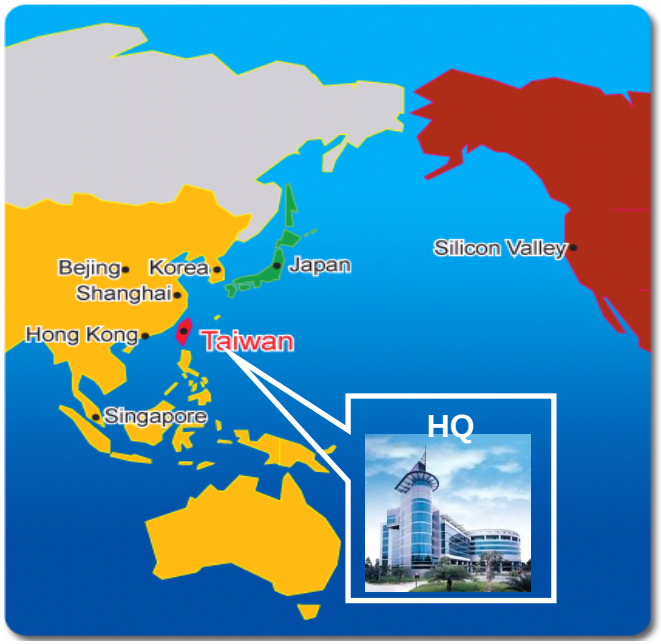
Company Profile

Etron Technology

- Founded in 1991 as memory company
- Headquarters: Hsinchu Science Park, Taiwan
- IPO (TPEx: 5351.TW) in 1998
- Fabless business model from inception

Today (as of September 2016)

- Shareholder's equity: US $132M
- Assets: US $248M
- Patents: 563
- Employees: 470



Memory

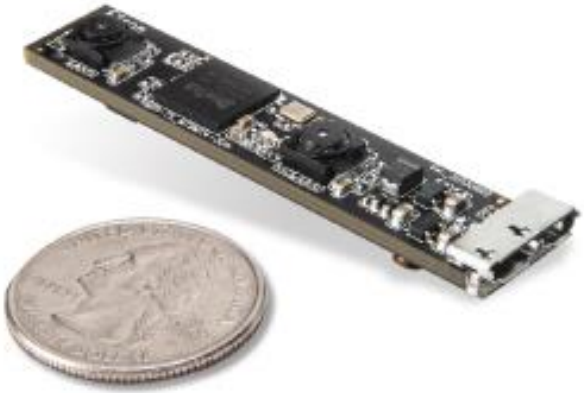
- Pioneering Application-Driven Buffer Memory
- Leader of Known-Good-Die Memory Products

Imaging

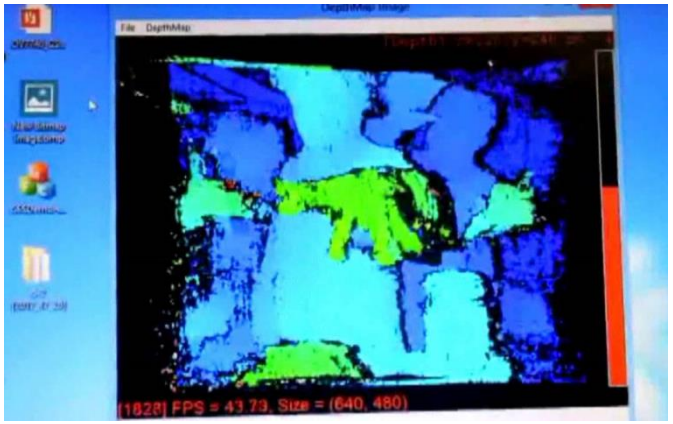
- 3D Cameras and Controller ICs
- 360° Cameras and ICs

Etron Imaging Products

ASICs for
360 degree
Spherical Cameras



ASICs for
Stereoscopic
3D Depthmap
Cameras



Today we talk about what we do back in the lab, not the products we build!

R&D Workbench: Camera EO Characterization

Important performance metrics often needed for design, calibration & optimization

- Read Noise
- Camera Gain
- Saturation Signal
- PRNU
- DSNU
- Linearity

Photon Transfer Methods are often used

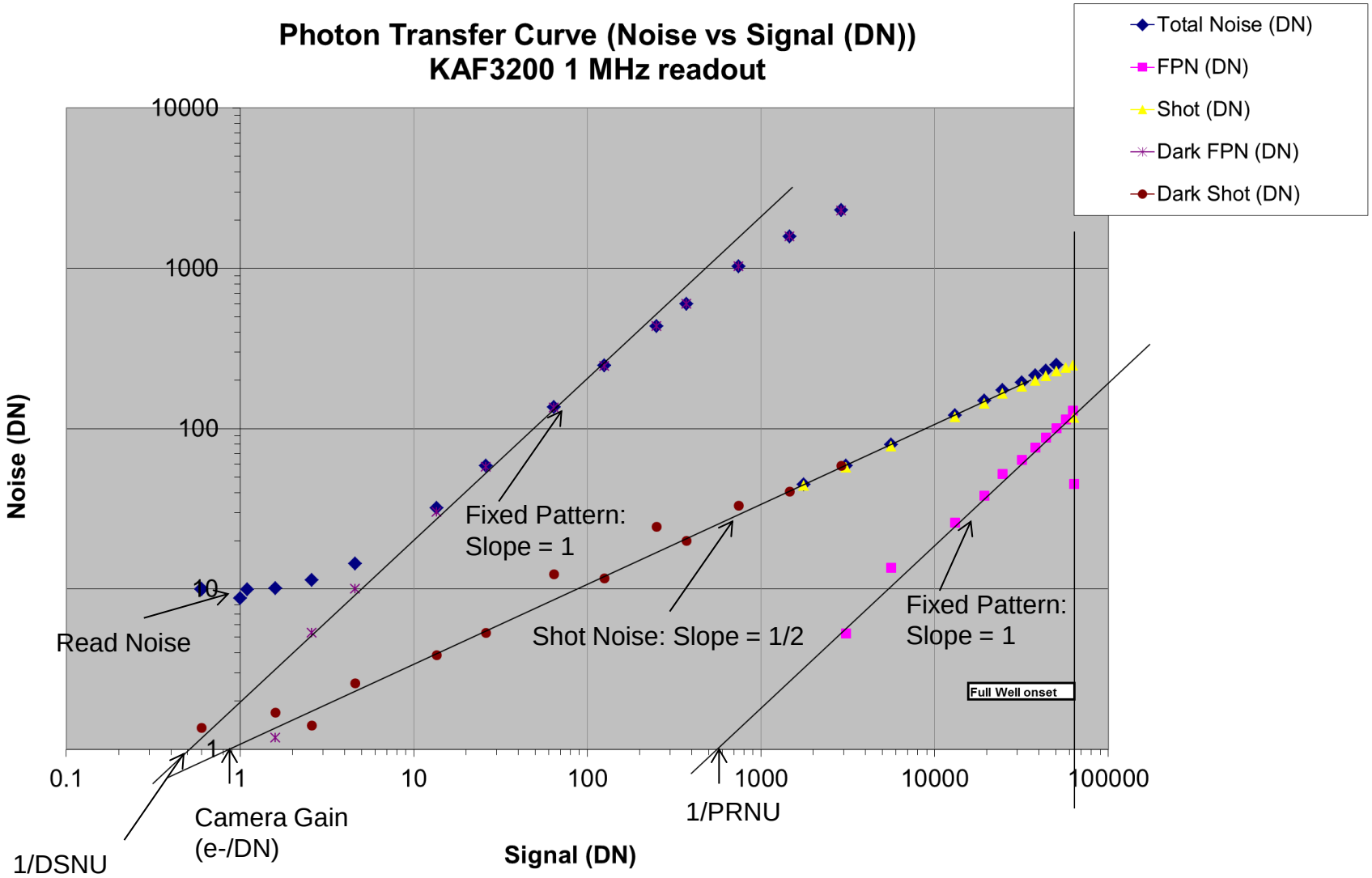
- Decomposes camera output into components using basic mathematical relationships
- Graphical method: plots noise against signal
- Simple equipment and procedure: light source, camera, spreadsheet
- Avoids need for calibrated source, calibrated photodiode
  "Can do at home on your kitchen table"

