Overwhelmingly Large CCDs for Astronomical Applications

2009 Detectors for Astronomy

ESO Garching
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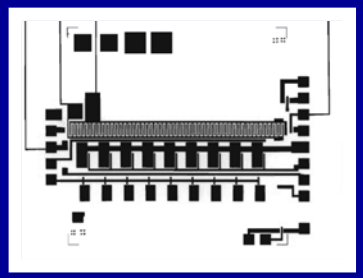
Introduction

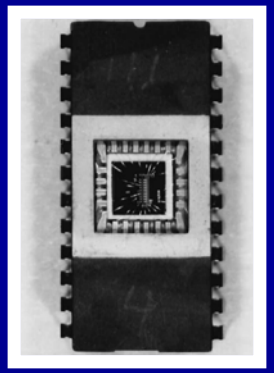
- Semiconductor Technology Associates, Inc. Est. 1999
- Providing imaging industry with custom charge-coupled device design, fabrication, and characterization.
- Past and current developments at STA
- Brief description of recently developed devices of interest for the astronomical community.
- Relentless growth to larger and larger devices with more and more pixels have lead to our current work on a 10k x 10k (Wafer scale Imager).

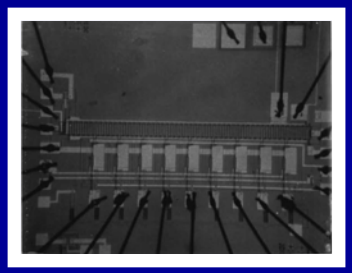
Big Bang Theory

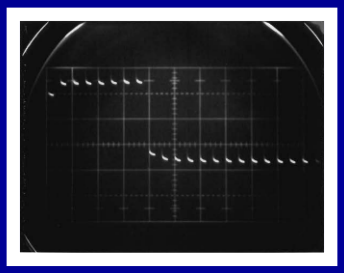
STA Heritage Technology

- Beginning of STA universe
- First devices fabricated at UC Santa Barbara 1974

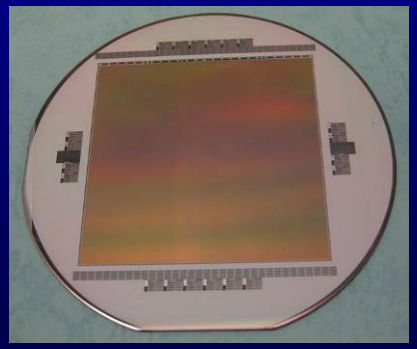








- First 2k x 2k 15 µm pixel produced at Ford Aerospace mid 80’s
- First 4k x 4k 15 µm produced in 1989
  - Whole wafer device, 100mm wafer



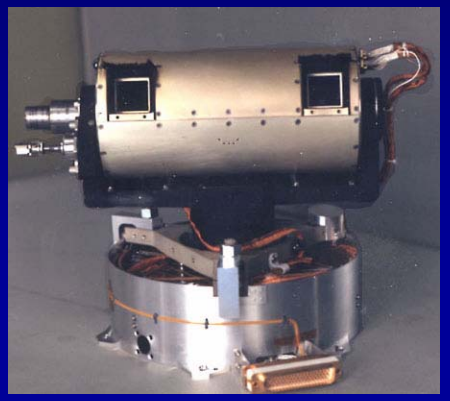
Expanding Universe

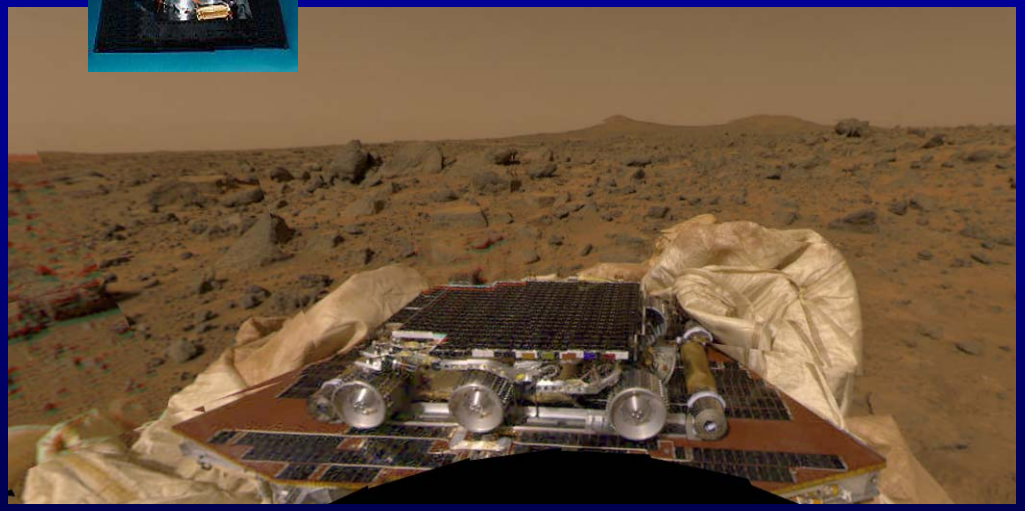
CCD Part Number	Format (pixels)	Pixel Pitch	Imaging Area (mm)	Features
STA0500A	4064 x 4064	15 um	60.96 x 60.96	4 low noise outputs, MPP mode,2 side buttable,2/wafer - BI
STA0700A	2048 x 4000	15um	30.72 x 60.00	2 improved low noise outputs,- BI **FAME**
STA0820A	2048 x 2048	15 um	30.72 x 30.72	2 low noise outputs, 2 High Speed outputs, MPP mode BI
STA0900A	2200 x 1044	27 um	59.4 x 28.188	2 improved low noise outputs-BI **Kepler**
STA1600B	**10560 x 10560**	**9 um**	**95.04 x 95.04**	**16 low noise outputs, MPP mode available,4 side buttable,1/wafer BI URAT / PEPSI**
STA1900A	4072 x 4000	10 um	40.72 x 40.00	16 outputs , deep depletion-BI **LSST**
STA2200A	3840 x 3952	12um	64 cells @ 5.76 x 5.928	Orthogonal Transfer, NMOS logic, 8 outputs deep depletion – BI **ODI**
STA2900A	4032 x 4096	15 um	60.48 x 61.44	4 outputs, MPP high speed- BI
STA3000A	5000 x 2000	8 um	40 x 16	Two outputs, guider chip
STA3200A	**4000 x 4000**	**24um**	**96 x 96**	**16 outputs Full wafer deep depletion - BI**
STA3400A	3840 x 3952	12um	64 cells @ 5.76 x 5.928	Orthogonal Transfer, NMOS logic, 8 outputs deep depletion - BI **PanSTARRS**

Mars Pathfinder Mission

STA Heritage Technology

- Launched December 1996
- Landed Autonomous Rover on Mars July 4, 1997
- Stereo Color CCD Camera Images surrounding Terrain
- Identical to 256x512 CCD Array fabricated for Max Planck Institute and used for the Huygens Probe on the CASSINI Mission

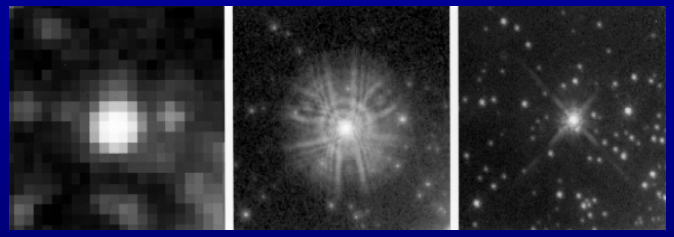


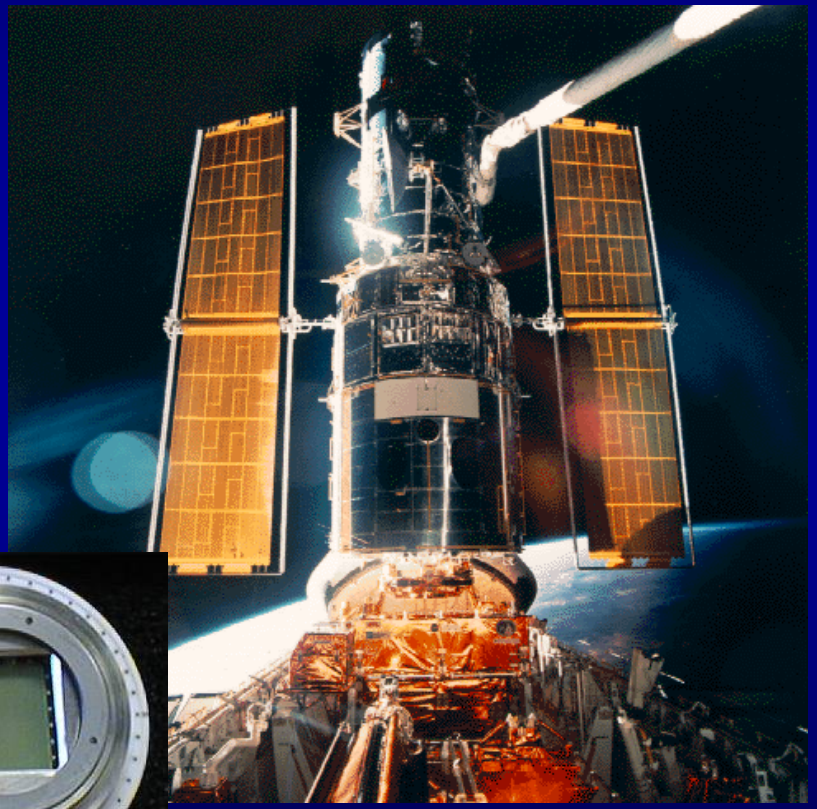


WF/PCCII Hubble Space Telescope

STA Heritage Technology

- Installed during repair mission
- 800x800 15 micron Pixel
  - Nitride-oxide gate dielectric
  - Tri-level polysilicon
- New process technology
  - MPP yields < 10pA/cm2 dark current
  - LDD output < 4e- rms noise





