OTA Detectors for the WIYN One Degree Imager

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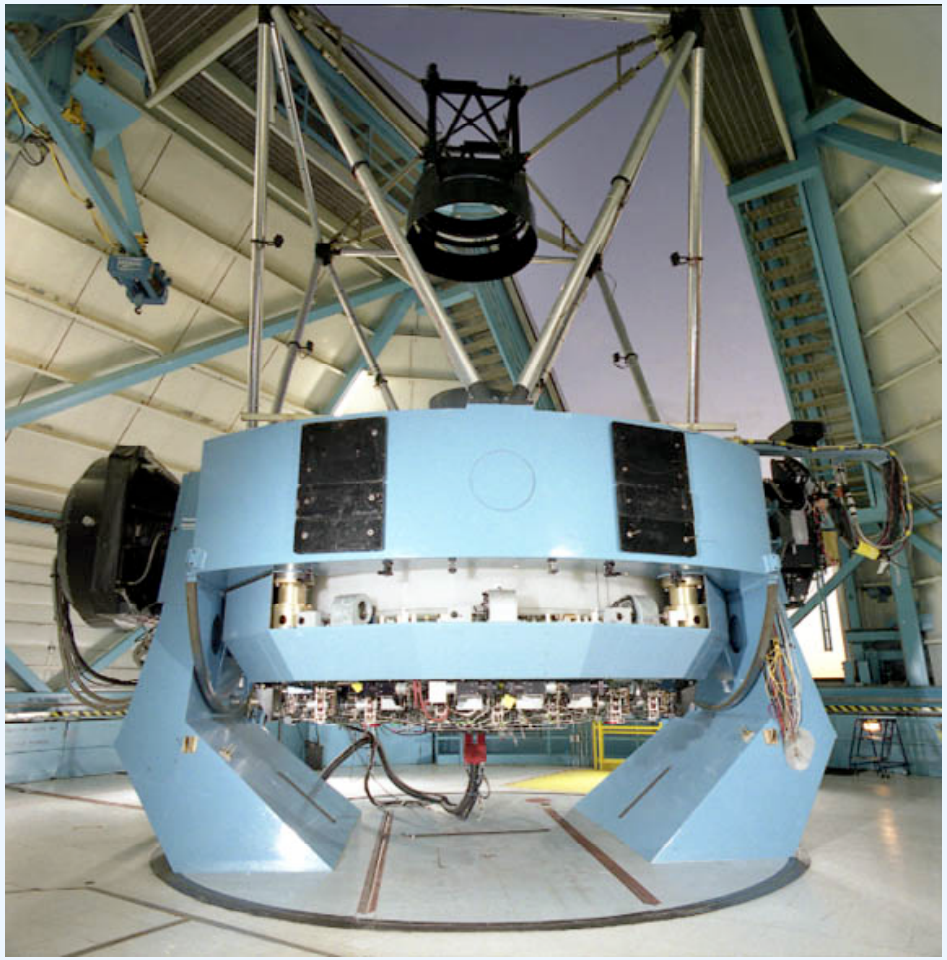
WIYN Observatory

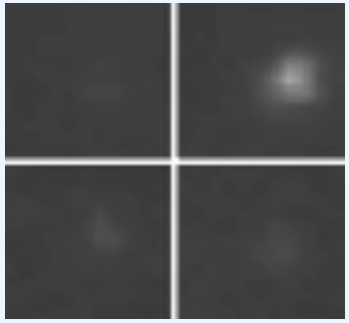
For the ODI team,
Collaborating with the PanSTARRS STARGRASP team.

WIYN - A modern 3.5m telescope

- Owned and operated by WIYN Inc. (**W**isconsin, **I**ndiana, **Y**ale, **N**OAO).
- Located at Kitt Peak, Arizona.
- Excellent site meets modern telescope.
  - Active mirror support system.
  - Median image quality in R ~ 0.65”.
  - Regularly delivers image quality << 0.4”
- 1° build-in field of view.