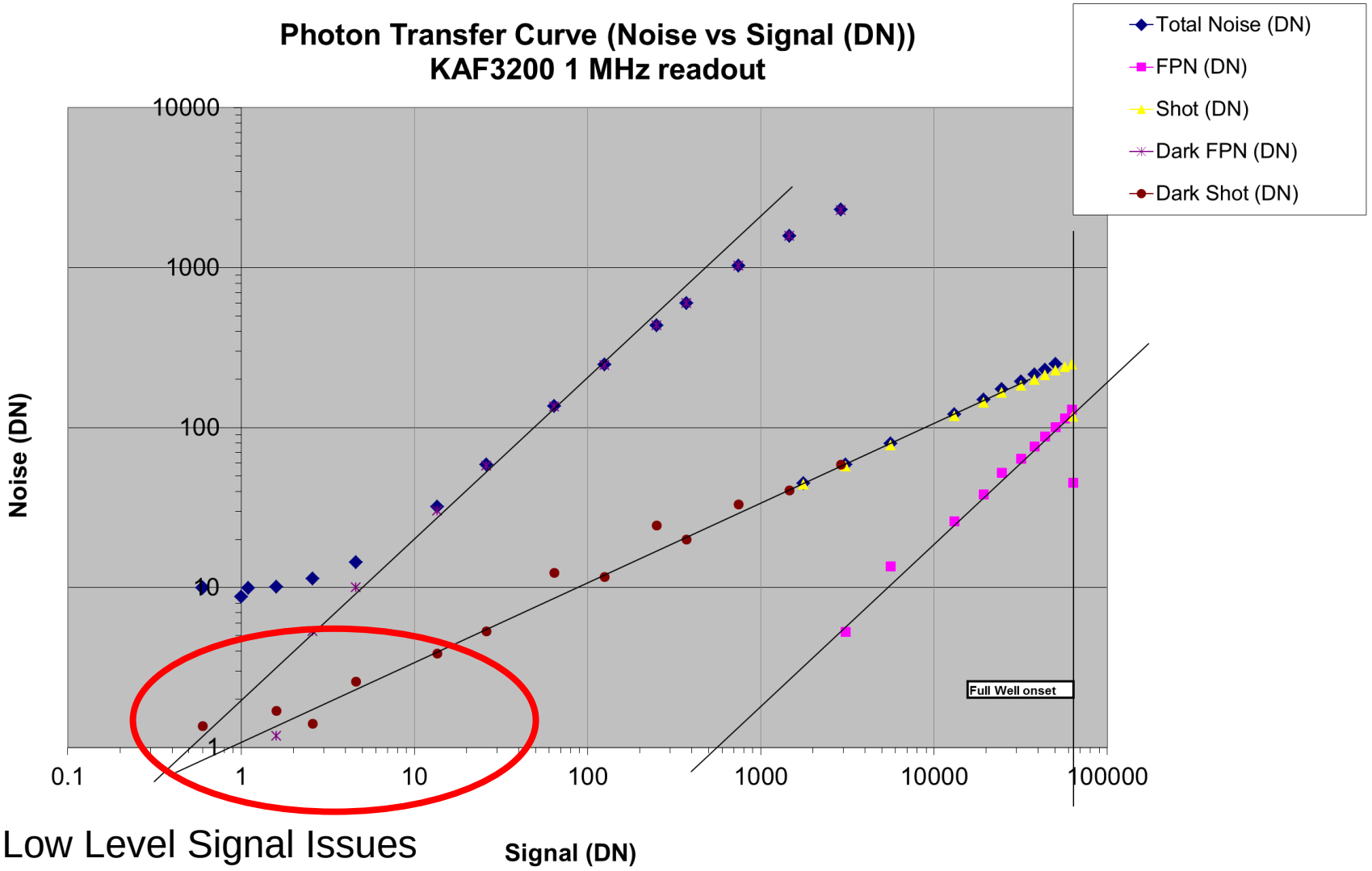
Photon Transfer Basics

Write Equations for Noise considering relevant parameters

- Common ones
  - Total noise
  - Read Noise
  - Fixed Pattern Noise
  - Signal Shot Noise
  - Dark Shot Noise
  - Dark Fixed Pattern Noise
  - Camera Gain
- Capture pairs of identical flat field and dark exposures ranging from very low level to full well
- Measure std deviation of 100 x 100 pixel region and average values in each frame
- Make difference frames of pairs of identical exposures and measure std deviation