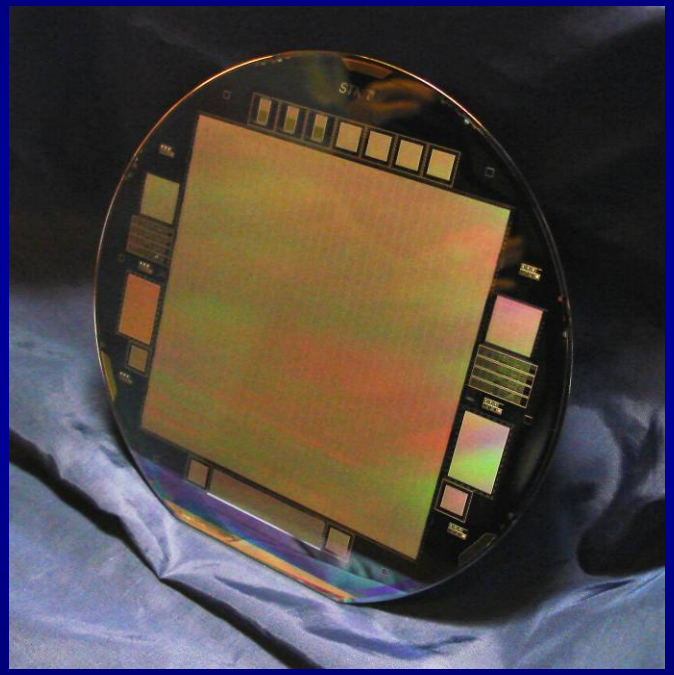
CASSINI Mission

STA Heritage Technology

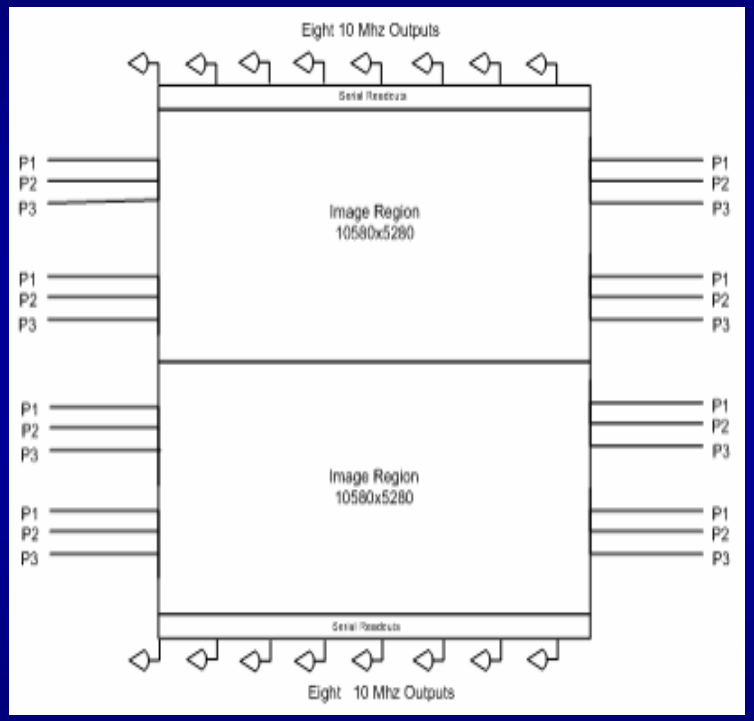
- Fabricated all CCD imagers on mission
  - Main Camera / JPL
    - 1024x1024 12 µm Pixel
    - Space Qualified Lots
  - JPL StarTracker
    - MPP Mode for Low Dark Current
  - Max-Planck Institute Huygens Probe
    - Special Anti-blooming requirements
  - Officine Galileo VIMS
    - Frame transfer 24 µm Pixel

STA1600B 111Mega pixel imager

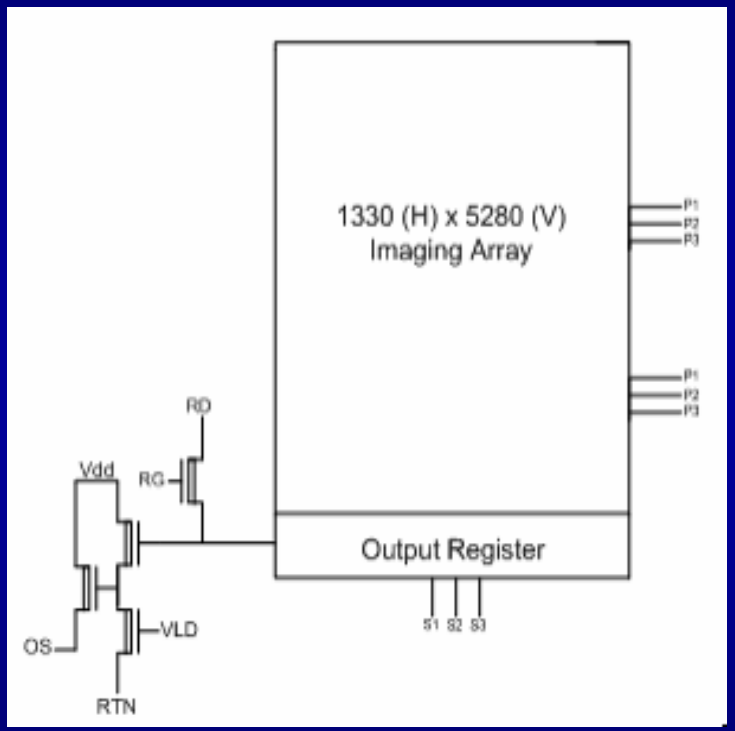
- Full 6” wafer imager
- 10560 x 10560 pixels
- 9 micron pixel
- 111,513,600 pixels per frame
- 16 low noise outputs
- Backside thinned available
- Acquisition speeds up to 1 frame/sec
- Designed for US Naval Observatory



STA1600B Schematic

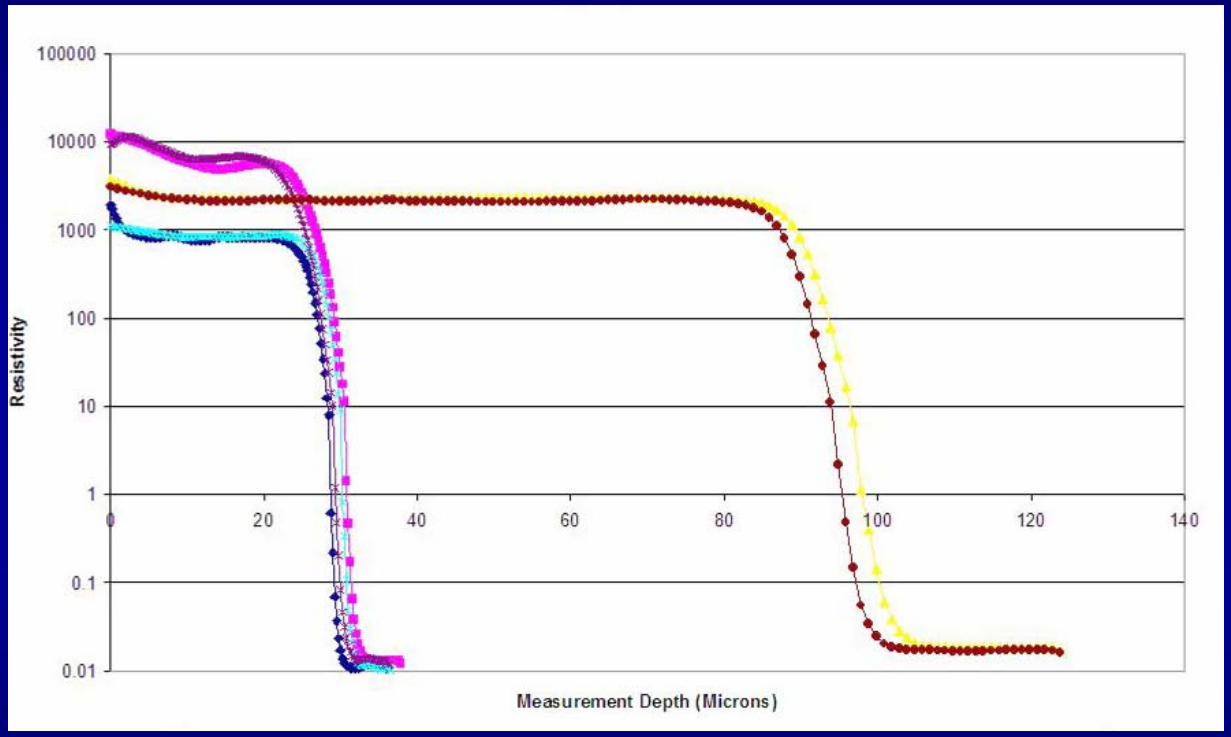


STA1600B Full Imager Schematic



STA1600B Output Section Schematic

STA1600A Epitaxial Material

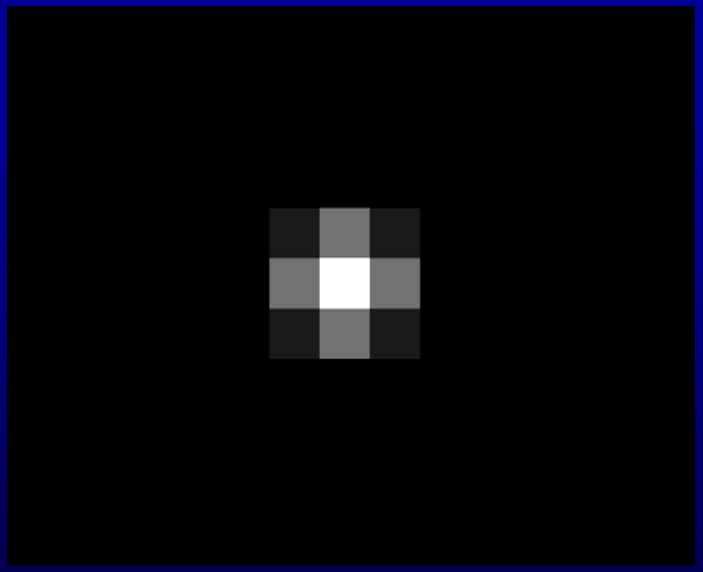


- Material cross section measurement of the Epitaxial Doping
- Two materials: 30 um/ >1000 Ohm-cm and 100 um/ >4000 Ohm-cm

