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# 2048x2048 HgCdTe FPA Status

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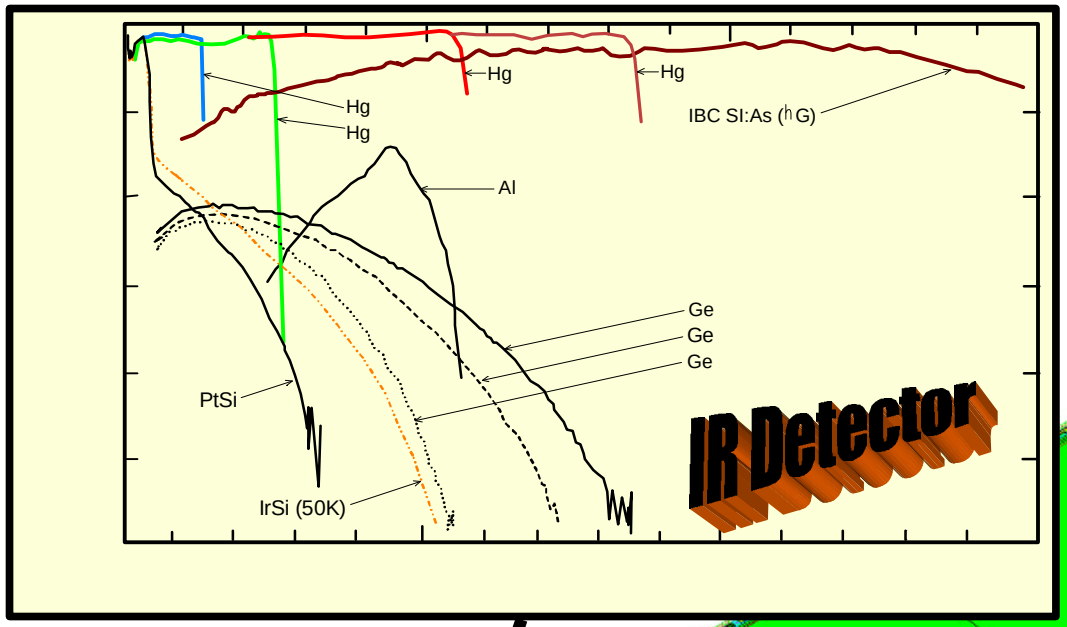
# Outline

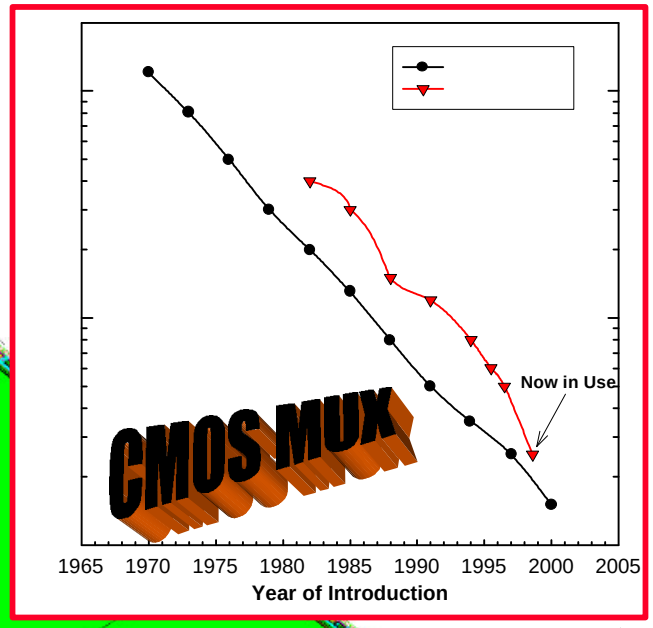
- Introduction
  - Hybrid Methodology
    - Continuing FPA Development Progress
- HAWAII-2 Details
  - Detector Array
  - CMOS Readout
- Latest HAWAII FPA Data
- Status
- Summary & Conclusion

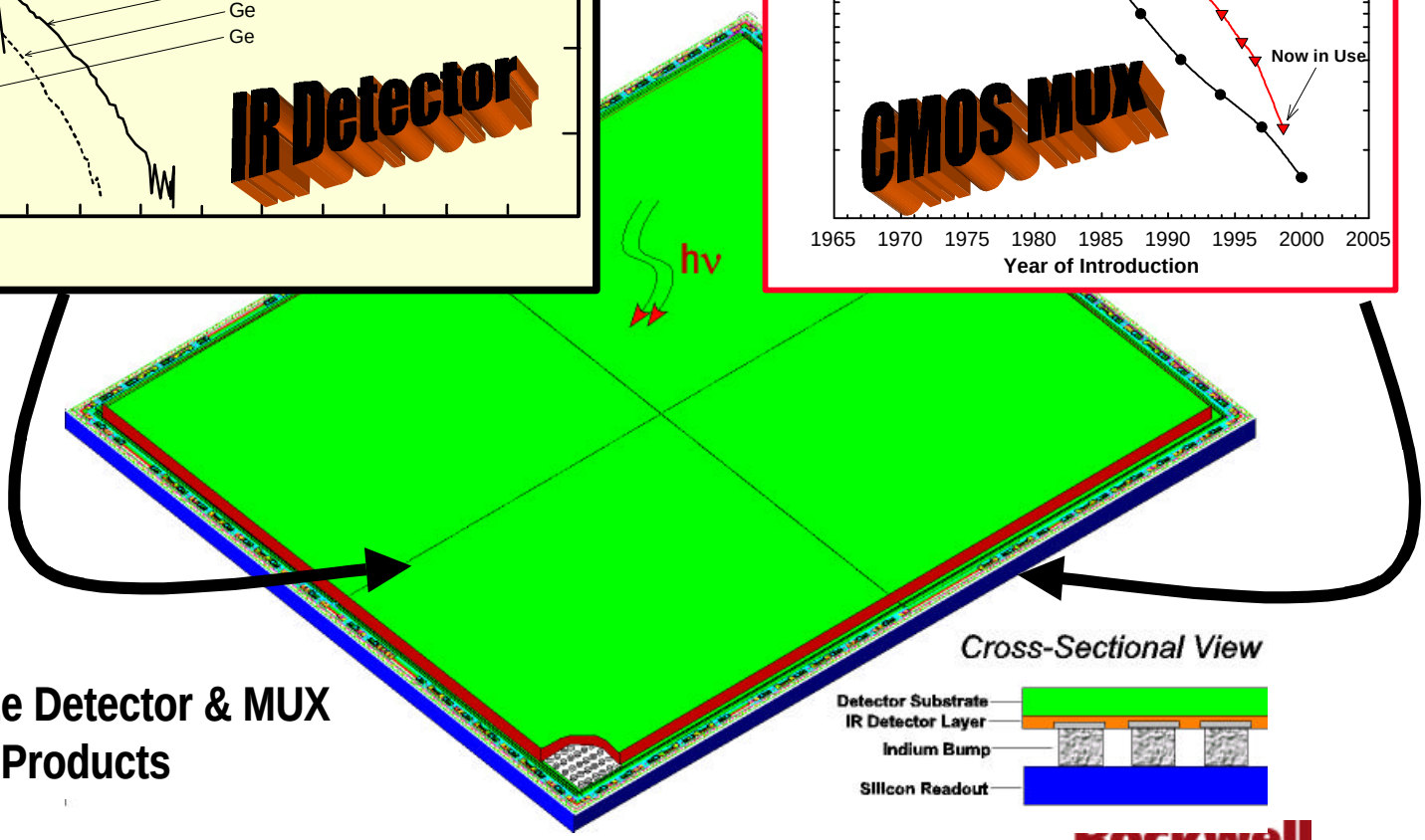
# Acknowledgements


- Development of the $2048^2$ HAWAII-2 FPA was orchestrated and is being led by the University of Hawaii, Institute for Astronomy
  - Klaus Hodapp and Donald Hall
- Other members of the consortium currently include ESO and Subaru, but list is now growing