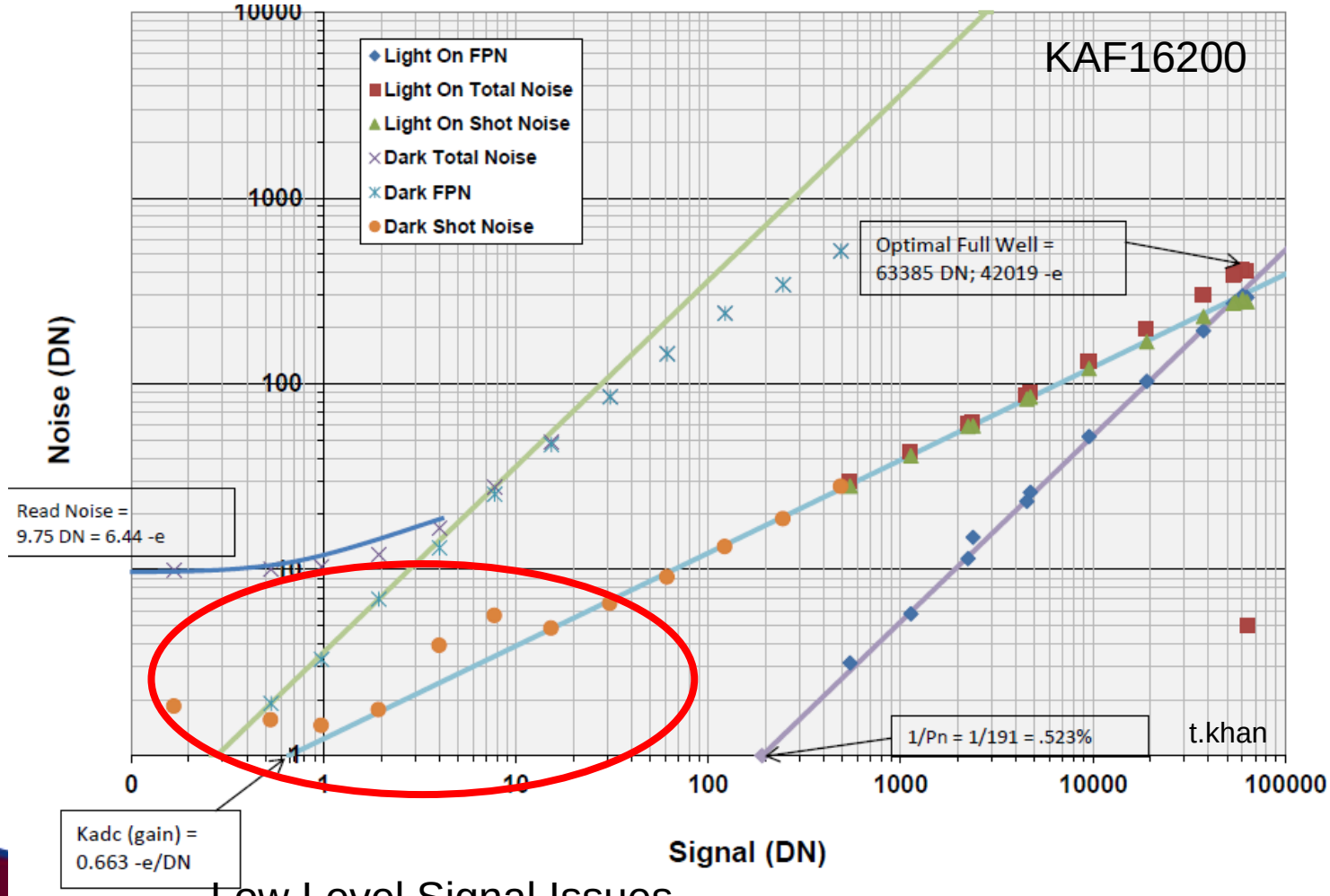
- Compute and plot desired noise components versus signal or versus time
  - Use logarithmic axes to cover many orders of magnitude
- Plot light-on and dark signal data on same graph
  - Easy way to extend from very low signal to full well
- Look for straight lines and slopes for shot noise & fixed pattern noise
- Look for intercepts for gain, PRNU, DSNU, read-noise