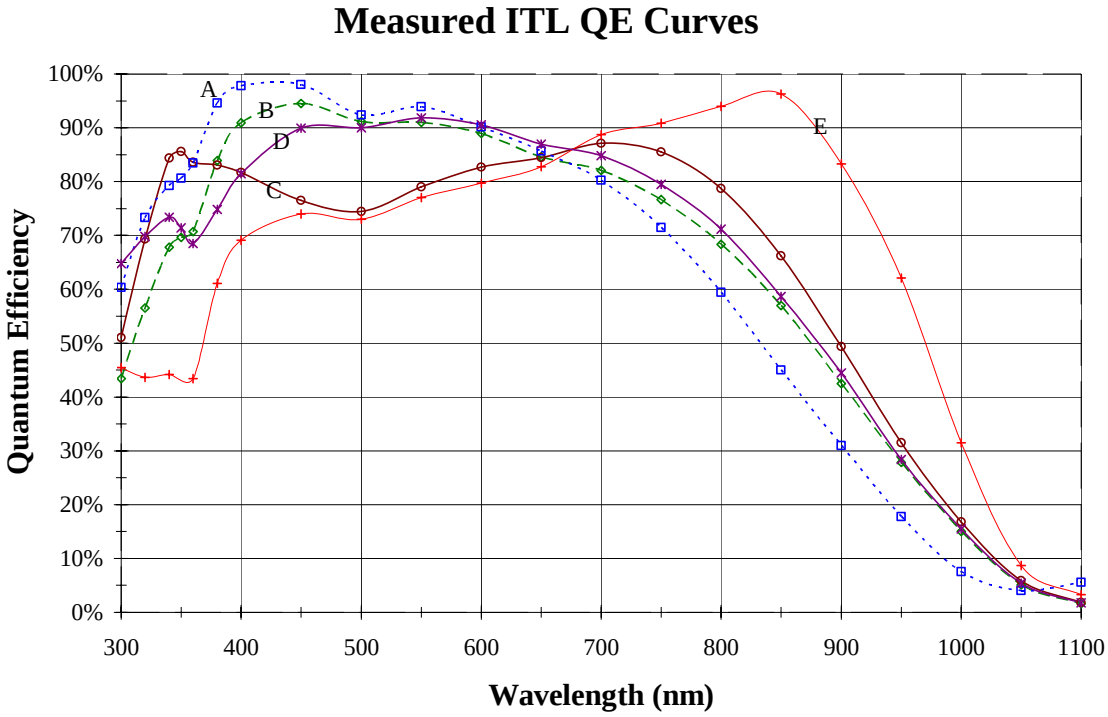
STA1600B Point Spread Function

- PSF Test Set: 20 µm pin hole with reduction optics for a 2 µm spot on the device surface.
- X-Y-Z digital control for focus and virtual knife edge scanning.

- Spot measurement on the 30um thick material with 0V back bias.
- Measured Ensquared Energy of 90%.



QE Examples



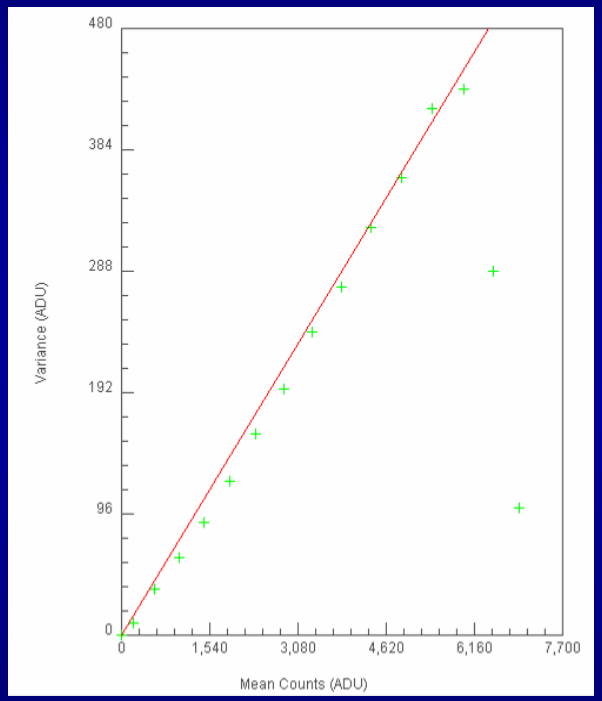
M. Lesser, University of Arizona Imaging Technology Laboratory

- A and B are blue optimized coatings.
- C and D are broadband. D is a new AR coating .
- E is a device with a red optimized coating.

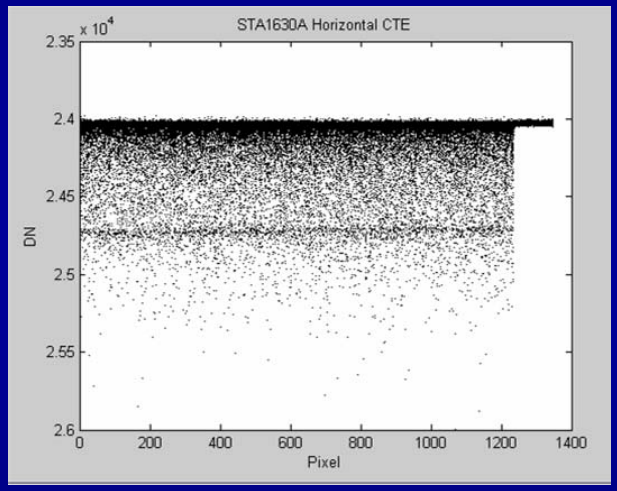
STA1600A Performance

- 7.0 electrons noise @ 1.0 MHz
- HCTE and VCTE > 0.999998
- Full well > 80,000 electrons non-MPP
- 16 amplifiers
  - 8 & 16 channel full frame readout
  - Frame Transfer optional
- Less than 1% non-linearity between 200 e- and 80ke-
- Capable of readout rates up to 20MHz

STA1600A Performance Cont.

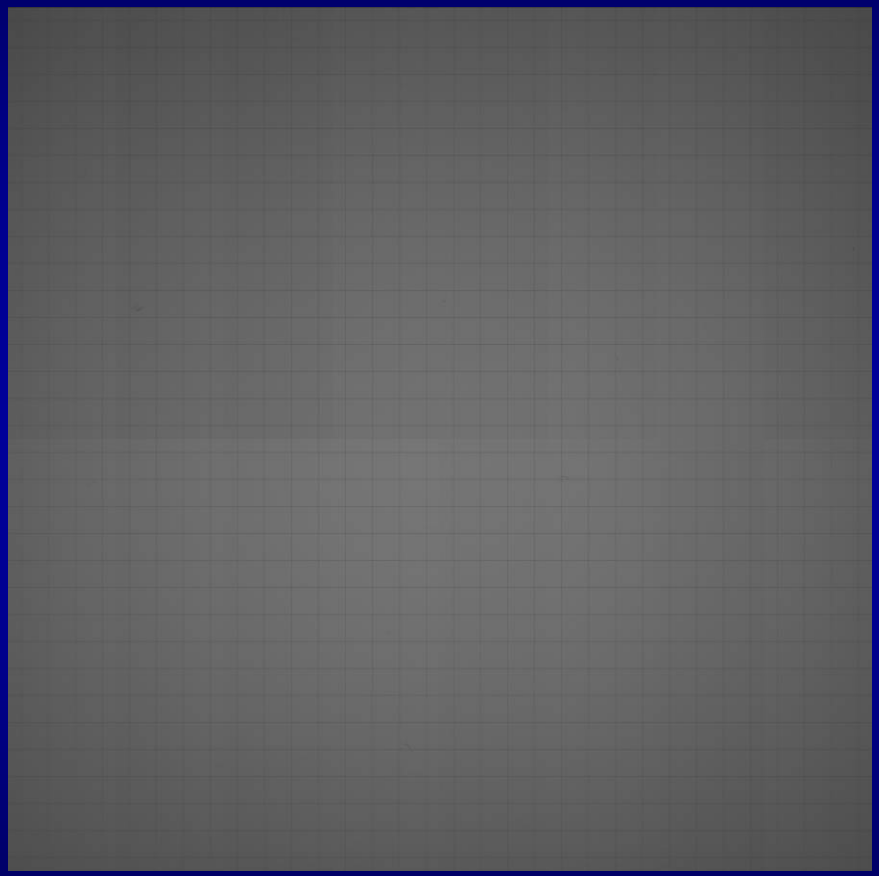


Photon Transfer Curve



Charge Transfer Efficiency

STA1600A Performance Cont.

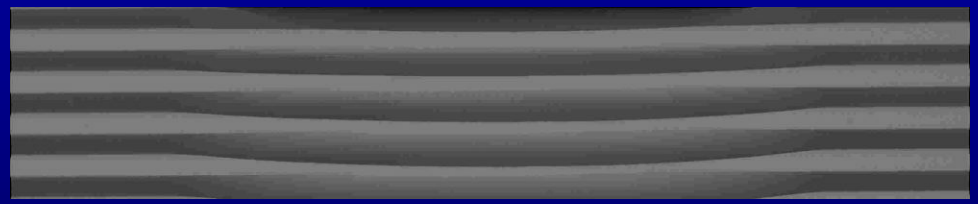


Uncorrected STA1600A Image. Each output section shown is 1320 pixels X 5280 pixels.
PRNU = 9.2% over a 4k x 4k area located at the center of the device. Wavelength is 650nm.