# Rockwell Hybrid FPA Methodology




- Independently Optimize Detector & MUX
- Mix-and-Match Hybrid Products

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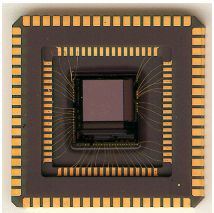
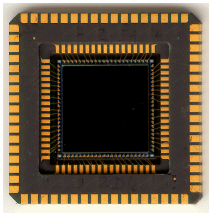
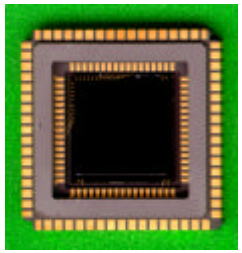
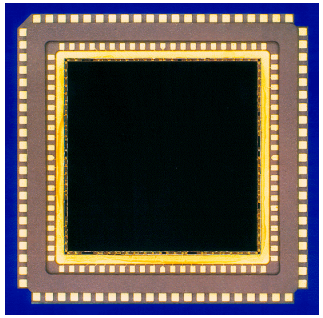
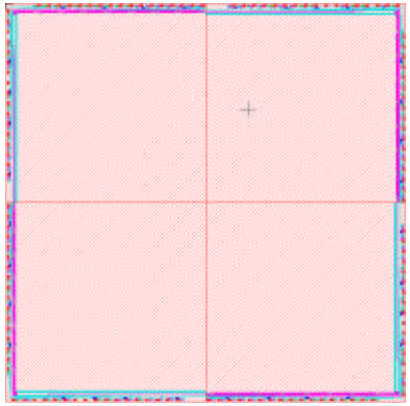
# Chronology of RSC FPAs for Astronomy

| NICMOS | | PICNIC | HAWAII | |
|---|---|---|---|---|
| 1987 | 1990 | 1994 | 1994 | 1998 |
|  |  |  |  |  |
| 16,384 pixels<br>70,000 FETs<br><50 e- | 65,536 pixels<br>250,000 FETs<br><30 e- | 65,536 pixels<br>250,000 FETs<br><15 e- | 1.05 million pixels<br>>3.4 million FETs<br><9 e- | 4.2 million pixels<br>>13 million FETs<br>Goal: <2 e- (Fowler) |

- $2048^2$ Readout Can Subsequently be Used for Visible and MWIR



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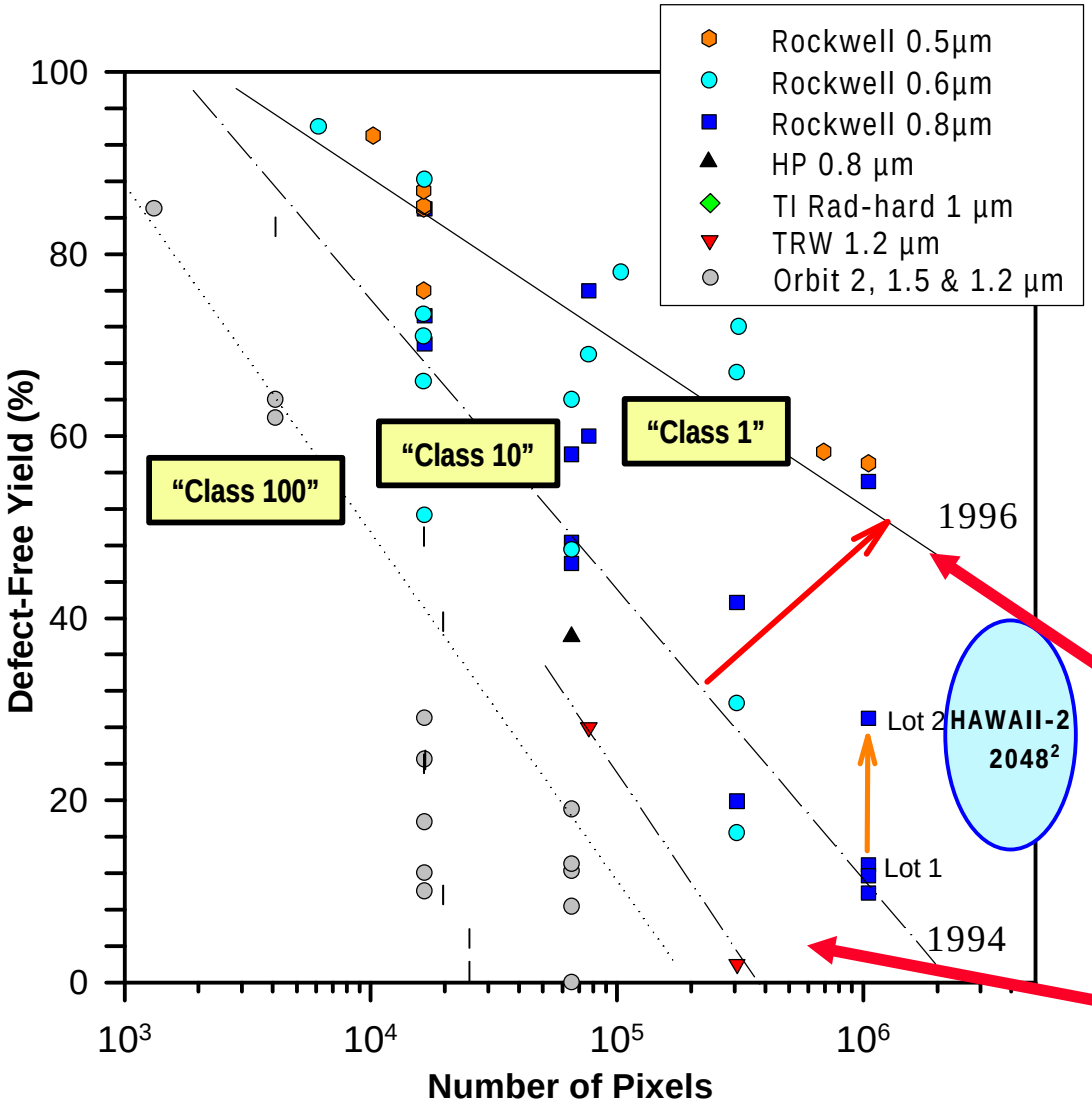
# World-Class Submicron CMOS:

## – High Yield, High Integration, Sets Large ROIC Pitch at ~20 µm




- **RSC is Exploiting Commercial CMOS to Fabricate Large and/or Complicated Readouts**
- **Expecting Up to 40% Yield of Defect-Free $2048^2$ Die**

**Class 1 Submicron Yields Translate to Success & <22 mm x 22 mm Die**

**<Class 1 Processes Compatible with Wafer-Scale Lithography Translate to Larger, but Defect-Riddled Die**

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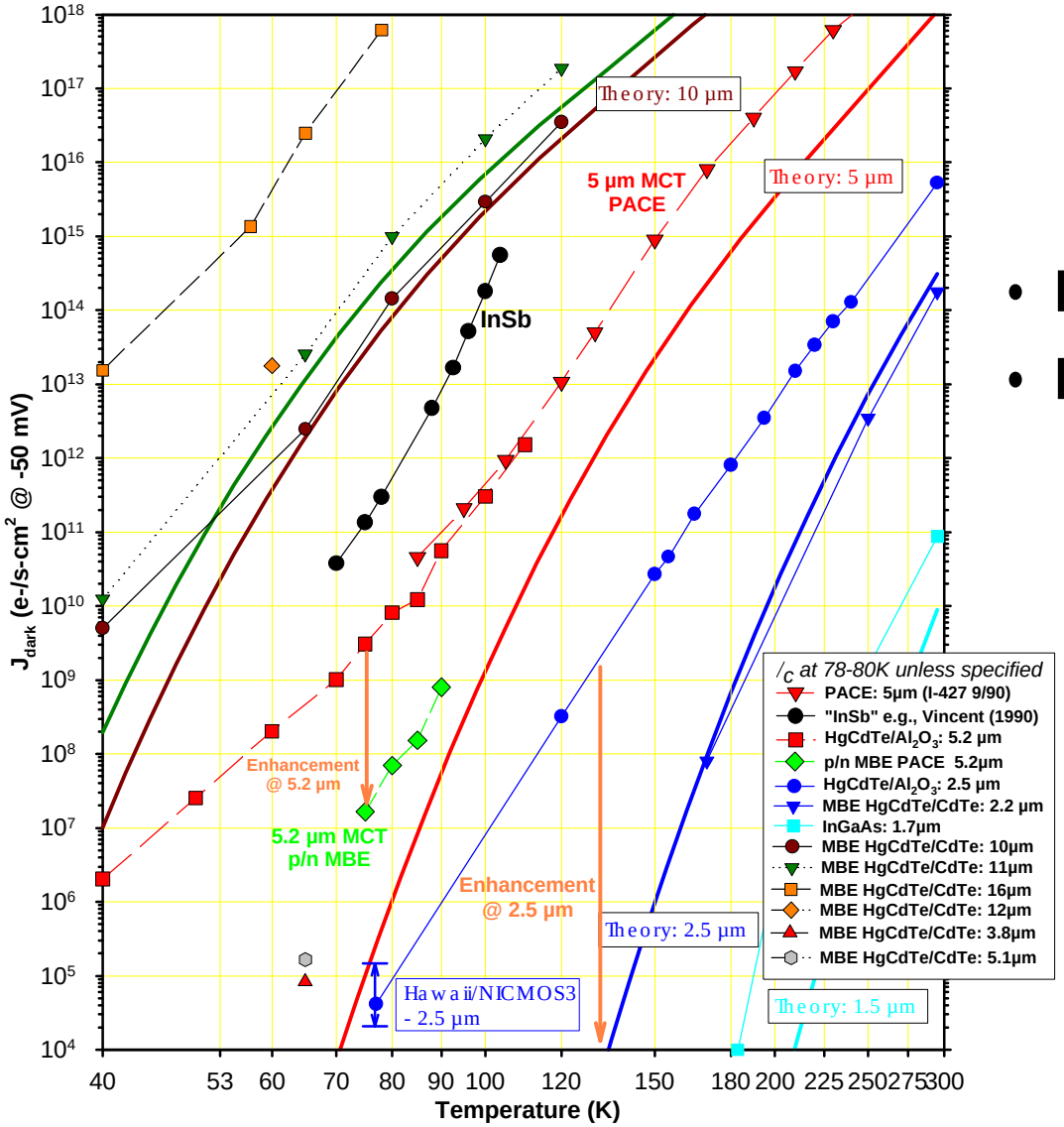
# HAWAII-2 is Also Leveraging Broad-Based HgCdTe Detector Array Development