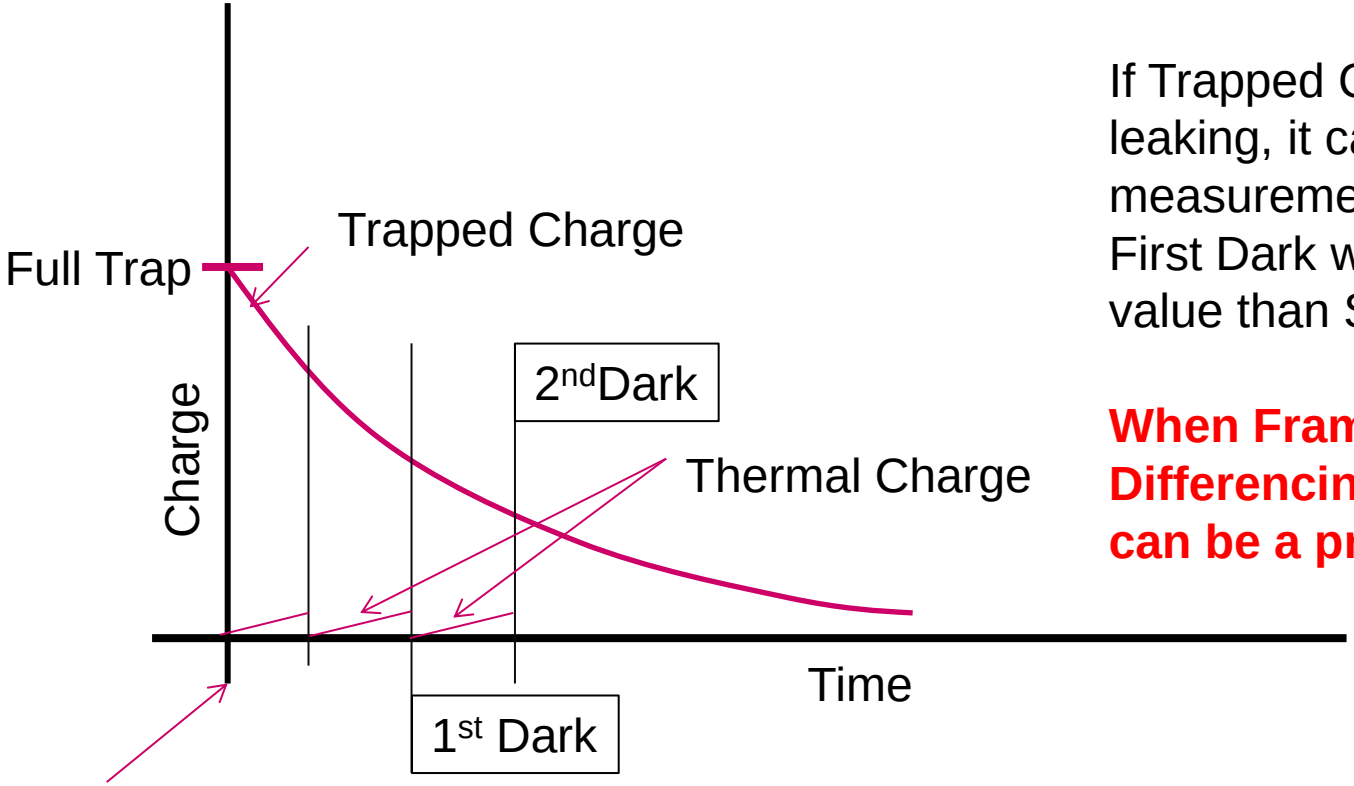
Low Level Signal Issues

Trapped Charge: Hazard for PTCs, No flushing before cooling after power-up



Low Level Signal Issues

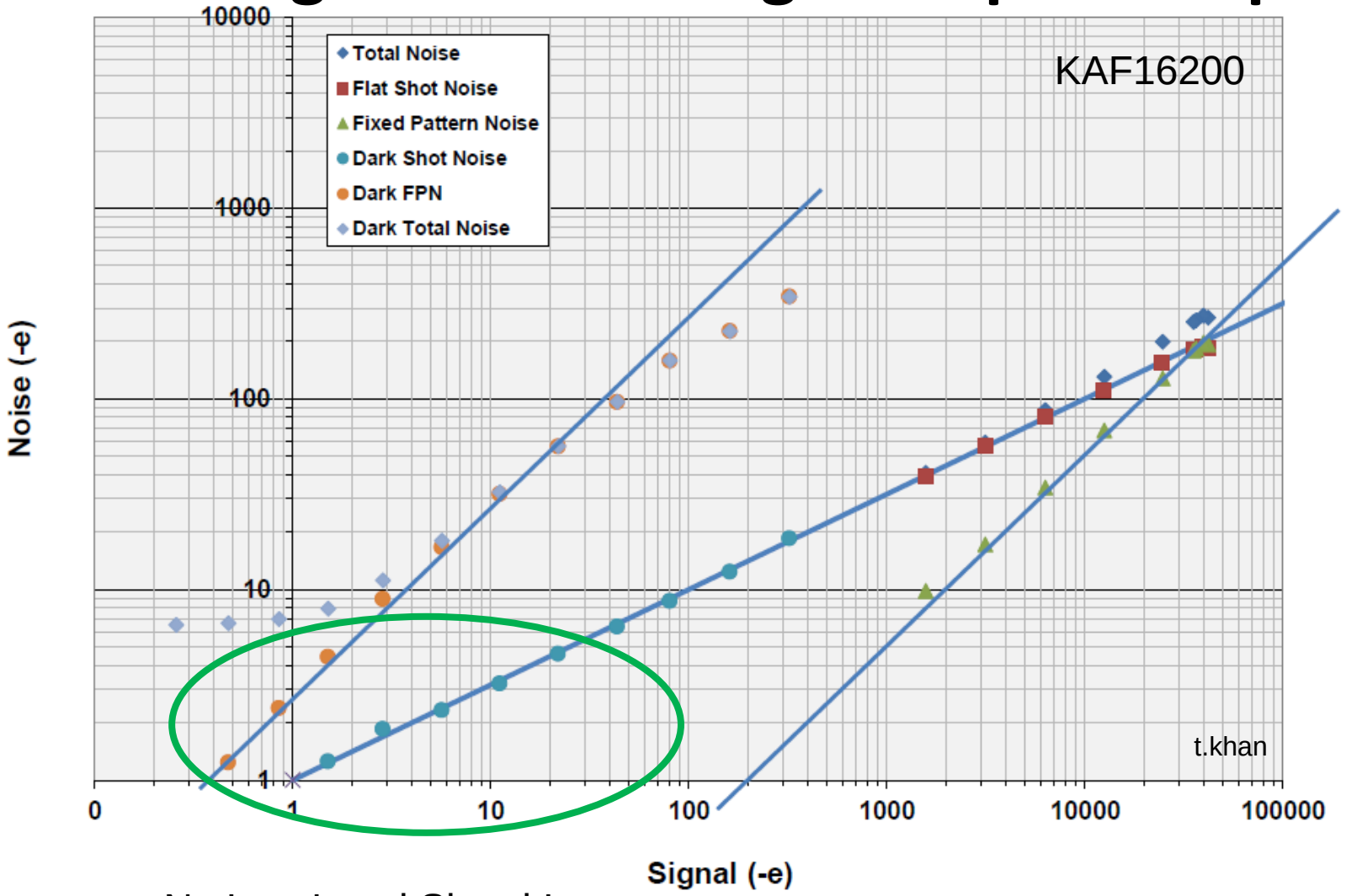
Low Level Signal Issues: differencing exposures in presence of trapped charge



If Trapped Charge is leaking, it can introduce measurement errors: First Dark will have higher value than Second Dark

When Frame-Differencing Darks this can be a problem

With flushing before cooling after power up



No Low Level Signal Issues

Trapped Charge PTC Investigation Methodology

Use Photon Transfer Methods

- Use PTC characterization data for Read Noise and Camera Gain measurement
- Measure Dark Signal Noise versus Time
- Take pairs of identical dark exposures and difference them to eliminate DFPN (leaves read noise and dark shot noise in remaining difference)
- Two major cases: with and without light flood
- Examine at -15, -20, -25, -30, -35 & -40C operating temperature