Unstrapped Parallel Transfer Degradation

300kHz Line Rate

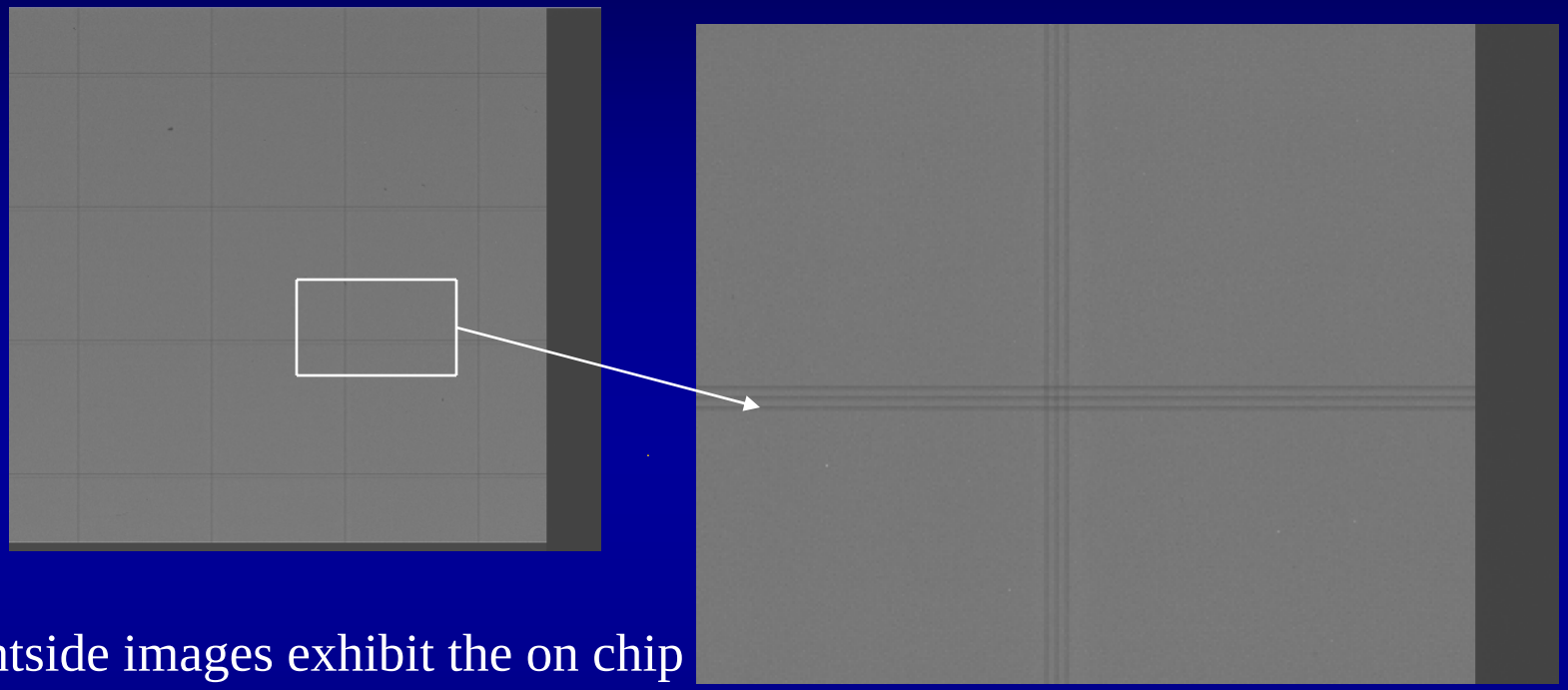
500kHz Line Rate



700kHz Line Rate

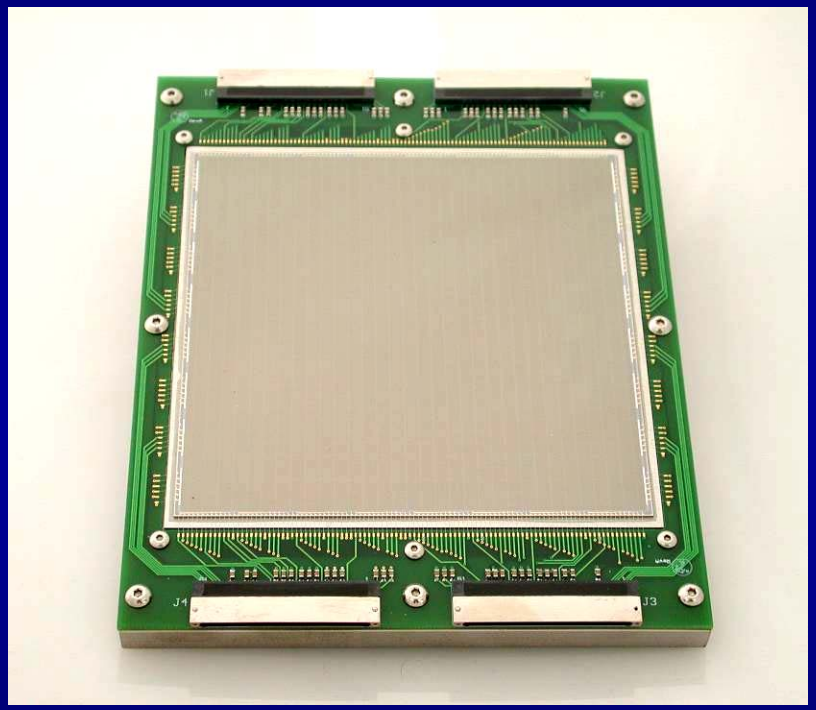
- Smaller unstrapped test chip
- High resistance of polysilicon gates limits vertical transfer frequency

STA1600B Performance Enhancement



- These frontside images exhibit the on chip strapping necessary to reduce vertical gate time constant.
- As a result the device can be driven at enhanced data rates without degradation of CTE or increased image smear.

STA1600A Single chip Package

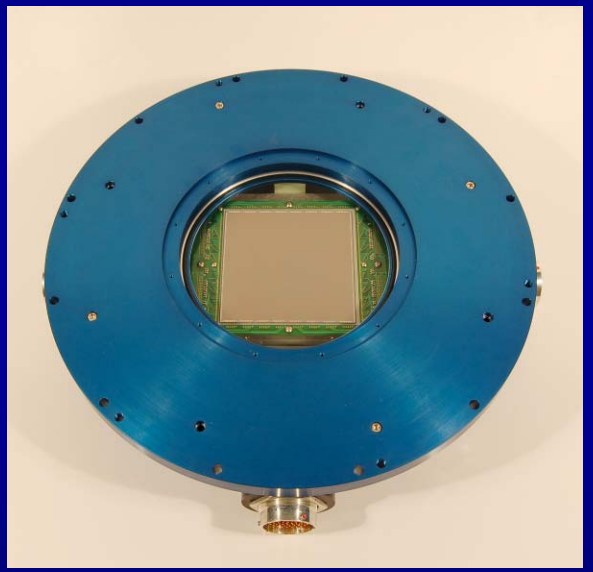


- Substrate fabricated on invar for good thermal matching to silicon, which allows the device to be cooled to -120C^{o}.
- The breakout board is a PCB manufactured on FR4, containing coupling components and miniature connectors.

STA1600A Frontside Package

STA1600B USNO Dewar Assembly

Dewar 61 Pin I/O and
18 Pin Temp Connectors

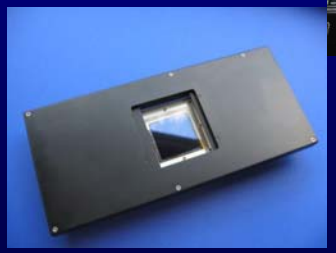


STA1600 Mount with
Neutral Density Filter

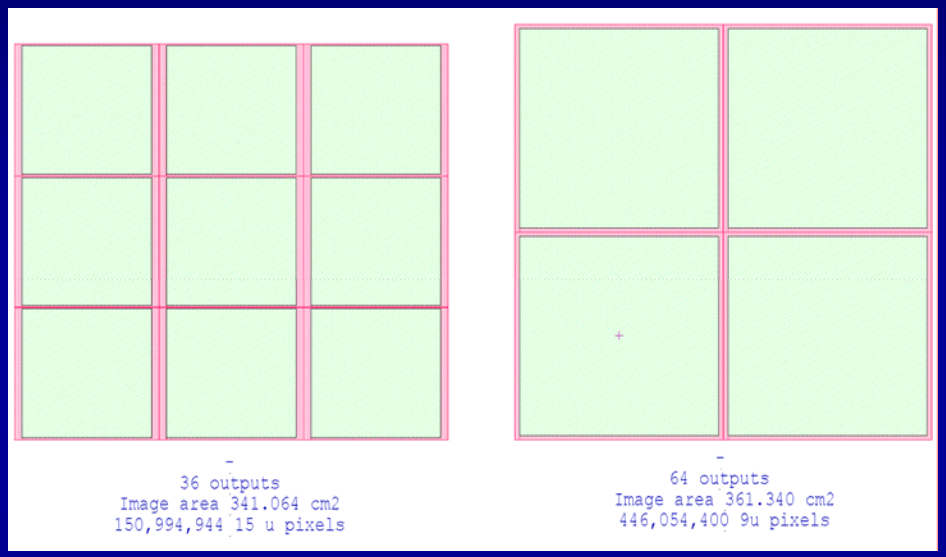
Demonstration Unit

USNO Robotic Astrometric Telescope URAT

- 8 inch Refracting Telescope for Astrometry
- Upgrade initiated to a 2x2 array by Dr Norbert Zacharias for an all sky survey - URAT
- STA is providing complete system including
  - Dewar – Window – Bonn Shutter
  - Four BI STA1600B CCDs – Three STA 3000 Guiders
  - Five Aura cameras with software
  - Telescope robotic control software