- PACE (HgCdTe/$Al_2O_3$)
- DLPH HgCdTe
  - HgCdTe/Si
  - HgCdTe/CdZnTe
    - Lower $I_{dark}$
    - Enhanced Characteristics
    - Negligible Persistence
    - Cutoff Wavelengths to 17.4µm Demo'd

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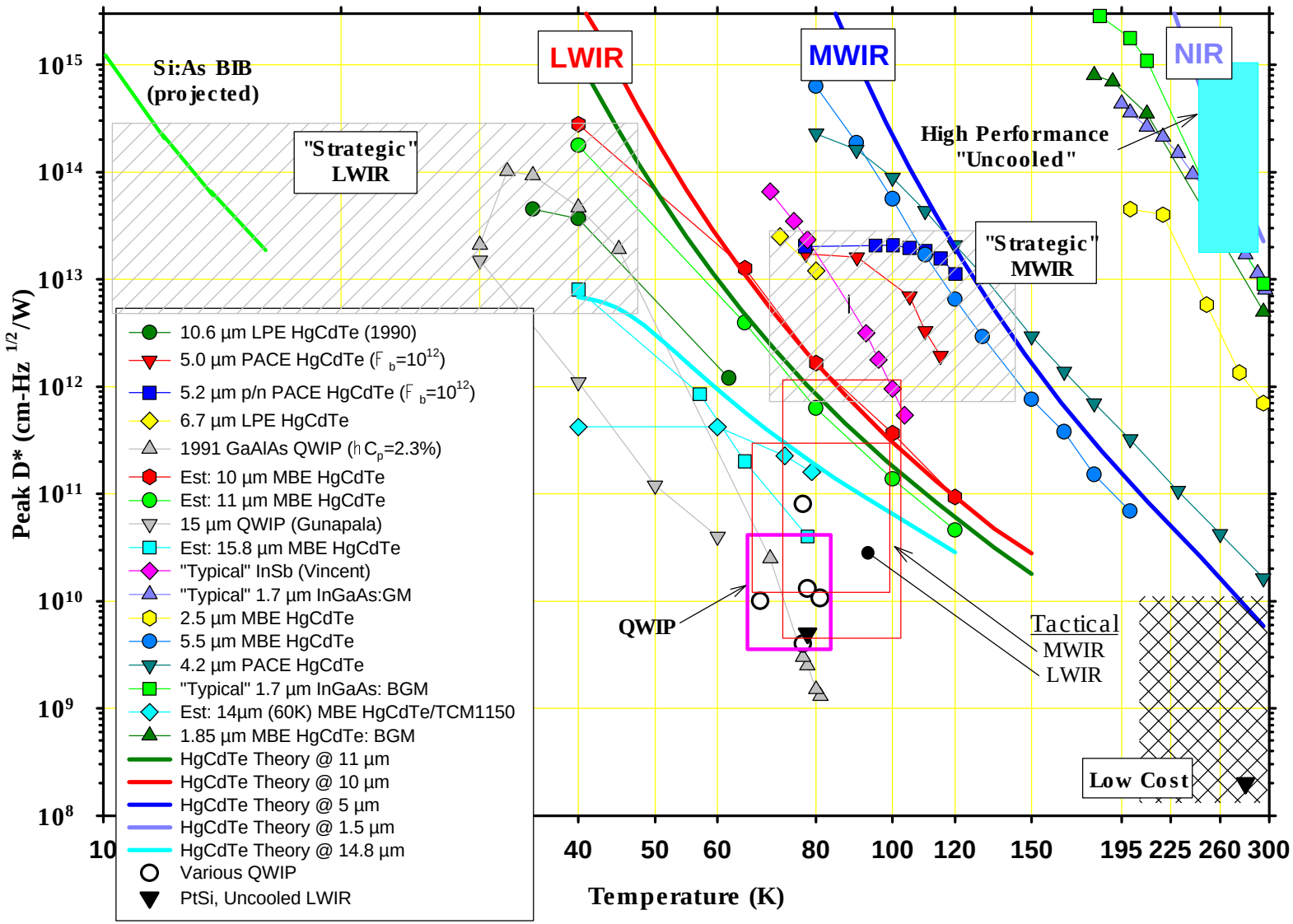
# HgCdTe: Unmatched All-Band Performance

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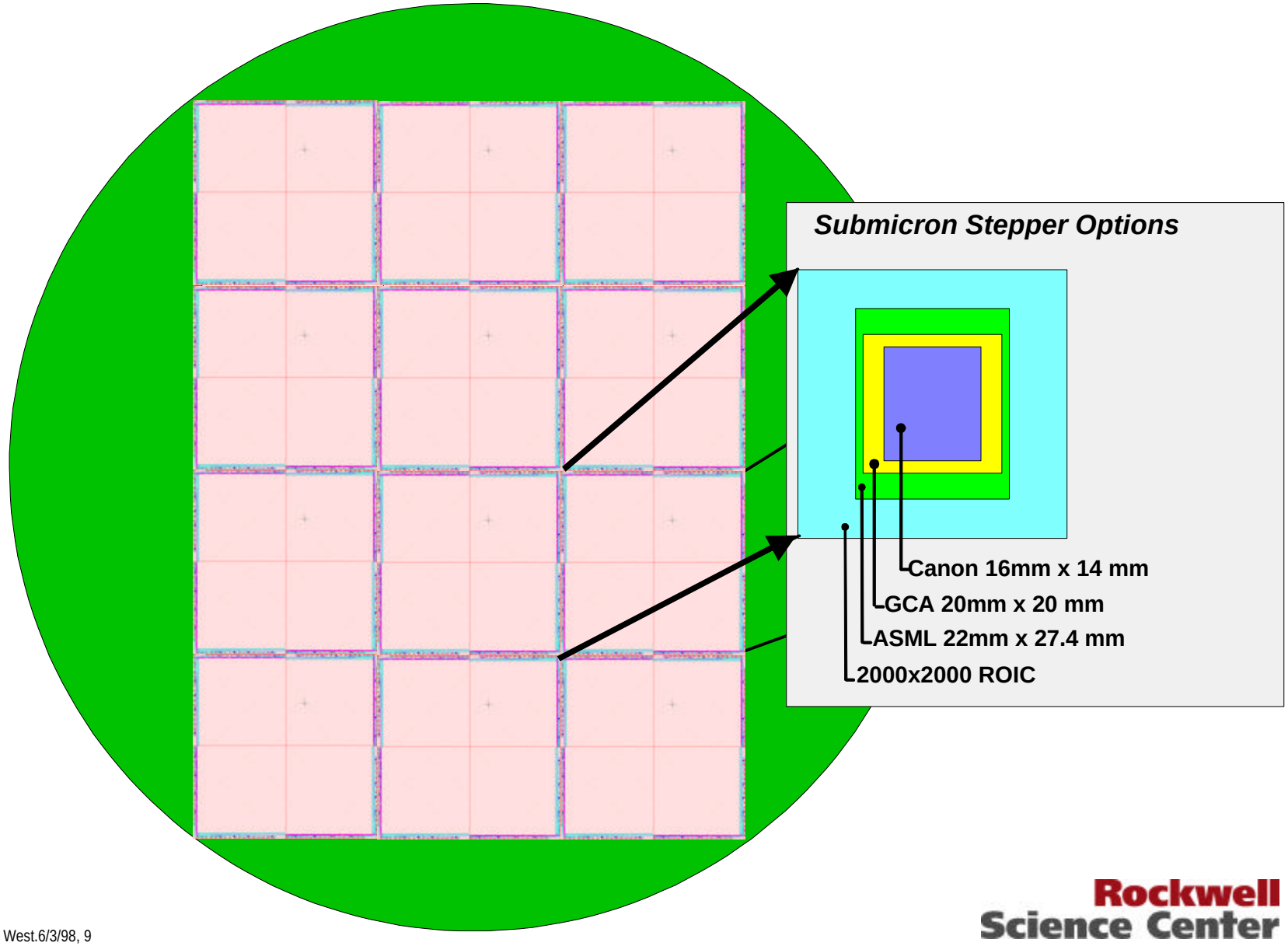
# $2048^2$ FPA for Astronomy
# - Will Stitch 4 Reticles via Photolithography



