Why Detectors are Important

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This is Why Detectors are Important

\[ SNR = \frac{S}{N} = \frac{\eta_{inst} A \frac{\Delta \nu}{h \nu} F_v tQE_v}{\sqrt{\left( \eta_{inst} A \frac{\Delta \nu}{h \nu} F_v tQE_v \right) + \left( \eta_{inst} A \frac{\Delta \nu}{h \nu} F_{back,v} tQE_v \right) + i_{dark} t + N_{read}^2}}. \]

for QLIDs, \( i_{dark} \to 0, N_{read} \to 0, QE_v \to 1. \)

TRANSLATION: With better detectors, you make more discoveries, solve more problems, cure more people, identify more threats, reduce war, and manage resources more effectively.
Make Discoveries: Galactic Center


Gatley/NOAO/KPNO, (PtSi array) G. Neugebauer & E. E. Becklin/Caltech (PbS)
The Galactic Center: Closeup

A major difficulty in doing infrared astrometry in the Galactic center region has been the limitation imposed by single detector systems that require scanning over large distances to form a map. We are now entering an era in which two-dimensional imaging at infrared wavelengths is possible, and images can now be obtained while keeping a telescope pointed in a fixed direction. We have obtained such images using the University of Rochester 32 × 32 InSb array camera that has been described elsewhere (Forrest et al. 1985), in an attempt to specify the location of the Sgr A* radio source with respect to infrared sources in the region.
"Imaging" Detectors for non-imaging Applications: Spectroscopy

Figer et al. 2000
Cure People

Examples of optical bioimaging

- trans-illumination
- single molecule fluorescence
- in vivo bioluminescence

Diffuse optical imaging-2

- Swiss Federal Institute of Technology
- Hitachi Medical Systems
Identify Threats

- Threats to national space security assets
  - inter-continental ballistic missiles
  - anti-satellite kill vehicle
  - orbital debris
  - laser blinding systems

- Threats to people/homeland
  - bio/chem hazards
  - dirty bombs
Reduce War

• Monitoring
  – treaty compliance
  – nuclear proliferation
  – arms buildup

• Enabling pre-emptive strikes

• Enabling conflict resolution
Manage Resources

Water

Vegetation

Forests

Atmosphere (e.g. ozone)
Enter Quantum-Limited Imaging Detectors
Quantum-Limited Imaging Detectors

• These detectors are limited by the information carried by a photon.
  – existence
  – wavelength
  – polarization

• The task to realize these detectors is difficult. It’s “easier said than done…..”
Read Noise

The Importance of Read Noise in Imaging

Images of the Arches cluster near the Galactic center, based on real data obtained with Keck/LGSAO. Each image has synthetic shot noise and increasing read noise (left to right and top to bottom: 0, 5, 10, 100 electrons).
This plot shows a curve of constant sensitivity for a range of telescope diameters and detector read noise values in low-light applications. A 30 meter telescope and zero read noise detector would deliver the same signal-to-noise ratio as a 60 meter telescope with current detectors.
James Webb Space Telescope

[Graph showing signal vs. wavelength with annotations for Sunshield, NGST requirement, NGST goal, and Zodiacal Light.]

[Graph showing duration of DRM NIR observations vs. read noise per exposure with annotations for Spectra and Images.]

Dark current = 0.126 e−/sec, 0.020 e−/sec, 0.003 e−/sec.
Hunt for Dark Energy

Brown 2007, PhD Thesis
Finding Earth-like Planets

TPF-C Detector Requirements

- Coronagraphic Camera
  - Small formats (2k×2k)
  - Wavelength response:
    - 500 nm - 1000 nm (Si) [500 nm - 1.4 nm (InGaAs)]
  - High dynamic range
    - Target acquisition
    - Wavefront sensing and control
    - Loss of lock (robust against extreme overillumination)
  - ≤ 2 e⁻ read noise (0 e⁻ preferred)
  - Low dark current (≤ 1 e⁻/pixel/hr)
  - Low power
  - Effective operations strategy for cosmic ray mitigation
    - (long exposures required)
  - Radiation tolerance

- Additional for Spectrograph
  - Zero read noise required
  - Energy Resolution (3-D spectroscopy @ R~100)

Clampin 2005, SDW
Imaging at Night

![Image of illuminated scene](image)

![Graph showing SNR vs. ground irradiance](graph)

- **SNR** (Signal-to-Noise Ratio)
- **ground irradiance (W/cm²)**

Legend:
- Photon shot limited
- 50um GM-PD
- KAI-4021 6x6 agg
- Fairchild TDI 6x6 agg

- **Starlight**
- **Half moon**
- **Full moon**
- **Nautical twilight**
- **Civil twilight**
- **Sunset/Sunrise**
Traditional Low-Light Limitations

Short Integration Time Infinite
LIDAR+Photon Counting Simulation

LIDAR Imaging

3D Point Cloud

Integrated 2D Intensity Image Utilizing Laser for Illumination

Full Moon

Half Moon

New Moon

Gm-APD as a Photon Counter Under Ambient Illumination
Key Detector Characteristics

- Homeland Safety
- Biomedical Imaging
- Earth System Science
- Defense

Quantum-Limited Imaging Detector

- Read Noise
- Dark Current
- QE
- $\lambda$
- $\lambda/\Delta\lambda$
- $\Delta t$
- P
Challenges
QLID Technology Challenges

- Non-standard (non-CMOS) fabrication
- Cold temperature operation (10’s mK?)
- False counts (afterpulsing)
- Long dead times
- Low spectral resolution
- Polarization?
Challenges=$$$
George Smith and Willard Boyle Invent CCDs at Bell Labs in 1969
In 1973, the American company Fairchild Imaging developed their first commercial CCD. Consisting of 100 x 100 pixels, it was used in 1974 to produce the first astronomical photo ever taken by a digital camera. It consisted of an image of the Moon captured using a 20-centimetre telescope, by Jim Janesick (http://astro-canada.ca/_en/a2310.html)
Summary

• Detectors play a crucial role in high performance photon sensing instruments.
• Some of the most demanding future applications require new advanced detectors.
• We are at the cusp of the era of quantum-limited imaging detectors.