Large Focal Plane Efficiency

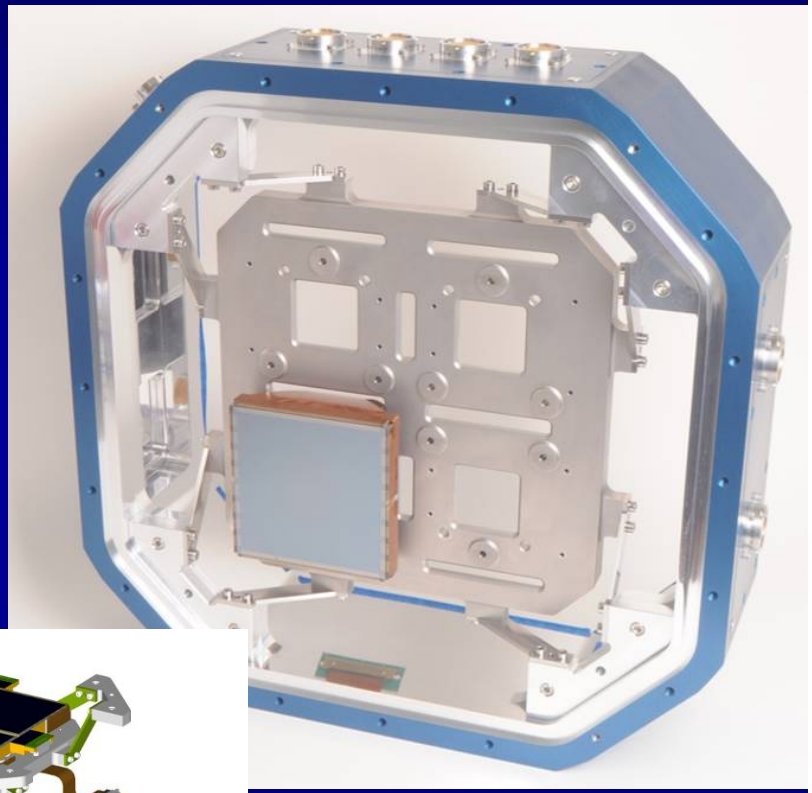


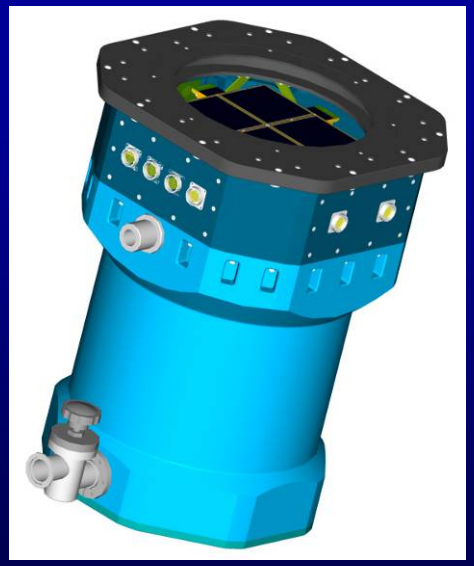
E2V CCD231 adjacent to STA1600

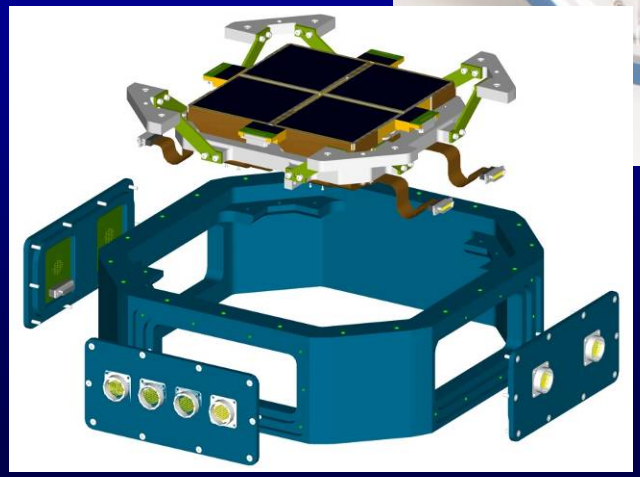
- Four 10ks provide more active image area than nine 4k imagers
- 91% Active area for 4k imager
- 95% Active area for 10k imager

URAT 2x2 Focal Plane

- Next generation astrometry focal plane
- Incorporates buttable package version of STA1600B
- GL Scientific Dewar

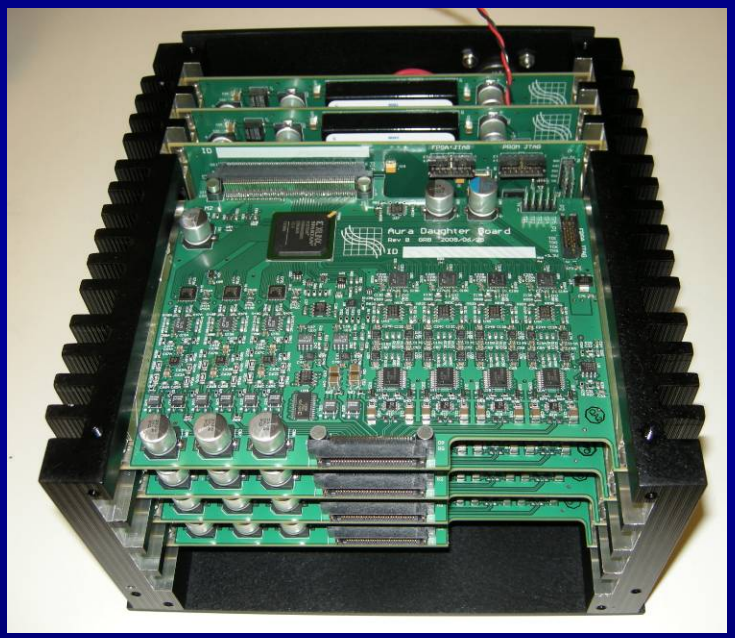




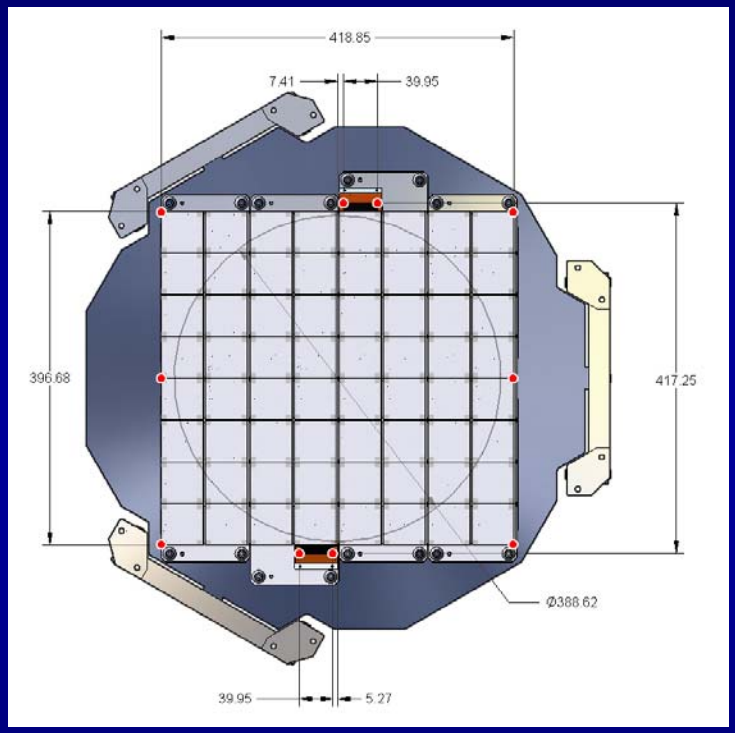


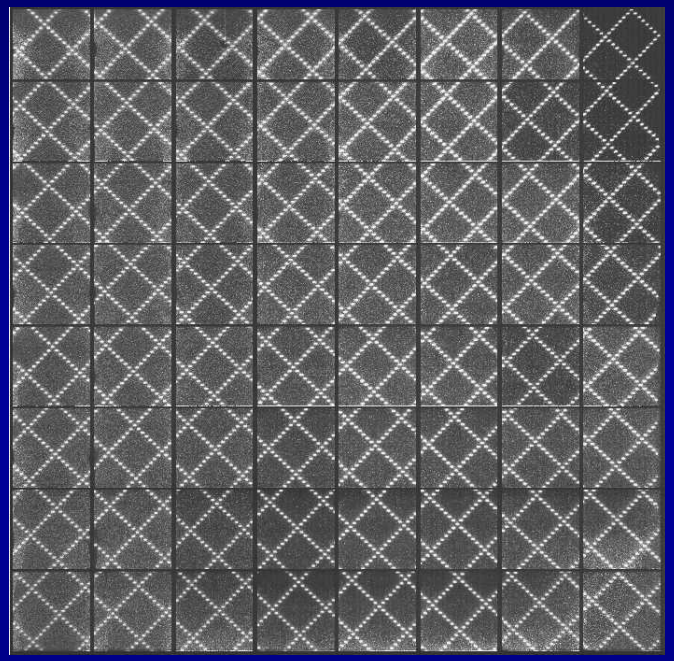
Aura Camera

- One of five cameras for URAT system
- There is a flexible programmable timing core
- CCD clock signals are generated from 60Mhz DACs
- 16 ADC channels each have low noise fully differential AC-coupled preamps with high and low gain