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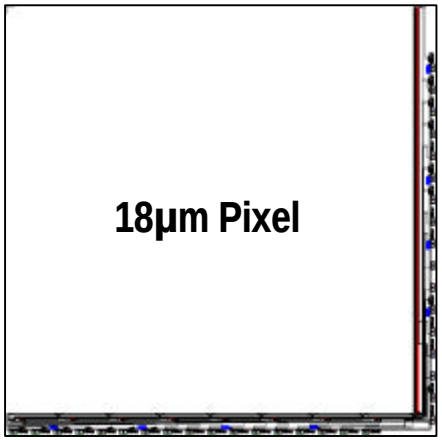
# HAWAII-2 vs. HAWAII




34 I/O Pads per Quad

- Increase Format to 2048x2048
- Change from 4 Outputs to Programmable 4-32 Outputs With Optional Amp Offset Suppression Mode
- Compatibility with 10X Higher Background Irradiance
- Increase Die to 39x39 $mm^2$ from 19.8x19.8 $mm^2$
- Reduce Pixel Pitch to 18 µm from 18.5 µm
- Change to zero-insertion-force (ZIF) pin grid array (PGA) package from leadless chip carrier (LCC)
- Refine Basic HAWAII Design Aspects
  - Change Clocking to Eliminate Glow
    - Requires 10 Clocks for Highest Performance Operation
  - Reference Output Added to Each Quadrant



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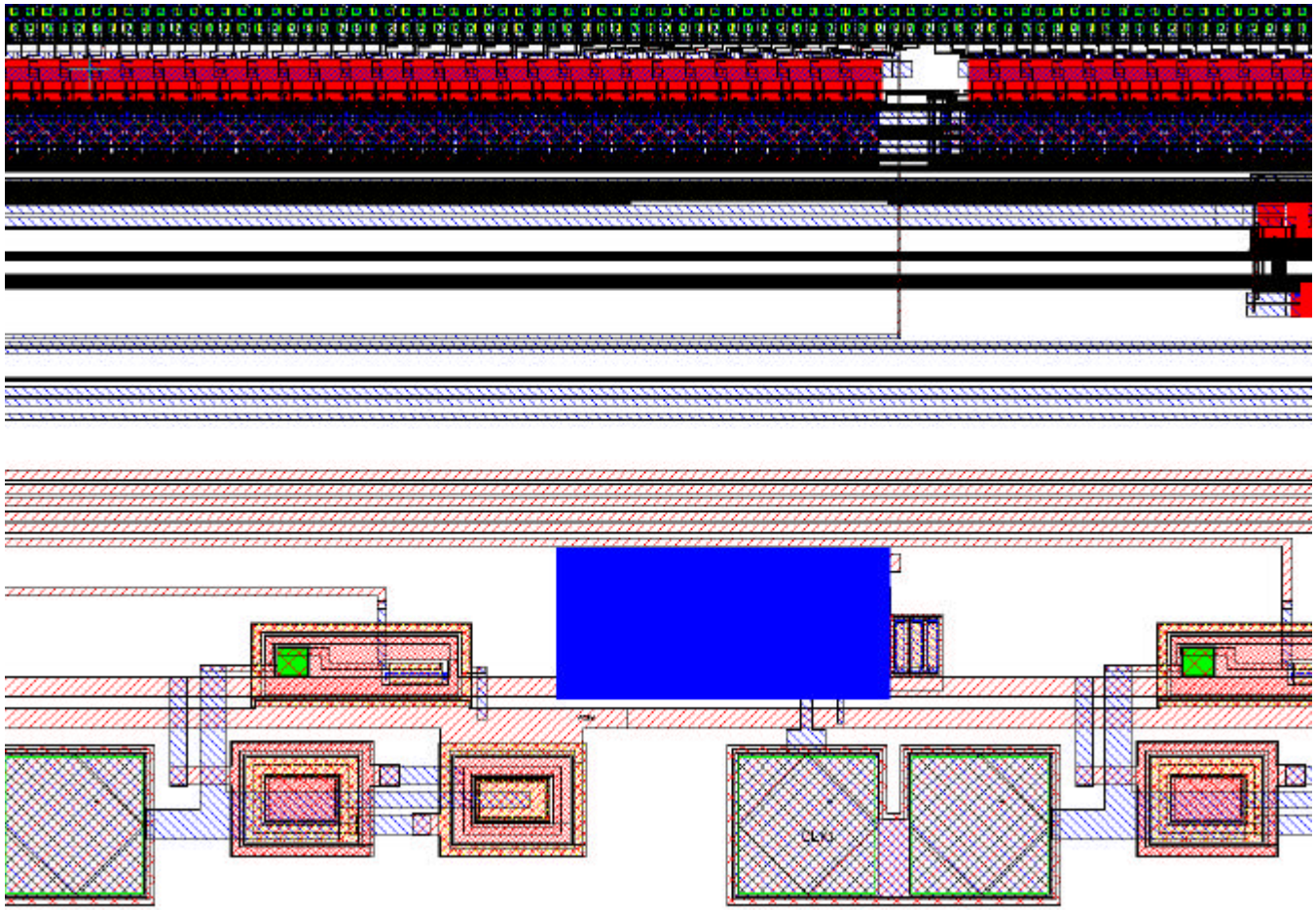
# Negligible “Glow” Expected

- **18µm Pitch: Larger Space between Output Amps and Active Array**





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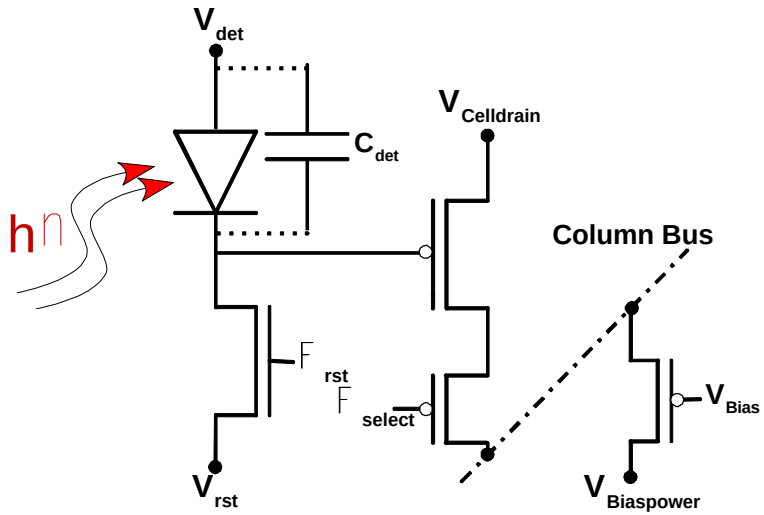
# Detector Interface: Source Follower

- **Post-CDS: SNR is High and Read Noise Low**




**Fraction of BLIP:**

$$\eta_{BLIP} = \sqrt{\frac{\eta A_{det} Q_B \tau_{int}}{\eta A_{det} Q_B \tau_{int} + \frac{2kT\tau_{int}}{qR_{det}} + N_{amp}^2 + \frac{2kT\tau_{int}}{qR_{rst}}}}$$

**Amplifier Noise:**

$$N_{amp} = \frac{1}{S_V}\sqrt{2\int^{\Delta f} V_n^2(f)\frac{\left(1-\cos 2\pi f t\right)}{\left(1+\left(2\pi f T_D\right)^2\right)}df}$$