$$Total\_noise = \sqrt{Read\_noise^2 + Dark\_shot\_noise^2} \quad (1)$$

$$Dark\_shot\_noise = \sqrt{Total\_noise^2 - Read\_noise^2} \quad (2)$$

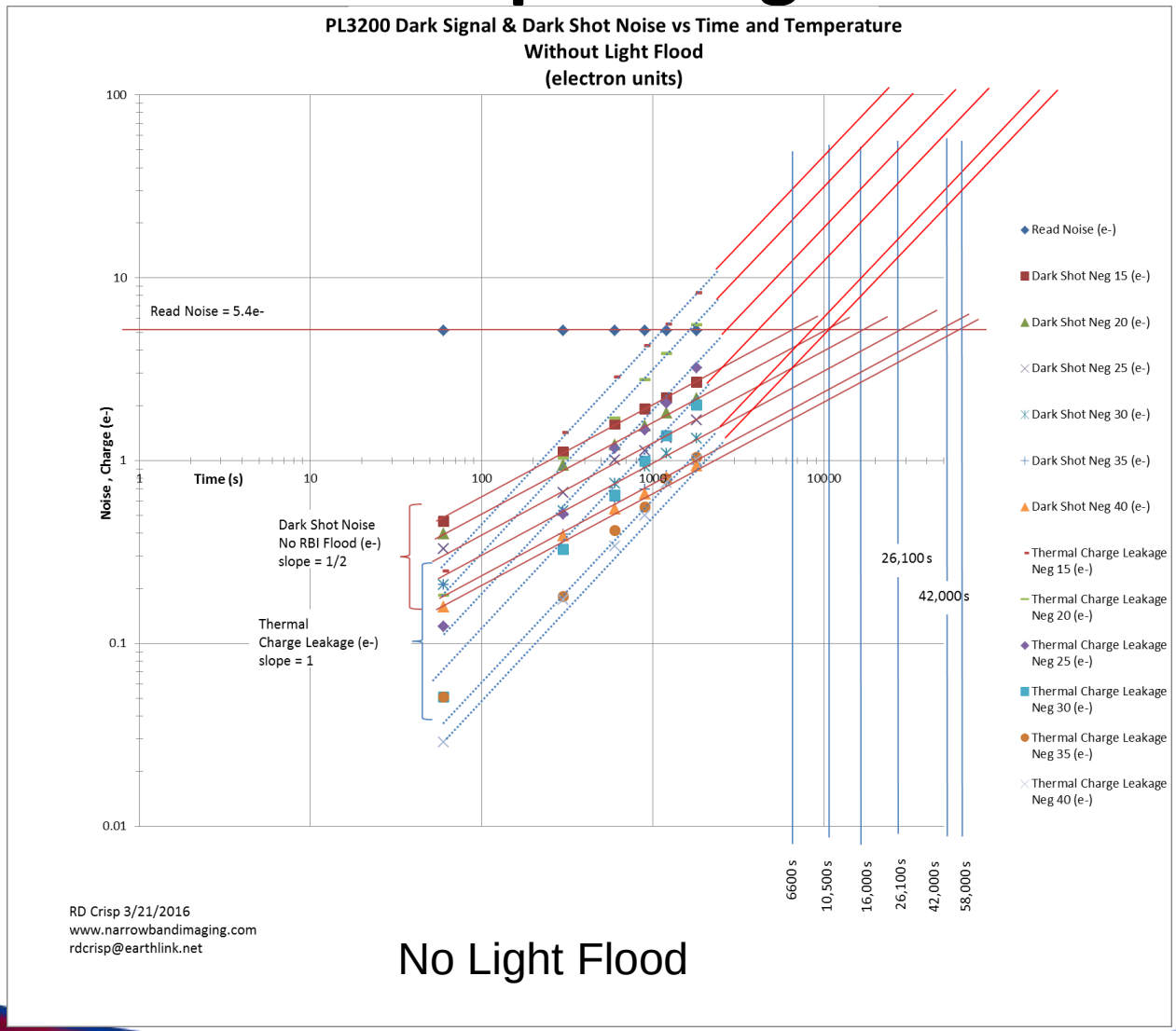
$$Dark\_shot\_noise = \sqrt{Total\_dark\_signal} \quad (3)$$

$$Total\_dark\_signal = Thermal\_dark\_signal + Trap\_leakage \quad (4)$$

For no-light flood case, Trap_leakage is zero:

$$Total\_dark\_signal = Thermal\_dark\_signal \quad (5)$$

Baseline Case: no trap leakage



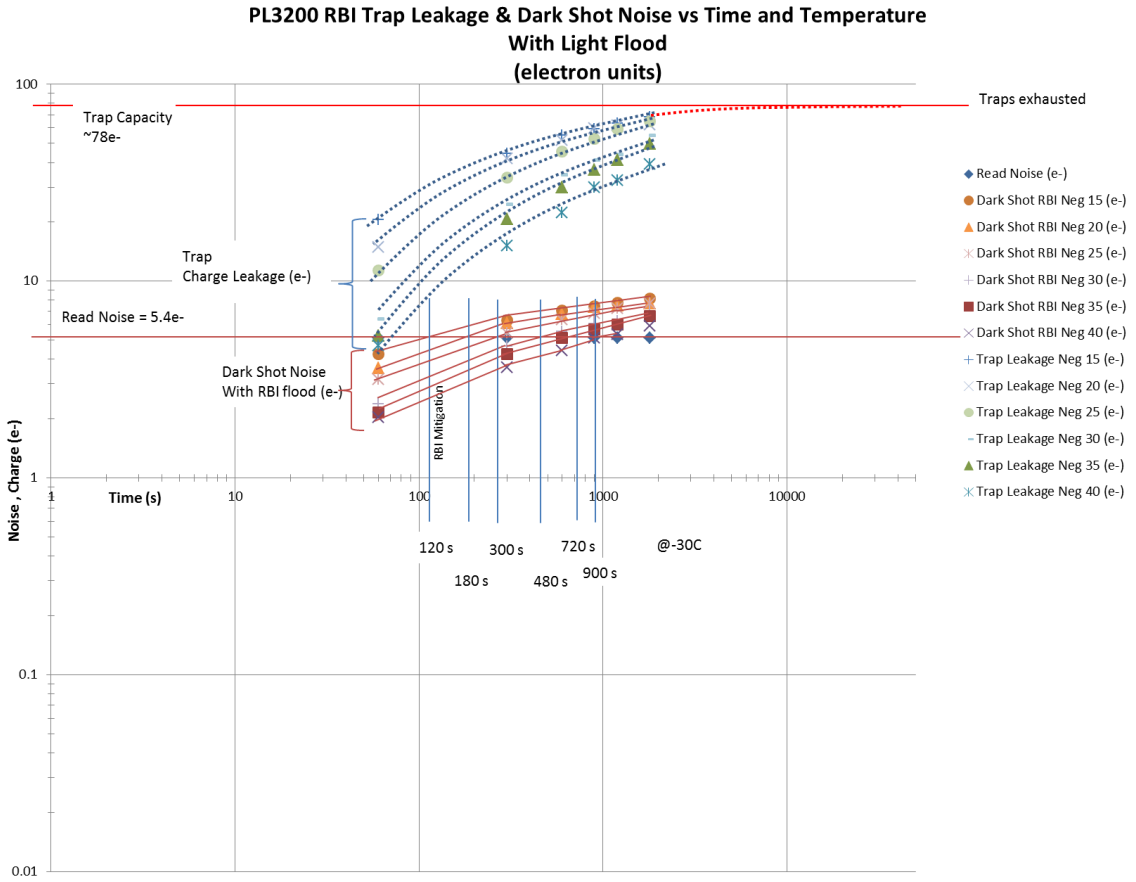
No Light Flood

Calculating Trap Leakage

To determine the trap leakage you use the thermal dark signal data from the non light-flooded case and the Total Noise from the light-flooded case

$$Trap\_leakage = Total\_noise^2 - Read\_noise^2 - Thermal\_dark\_signal \quad (6)$$