WIYN One Degree Imager

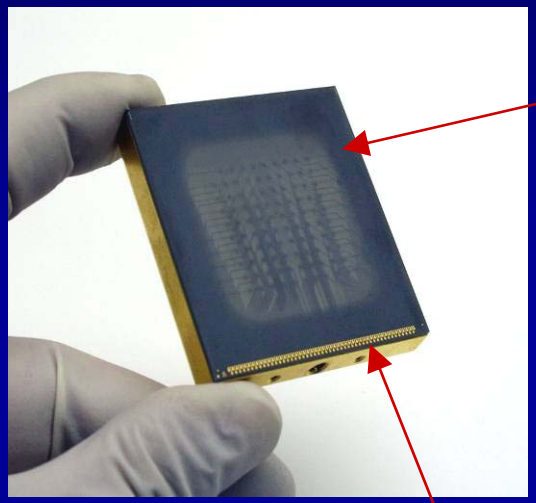


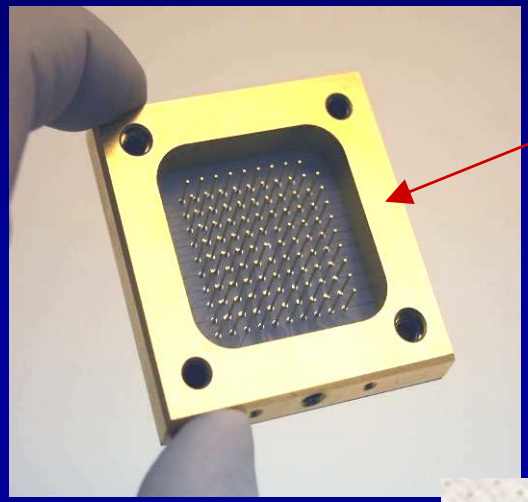


Grid projection

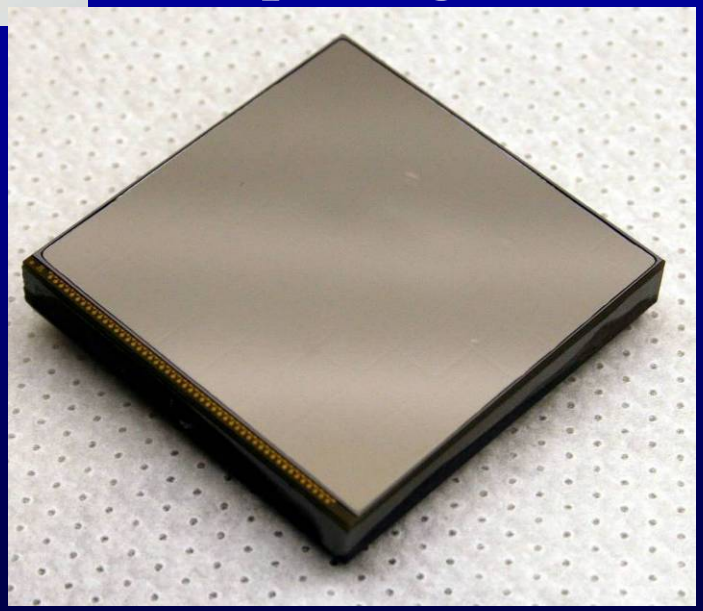
- Focal Plane of 64 Orthogonal CCDs
- Mounted on SiC frame
- 405 mm x 415 mm image area
- Similar devices produced for Pan-STARRS

OTA Four Side Buttable Package





packaged CCD

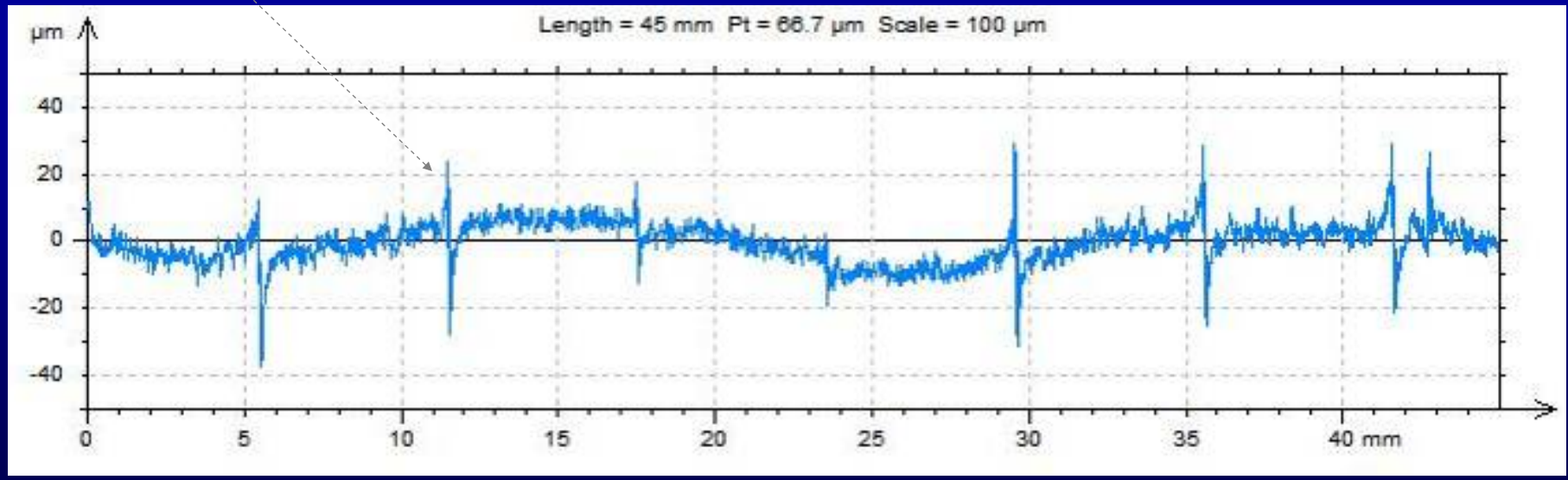


- Designed by Mike Lesser
  - University of Arizona ITL

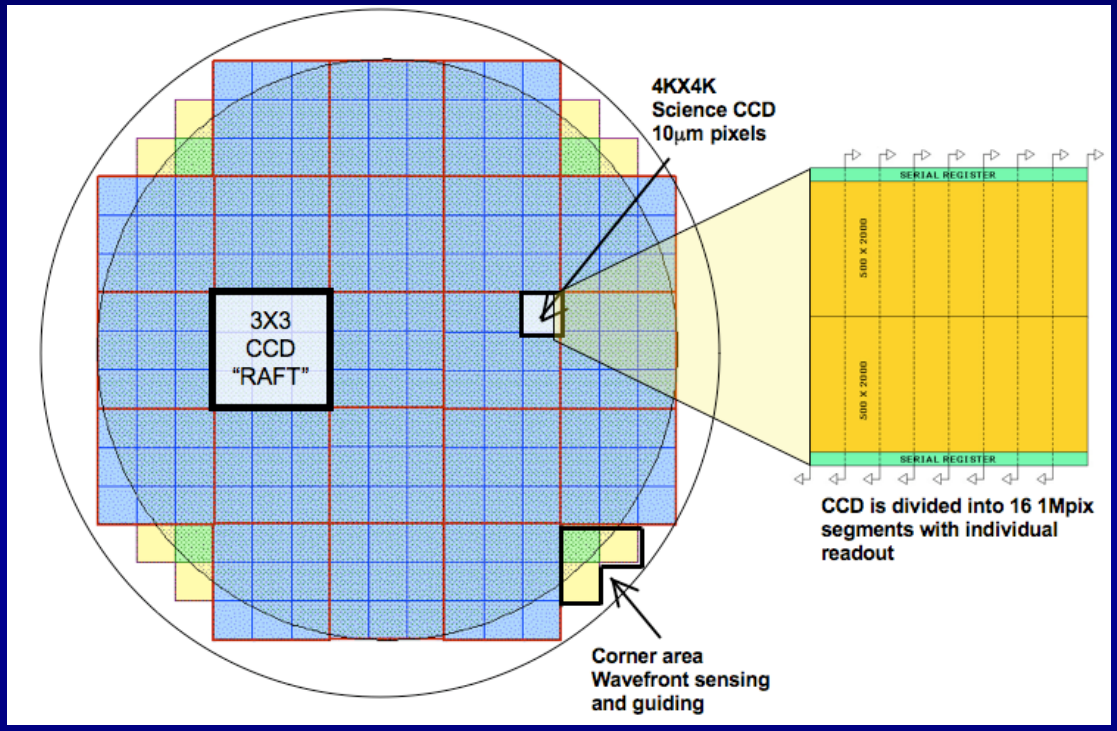
Detector Flatness

- Flatness at operating temperature is critical for many scientific applications
- This BSI device in final package is ~10 μm peak to valley at -100 C, internal structures affect surface profile

OTA cell "scatter"