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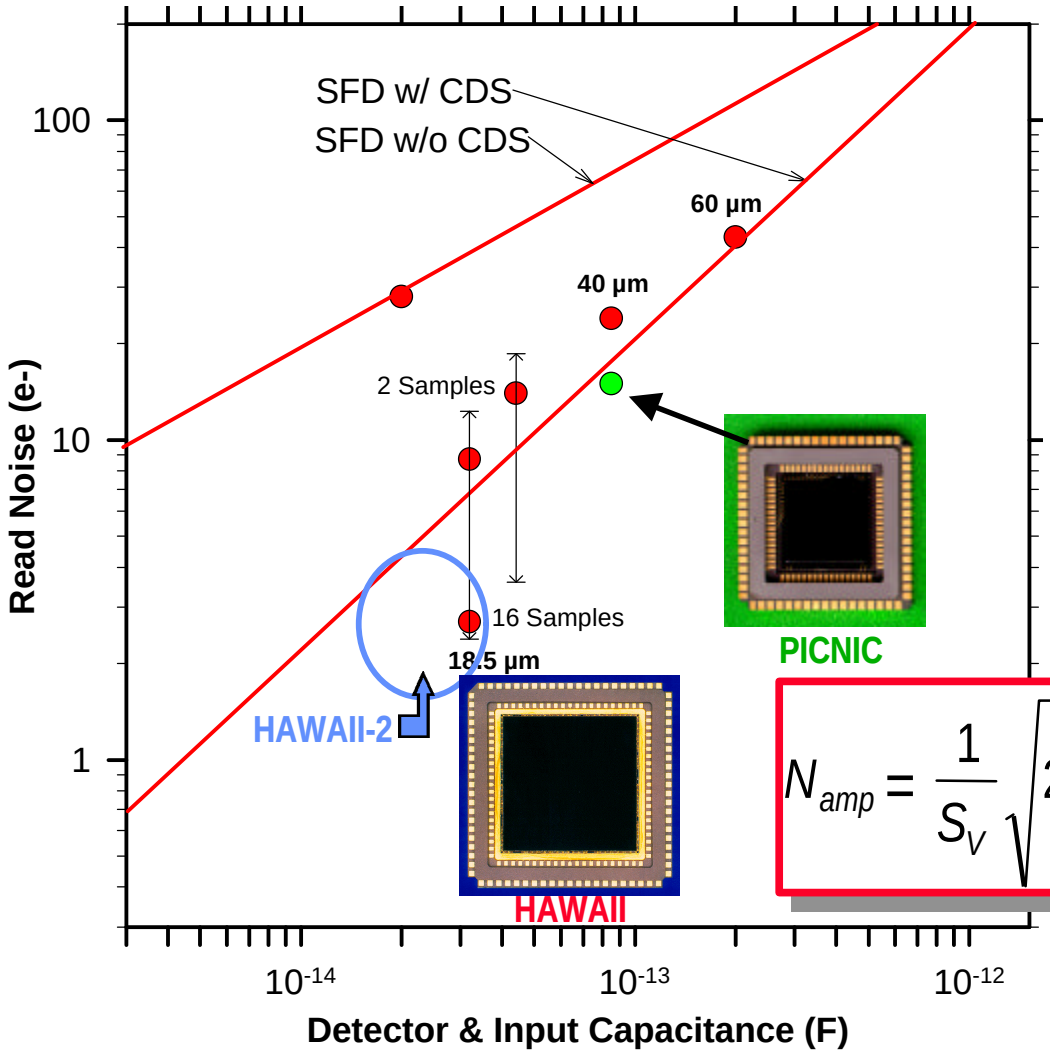
# HAWAII-2: Expect Multi-Sample Read Noise <3 e-




- **16 Fowler Samples**
- **<9 e- with CDS**

$$N_{amp} = \frac{1}{S_V}\sqrt{2\int^{\Delta f} V_n^2(f)\frac{1-\cos 2\pi f t}{\left(1+(2\pi f T_D)^2\right)}df}$$



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# Preliminary HAWAII-2 Specifications

| Parameter | Minimum | Maximum | Units |
|---|---|---|---|
| Format | 2048 ´ 2048 | | Pixels |
| Pixel Pitch | 18 | | µm |
| Chip Package (Optional) | 128 Pin | | ZIF PGA |
| Die Size | 39 x 39 | | $mm^2$ |
| Input Circuit | Source Follower | | |
| Temporal Noise Suppression | Off-chip: CDS or Fowler Sampling | | |
| Spatial Noise Suppression | 8-Tap Video Averaging | | |
| Supply Voltage | 5 | | V |
| Integration Capacitance | 20 | 35 | $10^{-15}$ F |
| Charge Capacity @0.5V | 0.102 | 0.180 | $10^6$ e- |
| Input Offset Nonuniformity | | <5 | mV p-p |
| Dynamic Range | >0.8 | 1 | $10^3$ |
| CMOS Clocks | 8 | 10 | |
| DC Biases | 2 | 7 | |
| Mode Select Lines | 3 | | |
| Output Taps | 4 | 32 | |
| Data Rate per Output Tap | | £ 2 | MHz |
| Read Noise | <3 | <9 | e- |
| Conversion Gain ($S_V$) | » 3.5 | » 7 | µV/e- |



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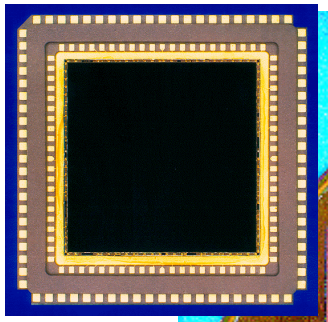
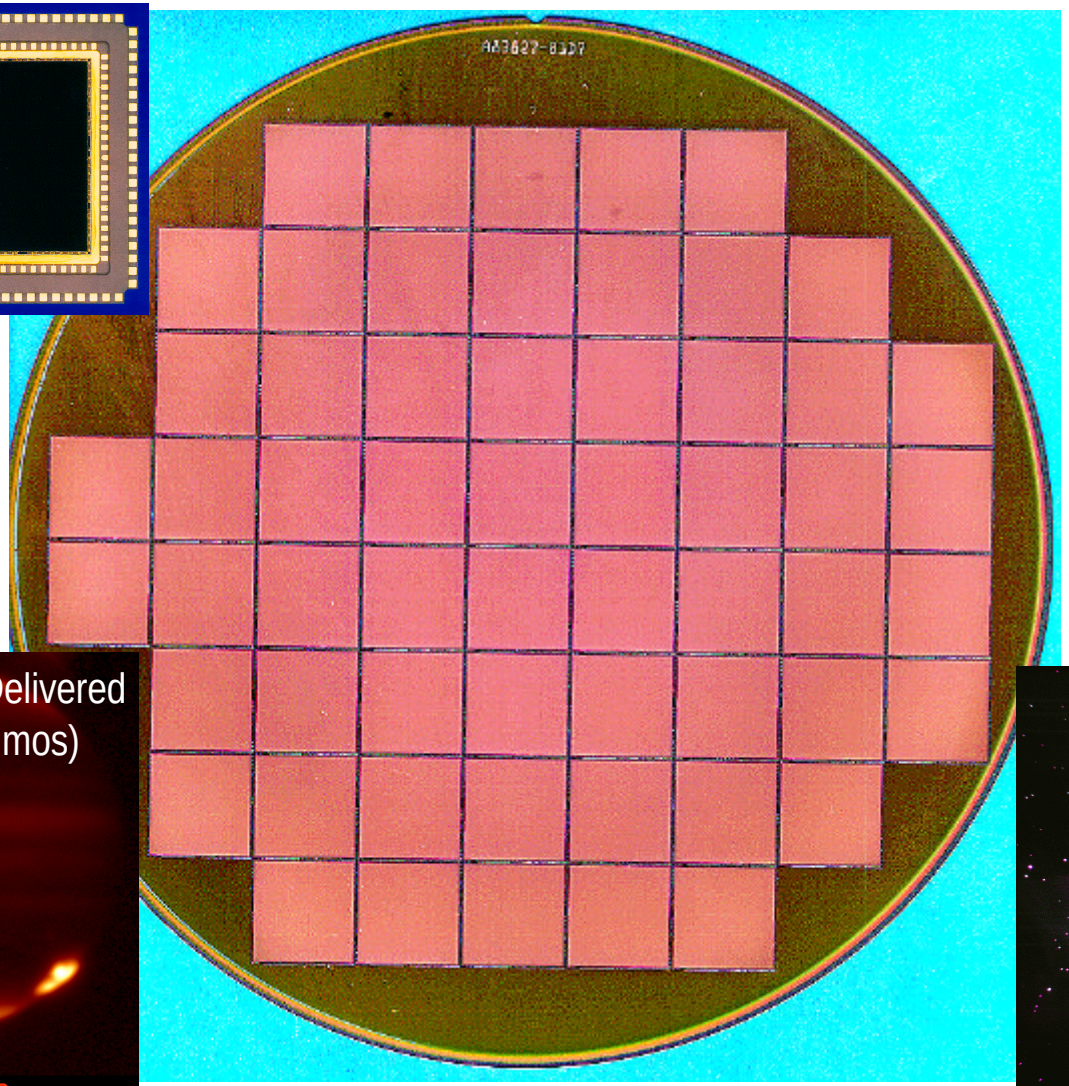
# HAWAII-2

| NAME | DEF. | FUNCTION |
|---|---|---|
| VDD,VDDA,CELLDRAINBIAS POWER | 5V | Power Supplies |
| VSS,MUXSUB | 0V | Multiplexer Ground |
| O1 | 0/5V | Mode Control |
| O2 | 0/5V | Mode Control |
| DRAIN | 0/5V | Output Amp Supply/Bus Output Select |
| VRESET | 0.5V | Detector Reset Voltage |
| DSUB | 0V | Detector Common |
| BIASGATE | 3.8V | Sets SFD Current |
| VCLK | 0-5 | Fast Clock |
| LSYNC | 0-5 | Line Synchronization |
| CLK2 | 0-5 | Line Clock 2 |
| CLK1 | 0-5 | Line Clock 1 |
| CLKB2 | 0-5 | Line Clock Bar 2 |
| CLKB1 | 0-5 | Line Clock Bar 1 |
| FSYNC | 0-5 | Frame Synchronization |
| RESET | 0-5 | Pixel Reset Clock |
| READ | 0-5 | Pixel Read Clock |
| LRST | 0-5 | Output Shuffle Reset |