With Trap Leakage



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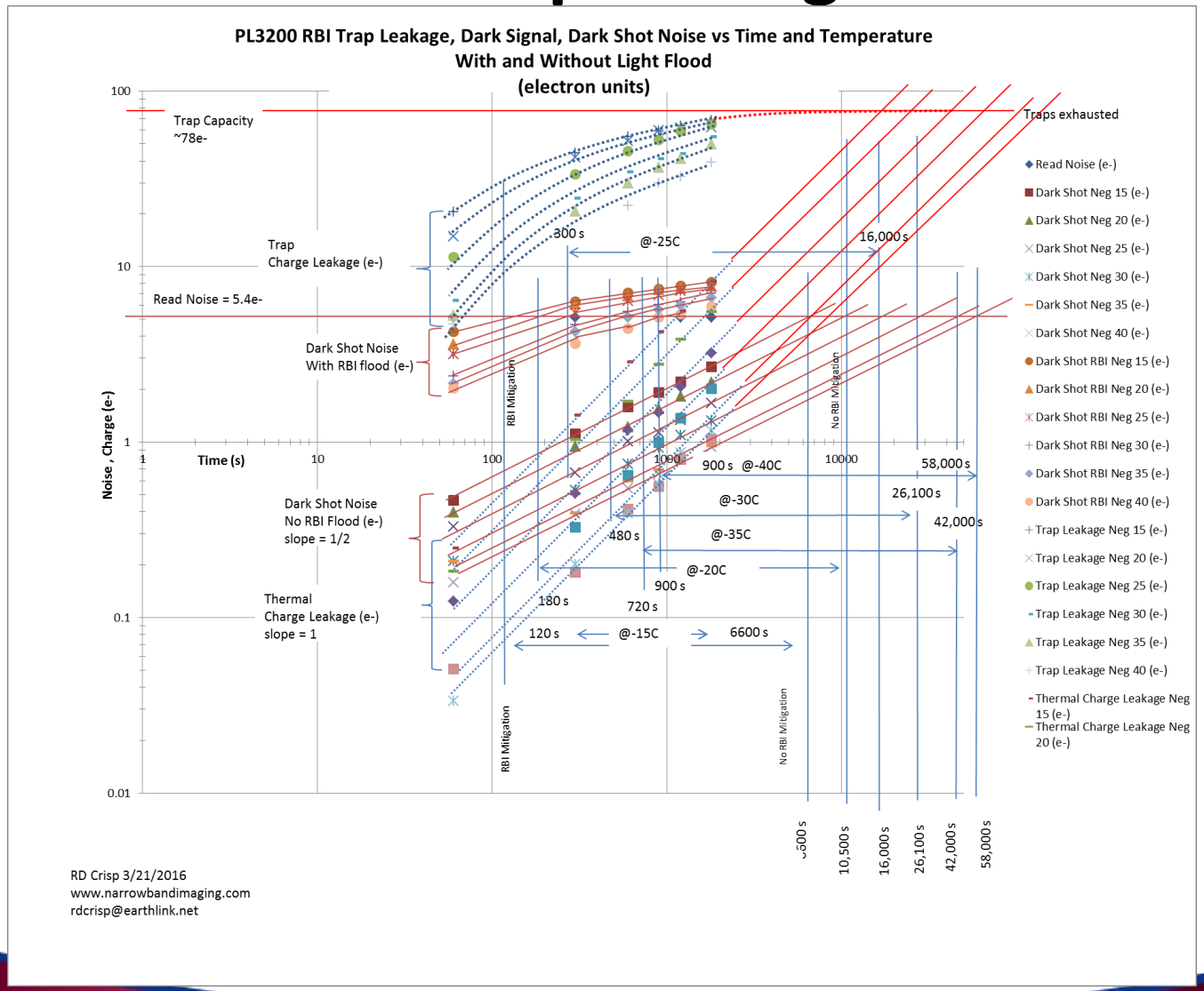
With Light Flood

With and Without Trap Leakage



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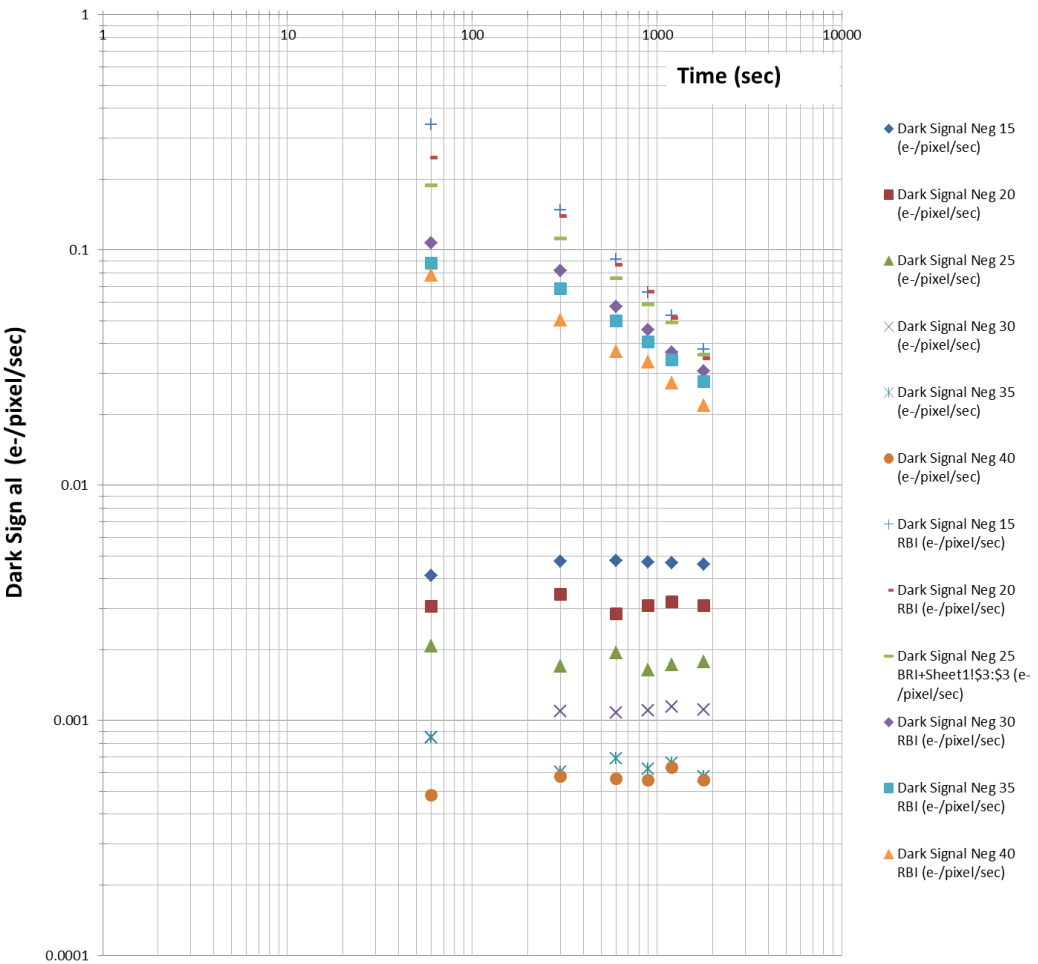
Dark Signal With and Without Trap Leakage