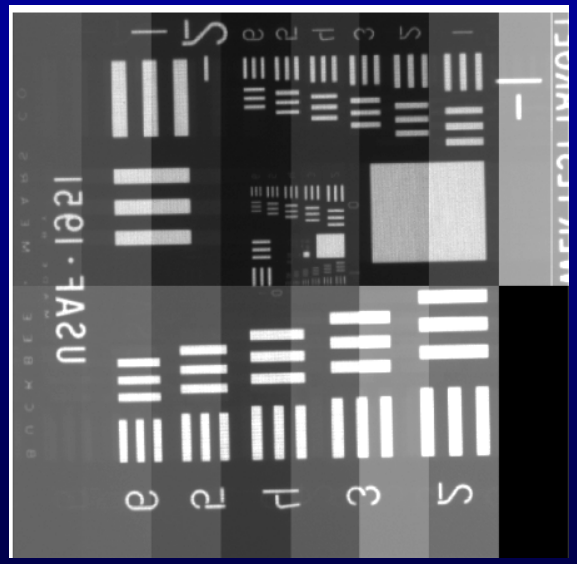
STA1900A LSST

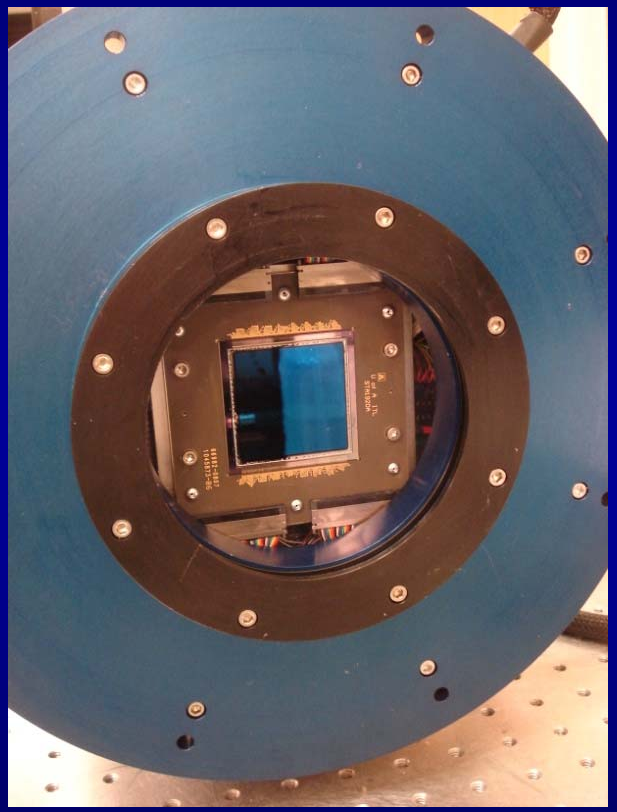


- Focal Plane of 189 CCDs
- 10 degrees field of view

STA1900A LSST

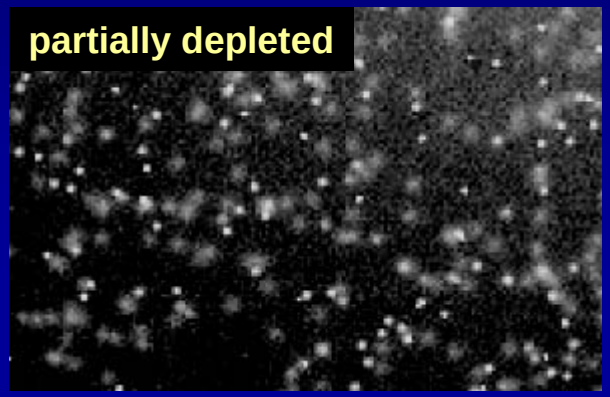
- Study contract device
- 100 µm thick, high resistivity bulk silicon, capable of overdepletion
- 4K x 4K, 10 µm pixels, 16 outputs

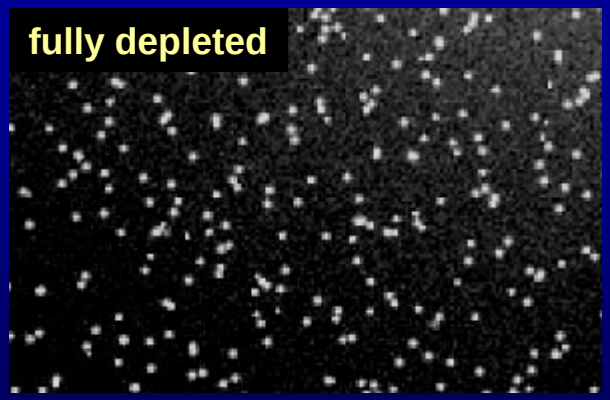




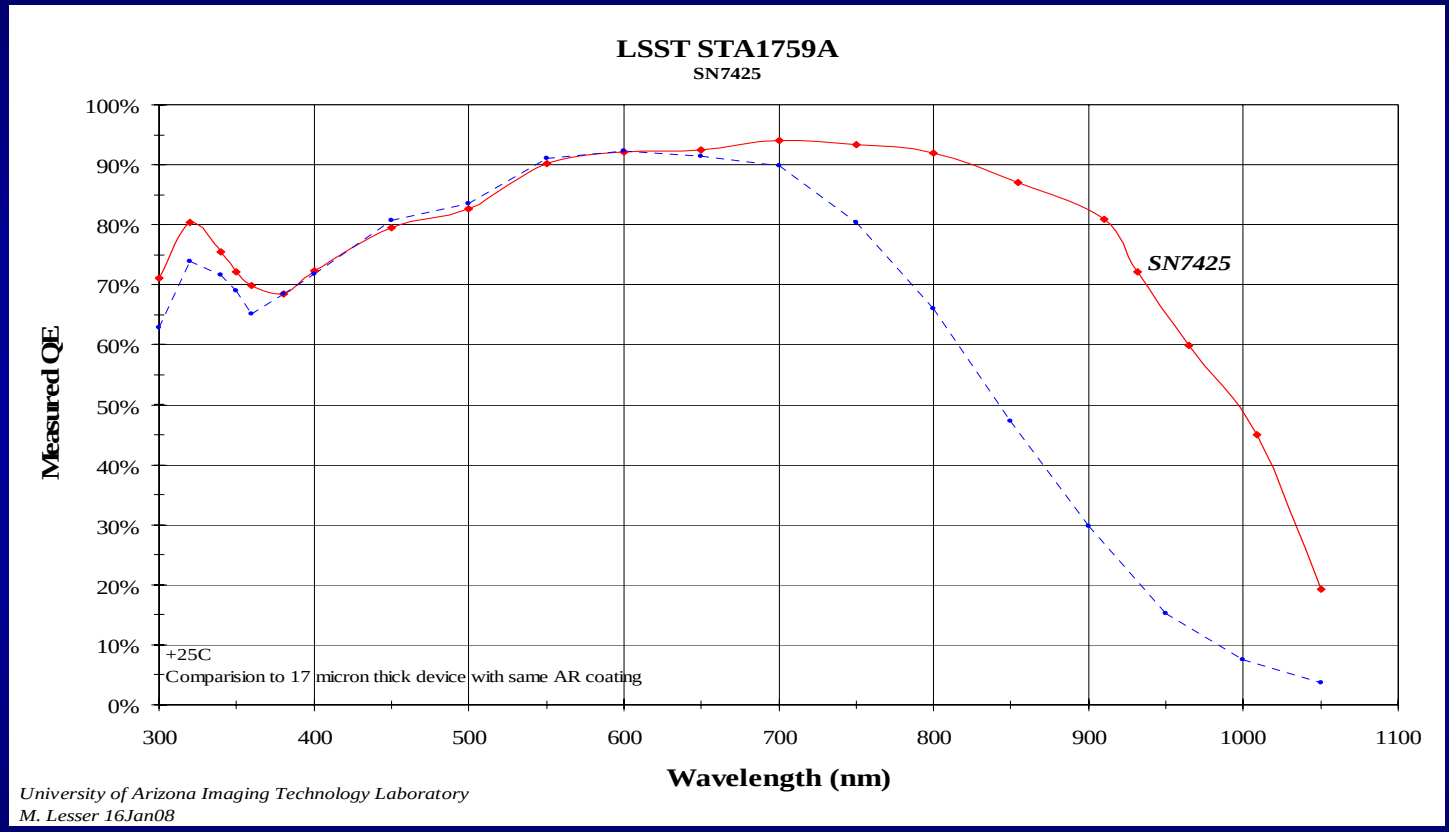
Substrate bias control of charge diffusion

- ^{55}Fe xrays generate compact charge clusters within ~30 µm of silicon surface.
- Charge generated in undepleted silicon experiences excessive diffusion.
- Fully depleting the silicon restores the PSF