# Latest $1024^2$ Data





1995 → 1998

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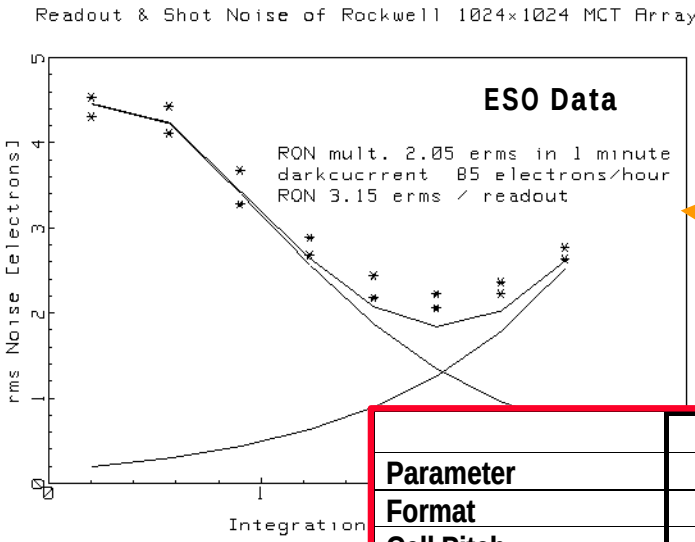
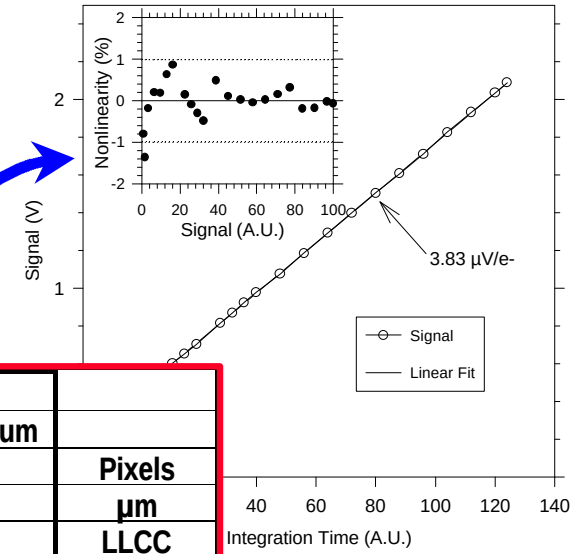
# World's First High Sensitivity $1024^2$ IRFPAs

## - Complementary Devices for Surveillance, Astronomy, ...




**HAWAII: Ultra-Low Noise, Power and Glow**

| Parameter | Astronomical Nominal | Astronomical Maximum | Surveillance Nominal | Surveillance Maximum | |
|---|---|---|---|---|---|
| Format | 1024x1024 | | 1024x1024 | | Pixels |
| Cell Pitch | 18.5 | | 18.5 | | µm |
| ROIC Package | 84 pin | | 84 pin | | LLCC |
| CMOS Technology | 0.8 | | 0.8 | | µm |
| Input Circuit | Source Follower | | Capacitive TIA | | |
| Noise Processing | Off-Chip | | On-Chip Bandlimiting | | |
| Supply Voltage | 5 | 5.5 | 5 | 5.5 | V |
| Video Rise Time | 300 | | 12 | 15 | ns |
| Video Fall Time | 50 | | 15 | 20 | ns |
| Video Swing | 0.4 | 0.8 | 2.2 | 2.4 | V |
| Charge-Handling Capacity | 0.102 | 0.105 | 0.574 | 0.626 | $10^6$ e- |
| Input Offset Nonuniformity | <5 | <15 | <5 | <25 | MV p-p |
| Dynamic Range | 1 | 1.25 | >4 | 21 | $10^3$ |
| Data Rate | 0.3 | 1 | 5 | <14 | MHz |
| FPA Read Noise | <3 | <10 | <30 | <40 | e- |
| Conversion Gain (S) | 3.41 | 6.25 | 3.83 | <4 | µV/e- |

**TCM8000: Low Noise High Speed + Linearity**

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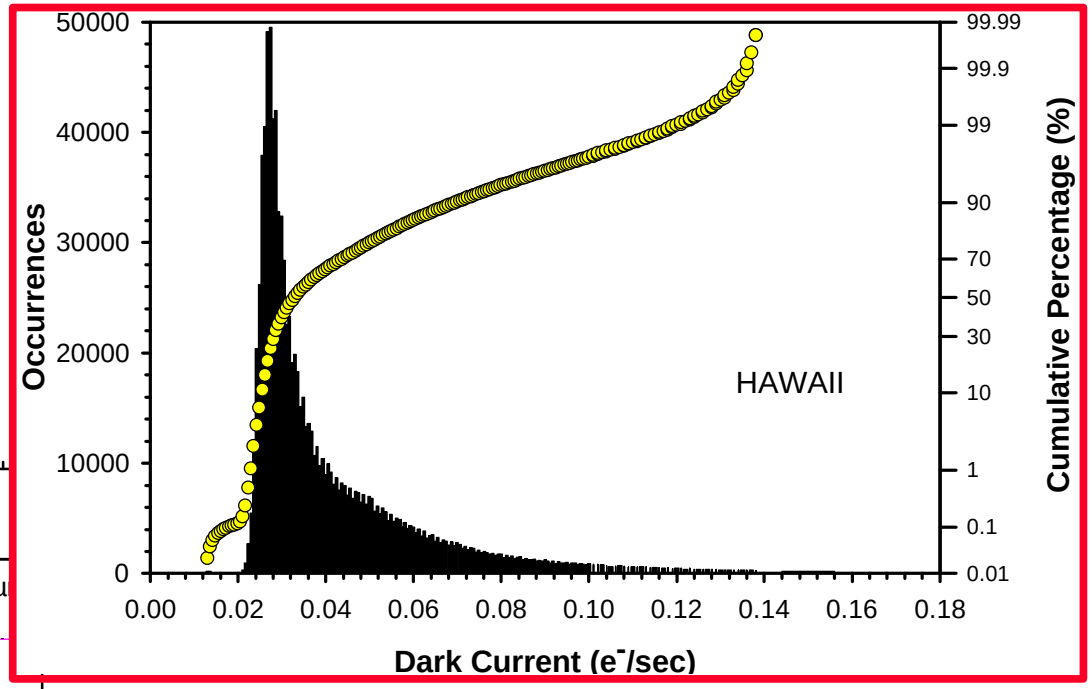
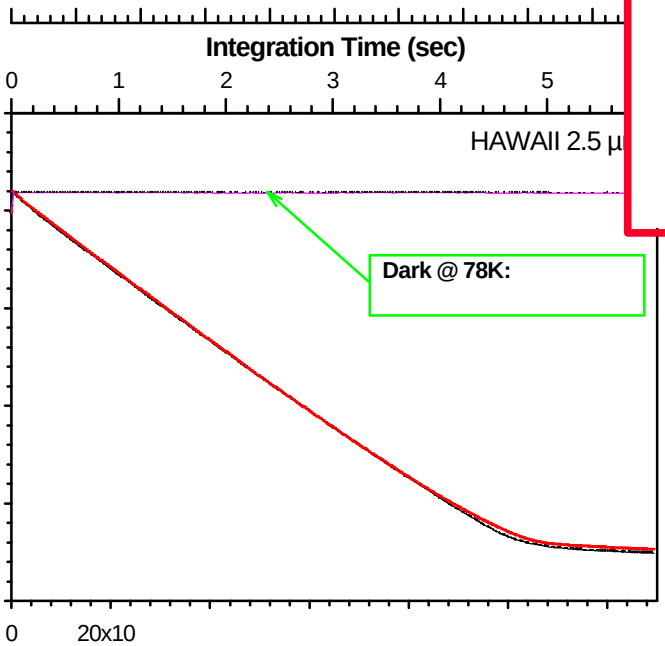
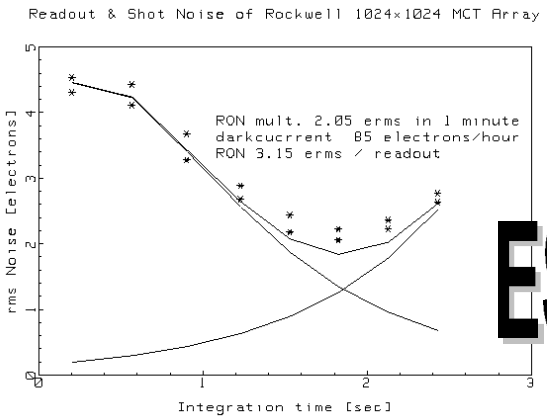
# HAWAII: $I_{dark}$ @78K: 99.98% <0.14 e-/s