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Residual Image Management

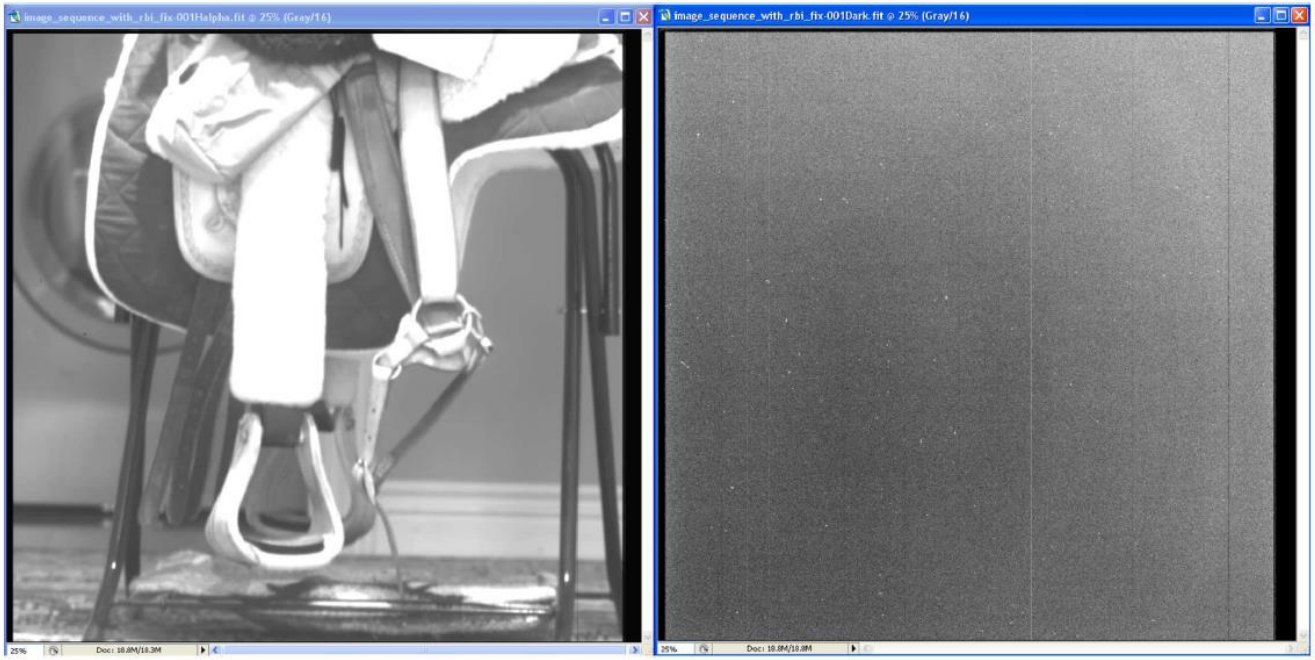
Residual Image

Image

5 Minute Dark Immediately following image

5 Minute Dark One hour following image

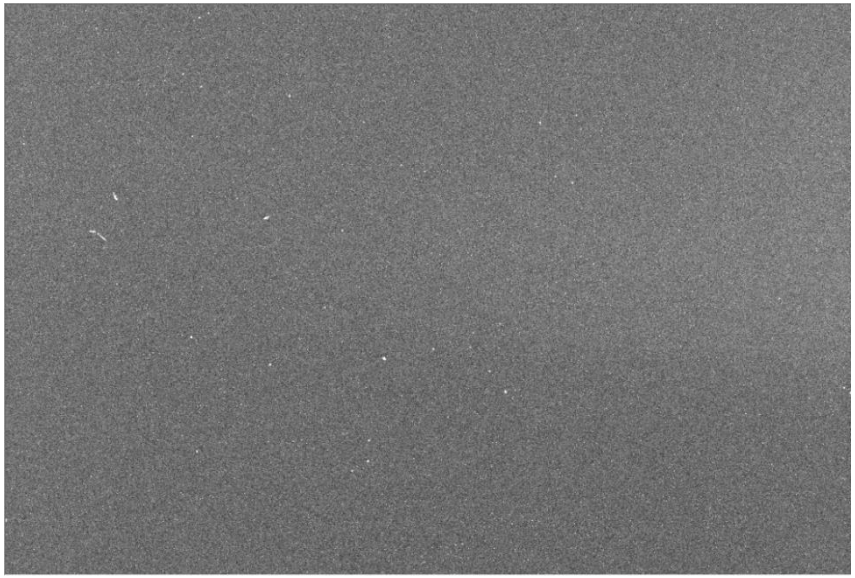
Residual Image Avoidance using Light Flood



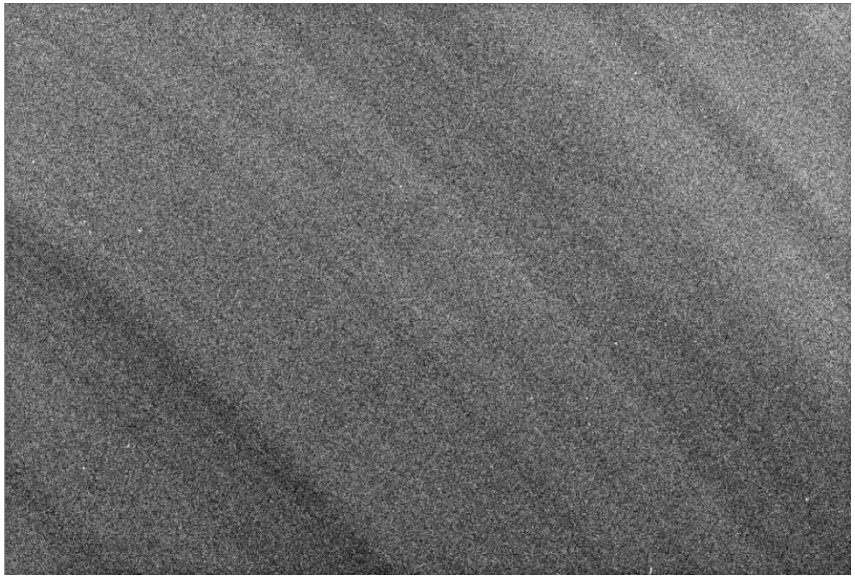
Image

Subsequent dark

Non Uniformity of Trap Distribution



No Light Flood: Neg 15C,
300sec dark frame



With Light Flood: Neg 15C,
300sec dark frame

Full Calibration (Flats and Darks)