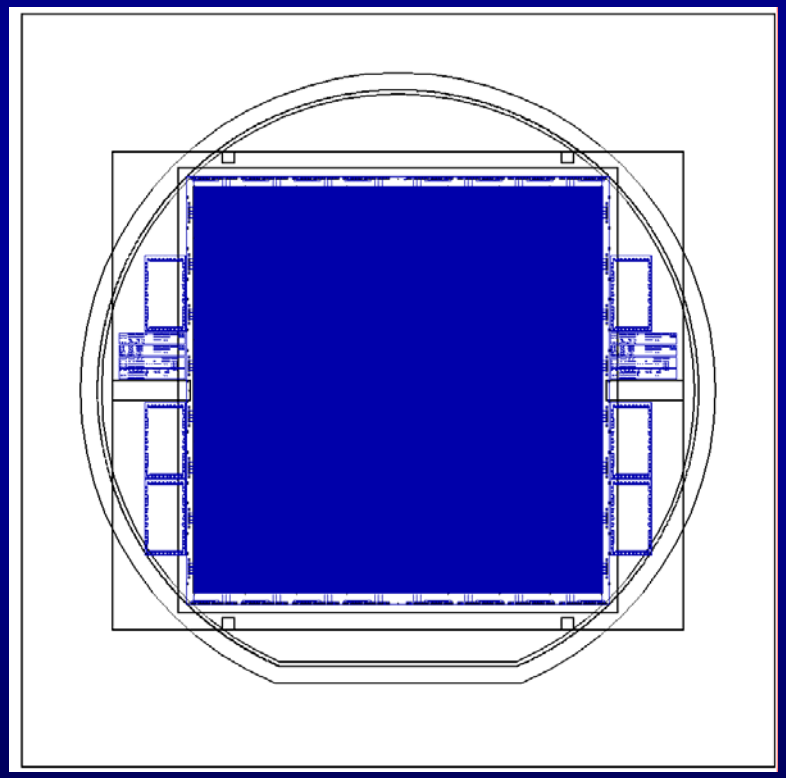
LSST CCD - 93 μm thick



- Deep depleted red-response

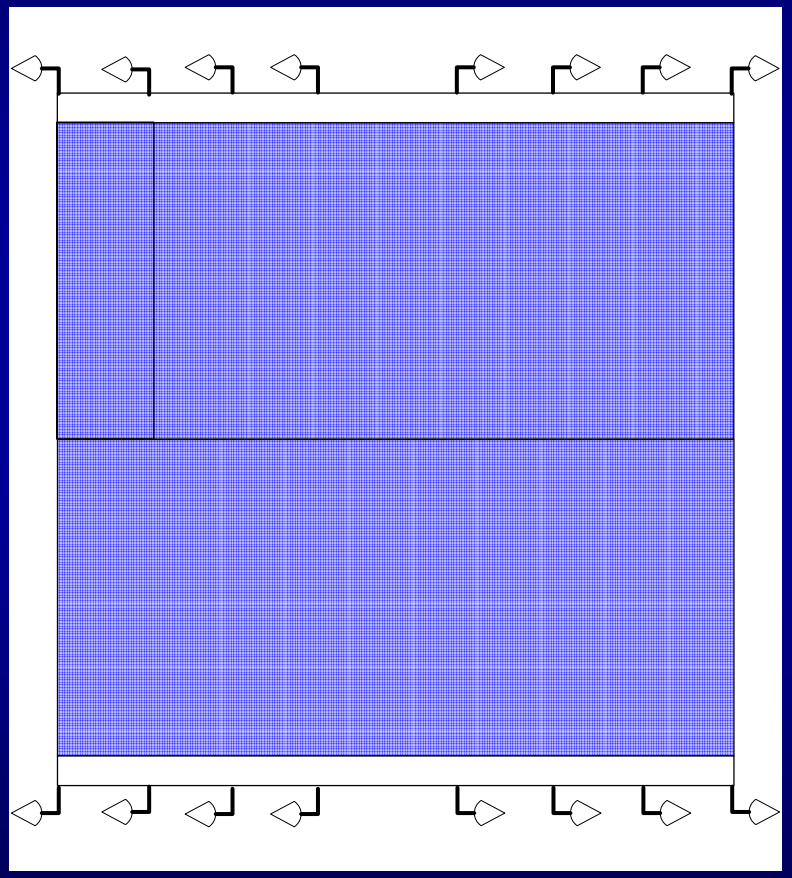
STA3200A X-Ray Imager

- Designed for direct X-Ray detection
- 4000 x 4000 24 micron pixels
- 20,000 ohm-cm p-type starting material
- Full depletion of 600 µm silicon
- Close to completion

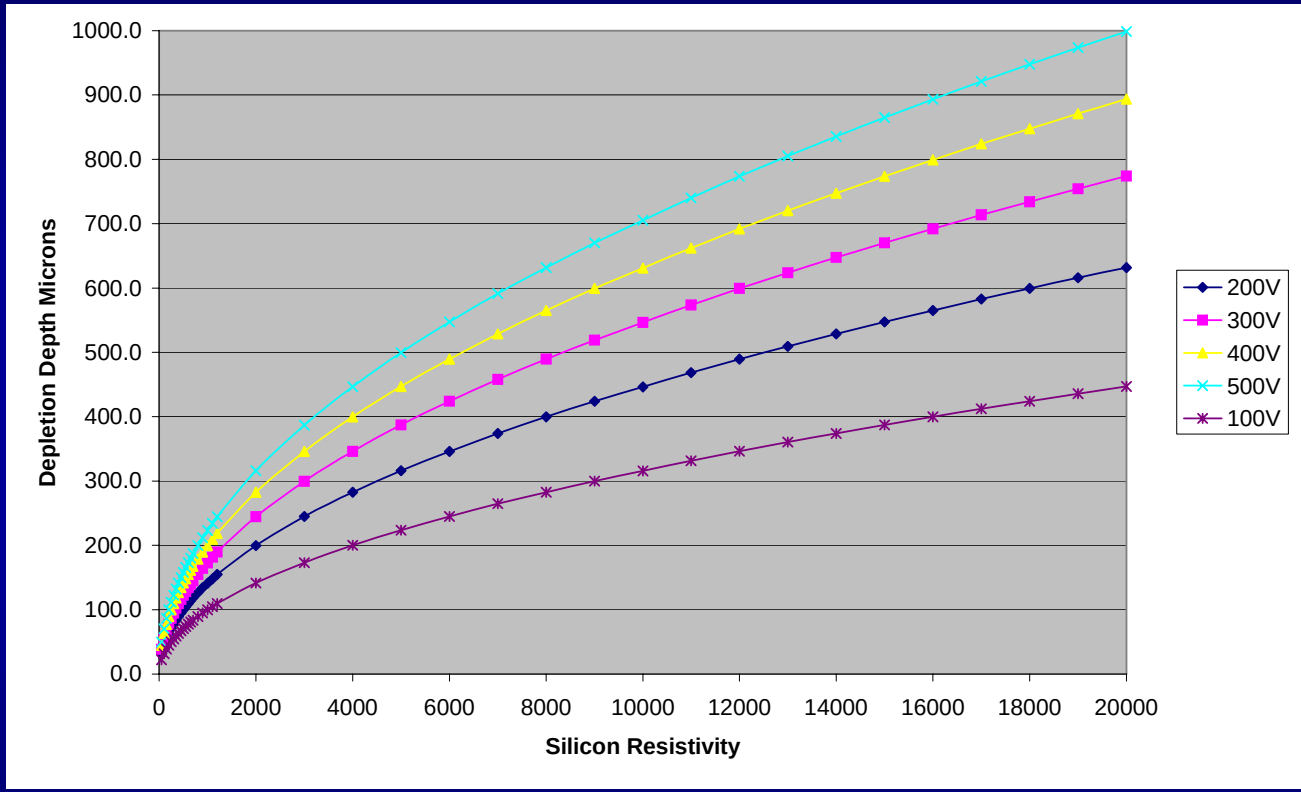


STA3200A CCD Layout

- Chip imaging dimensions 96 mm x 96 mm.
- 16 Separate outputs
  - Each output reads out a subsection of 500 x 2000 pixels when using all 16
  - Possible to readout complete array to top or bottom 8 outputs.

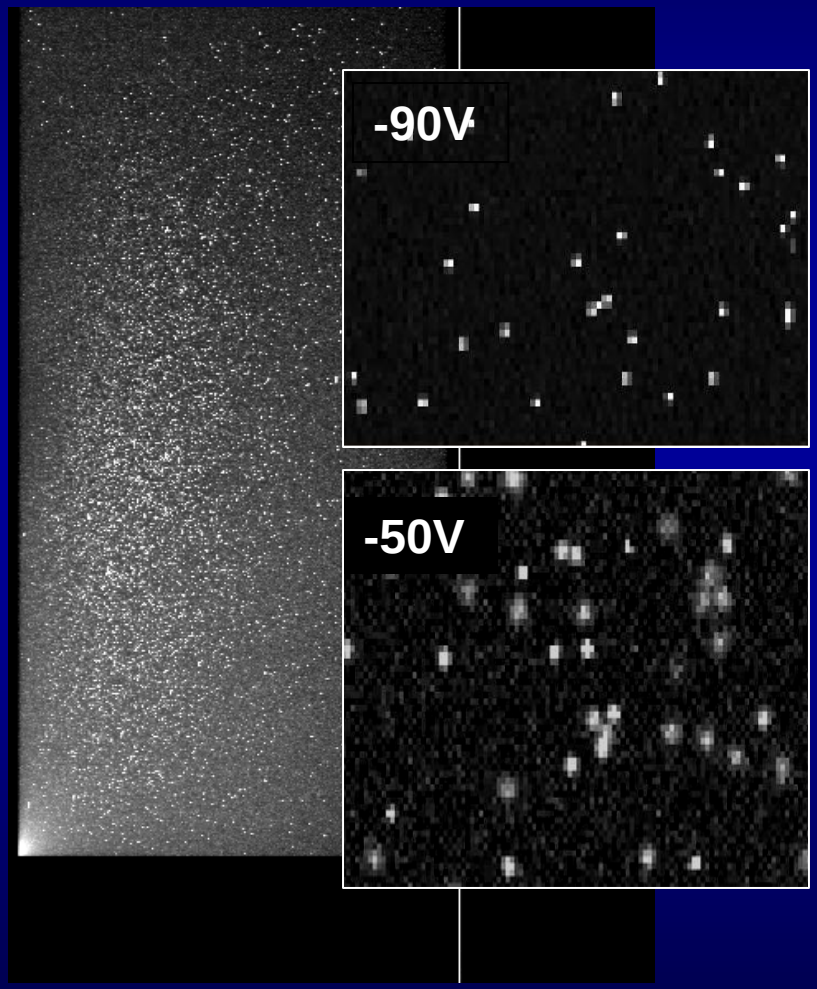


Depletion Depth vs Resistivity on P-type Silicon



- 20,000 ohm-cm silicon has one boron atom for every 10 billion silicon atoms
- For Pan-STARRS or LSST the depletion depth is 100 µm with a 5V bias .

STA1759A Preliminary Test Data



STA1759A Fe55 image.

- STA1759A 700 um thick device
- Regions of interest show PSF improvement with change in back bias voltage.
- Will provide samples for radiation testing

Summary

- The STA1600A is a result of the evolutionary growth of scientific imager requirements.
- The STA1600A Ultrahigh Resolution CCD will greatly decrease the number of devices necessary for large focal plane arrays.
- The high resolution, along with high speed low noise capabilities, makes STA1600A appealing to large area imaging.
- STA can provide full wafer custom imagers with pixel sizes from 7.5 µm to 150 µm
- Thank you for your attention.