**37 FPAs Supplied and in Global Use**




ESO

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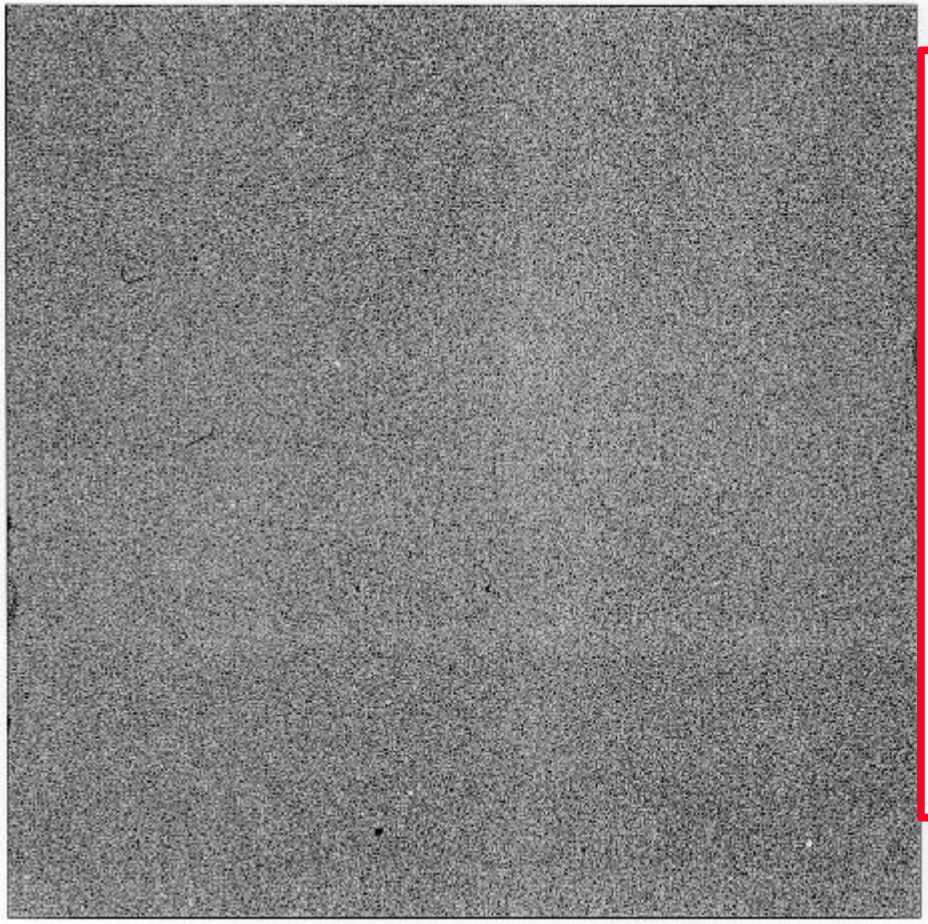
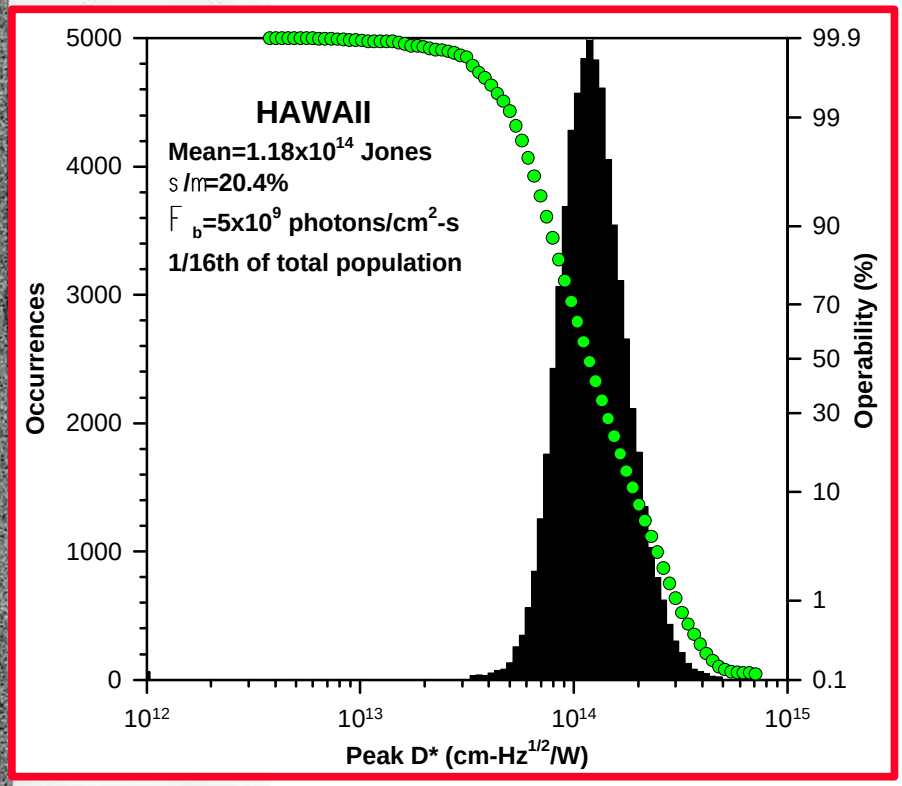
# HAWAII: SNR is Essentially BLIP at $5x10^9$ $cm^{-2}s^{-1}$