Visible Trap Artifacts Visible

No Trap Artifacts Remain

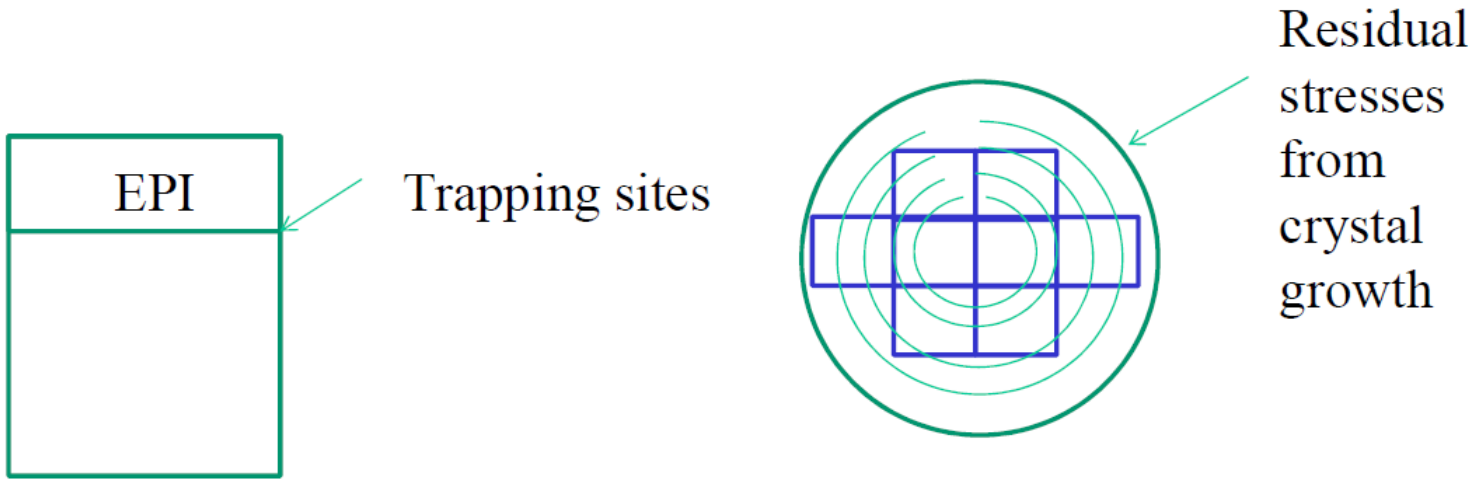
Not Calibrated
(900 second exposure)

Calibrated
(900 second exposure)

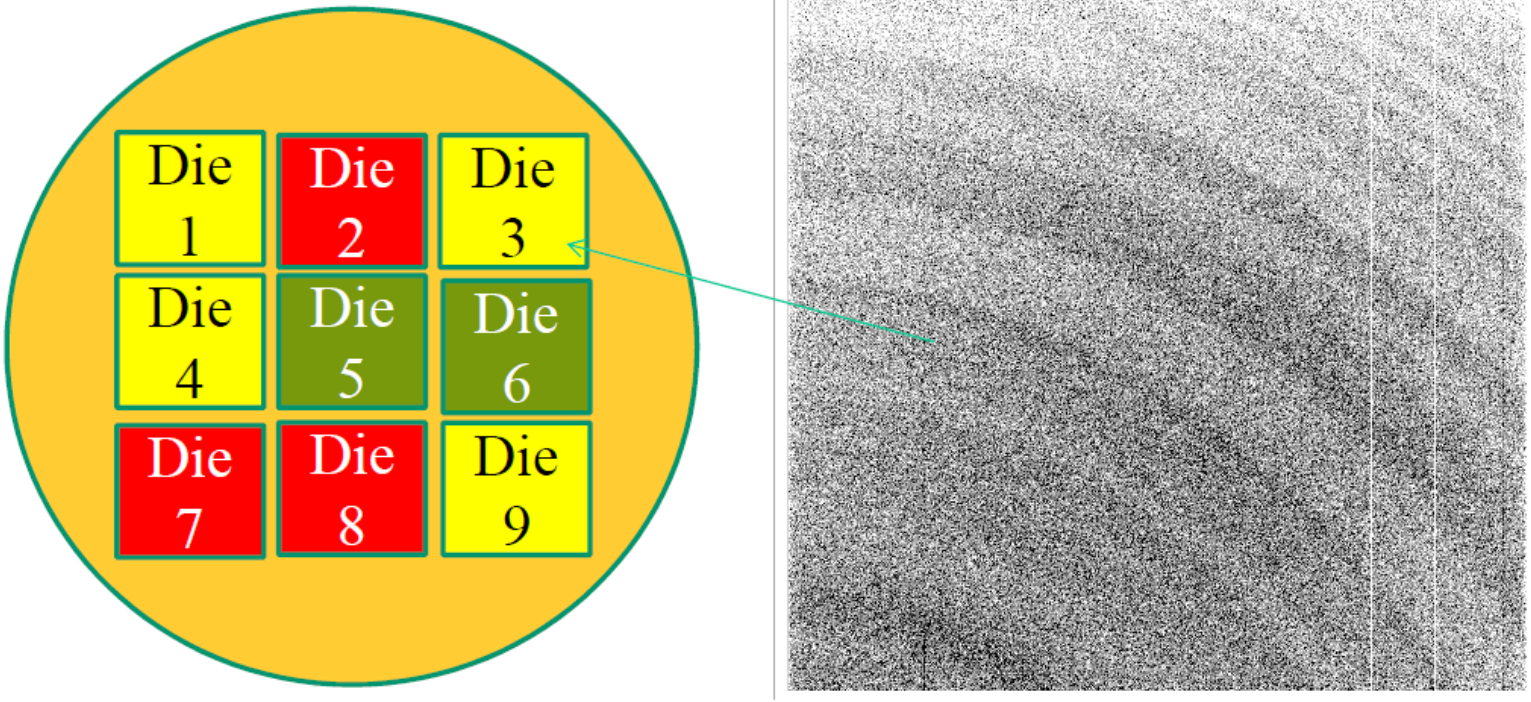
Theorized Trap Sources

Theorized Trap Sources

- Epi interface trapping sites
  - Spectral dependence
- Stress-induced trapping sites in lattice from crystal growth process
  - Swirling shapes in darks
- Random bulk defects in crystal lattice
  - No spectral dependence or swirling shapes



Wafer Mapping Example



Conclusions

Photon Transfer Methods can reveal anomalous camera behavior

- Showed that a light flood LED anomalously cycled at power-up in this wor

Trapped charge can introduce errors in camera EO measurements

- Be cautious when measuring a recently unpowered camera
  - Sensor starts out saturated!
- Be cautious about light exposure before taking dark data
- Be extra cautious with cooled sensors because leakage time is longer

Photon Transfer Methods can be used to characterize trap capacity and leakage characteristics

- Trap capacity
- Trap leakage
- Temperature behavior

Light Flood Method is effective at mitigating residual image

- Eliminates residual image
- Removes Dark Fixed Patterns from non-uniform trap distribution