- **High Pixel Operability Routinely Achieved**





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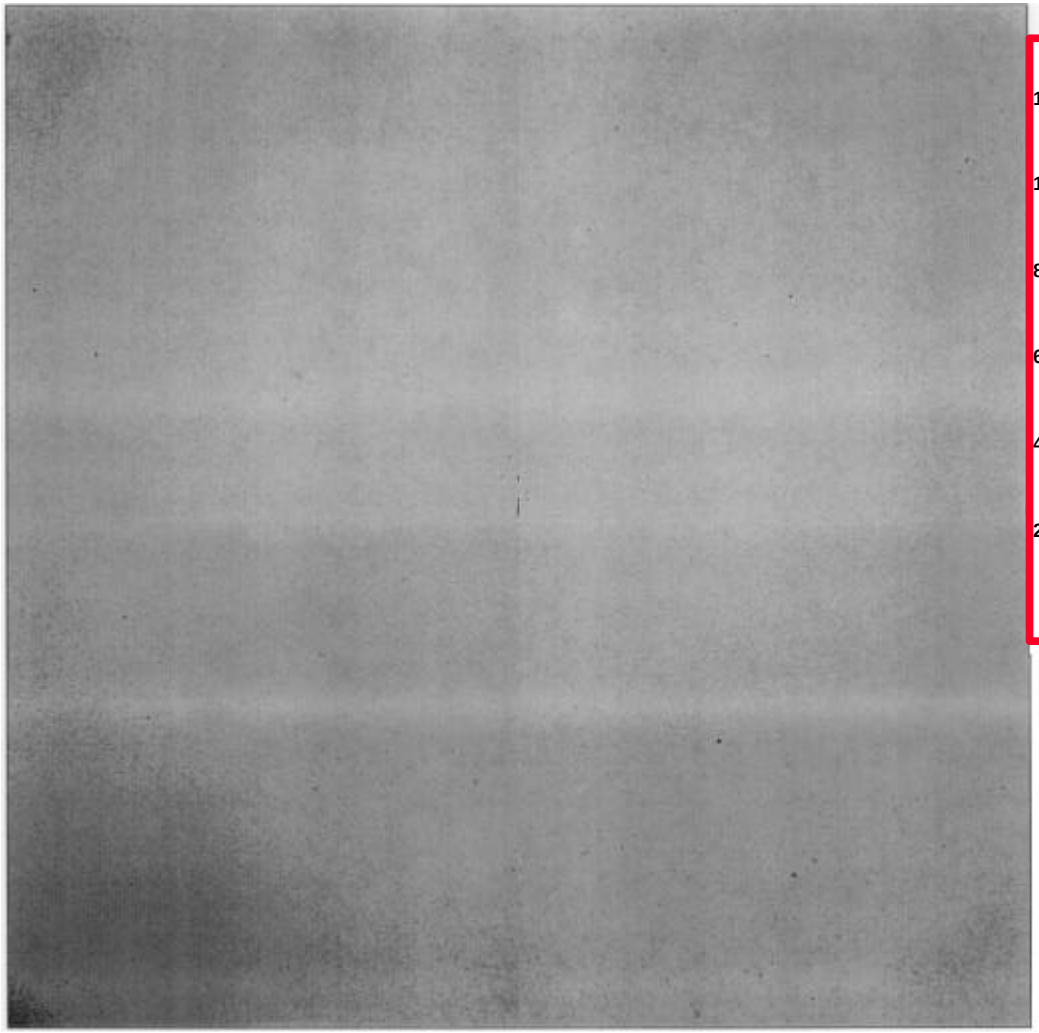
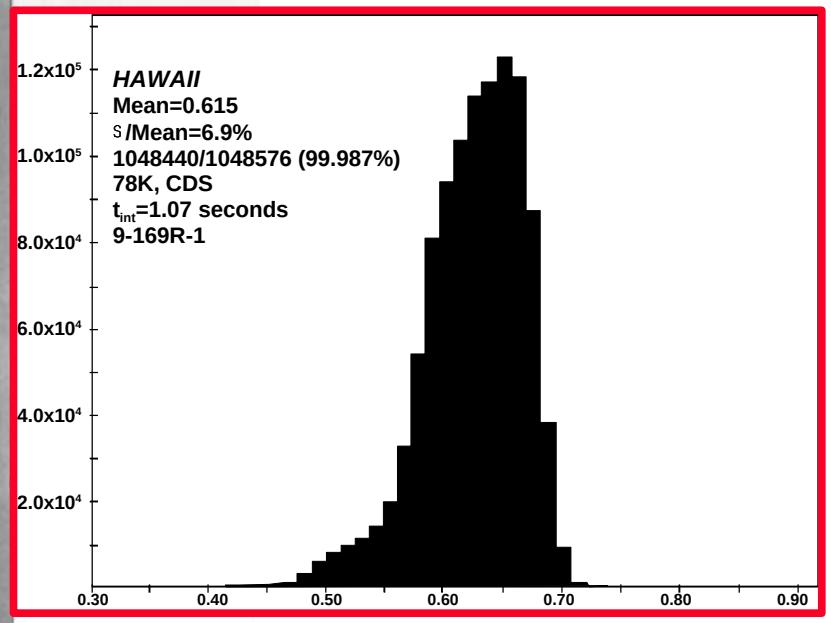
# HAWAII: QE Uniformity






**QE Nonuniformity Dominated by Aperture Shading**



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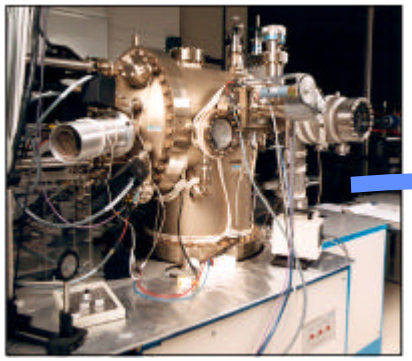
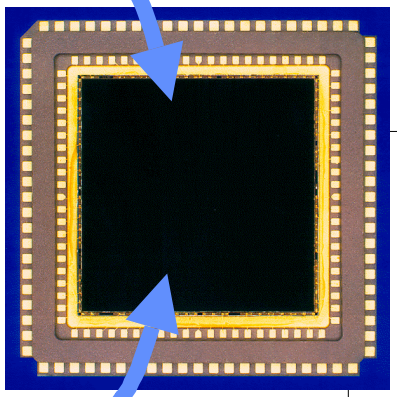
# High Quality 1024x1024 MWIR FPA Recently Demonstrated

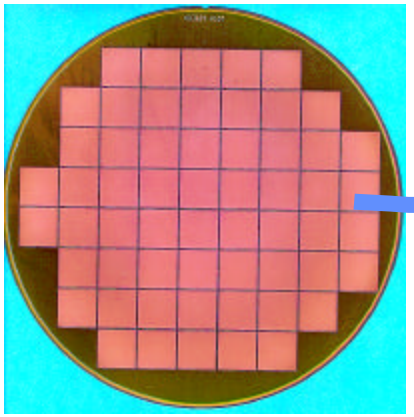
TCM8050 Snapshot ROIC:
7.5x10$^6$ FETs in 0.5µm CMOS



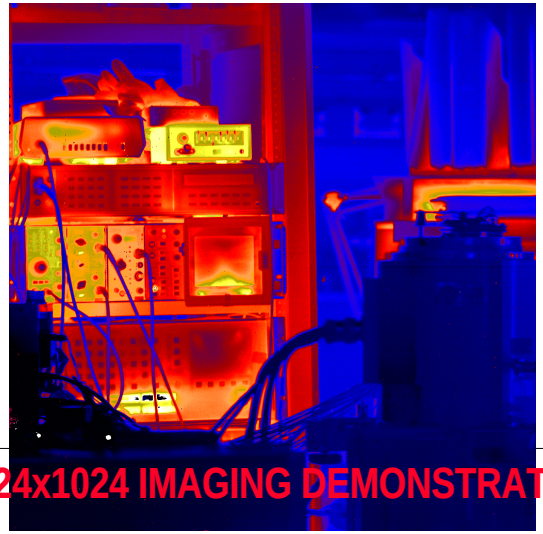
MBE DETECTORS



1024X1024 FPA

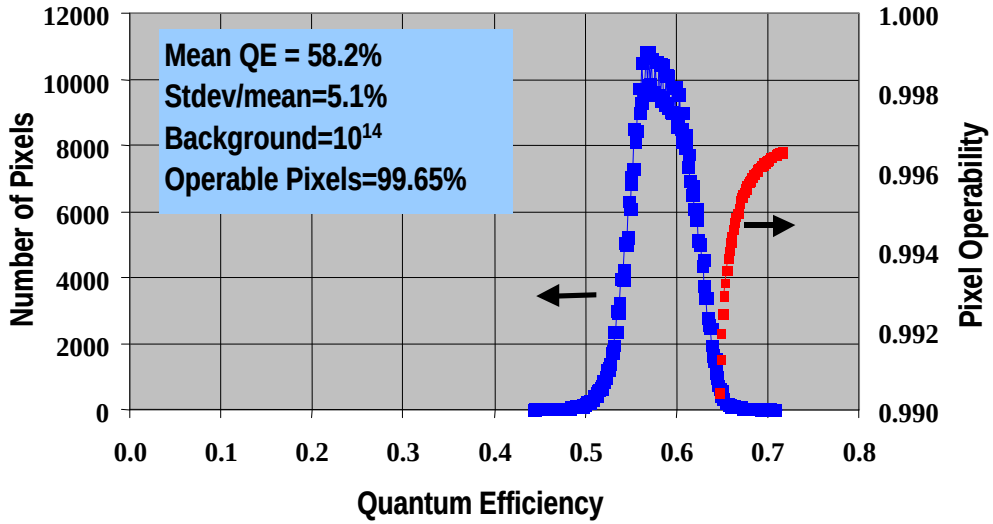


HIGH DENSITY MULTIPLEXERS



MWIR 1024x1024 IMAGING DEMONSTRATED

Focal Plane Array @120K

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# HAWAII-2 Status

- Multiplexer Design Completed and Verified
- Will Now Fabricate Masks and Silicon Wafers
- Will Start Fabricating $2048^2$ Detector Arrays as soon as Detector Arrays Masks are Delivered
  - PACE HgCdTe
  - DLPH HgCdTe (Silicon Substrate)

# Summary & Conclusion

- HAWAII-2 Development on Schedule
- Multiplexer Will Soon be Fabricated in 0.8 µm CMOS
  - Based on HAWAII, but Several Features Added
    - Original HAWAII Never Revised (1st Pass Success)
  - Several Subtle Performance Refinements
- Both PACE and DLPH HgCdTe Detector Array Technologies are Being Pursued
  - Elimination of Image Persistence
  - Reduction of Dark Current
  - Extension to MWIR