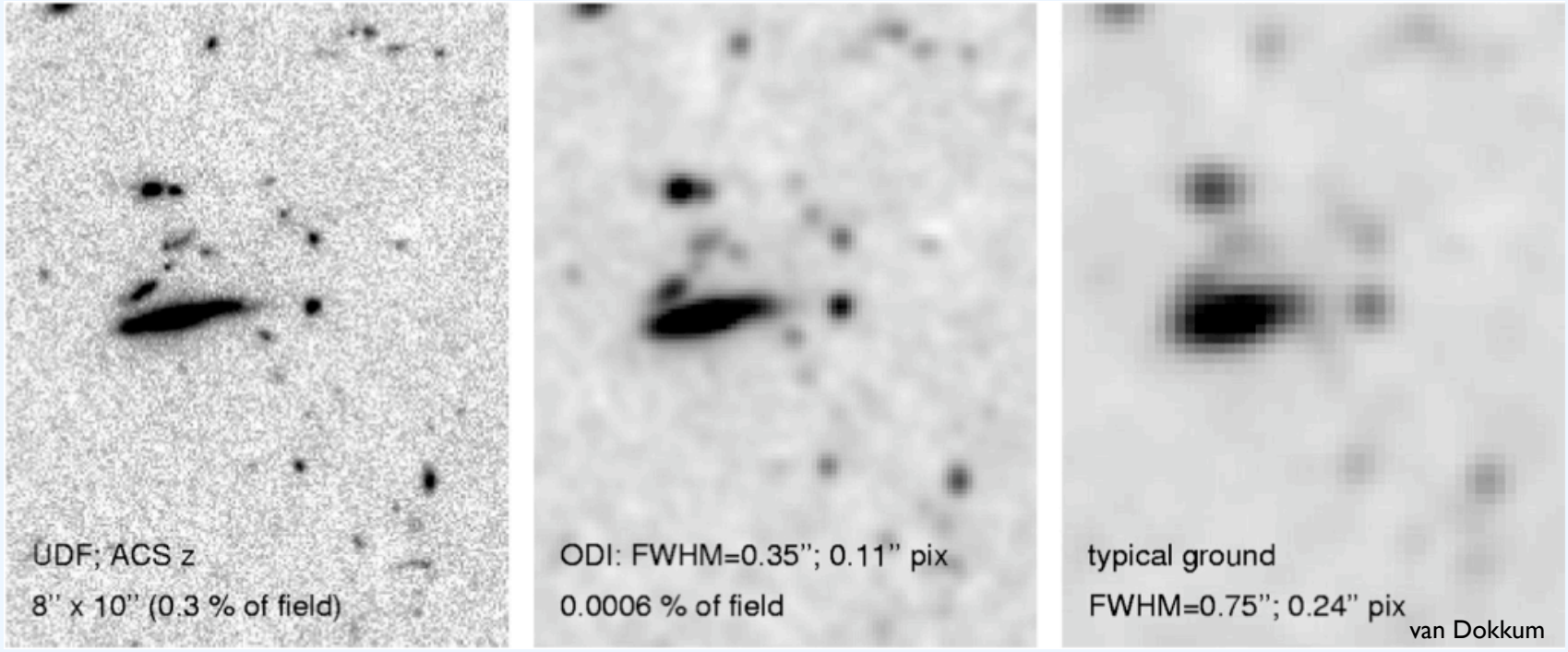


A One Degree Imager for WIYN



- Utilise full 1° FoV, operational efficiency
- Aim for image quality:
  - Actively compensate for *image motion* blur.
  - Blur caused by guide errors, wind shake, and atmospheric turbulence.
  - **Orthogonal transfer CCD detectors for *electronic* image stabilisation.**
  - Scientific niche: High-resolution, wide-field imaging. Time Domain. PI Instrument, not a survey.
- Small pixel scale for sampling even at best condition and small granularity.
- 64 detector array, 4x4k pixel / 8'x8' per detector
  - 1 Gigapixel array
  - Readout time << 10 seconds

Wide field - high resolution



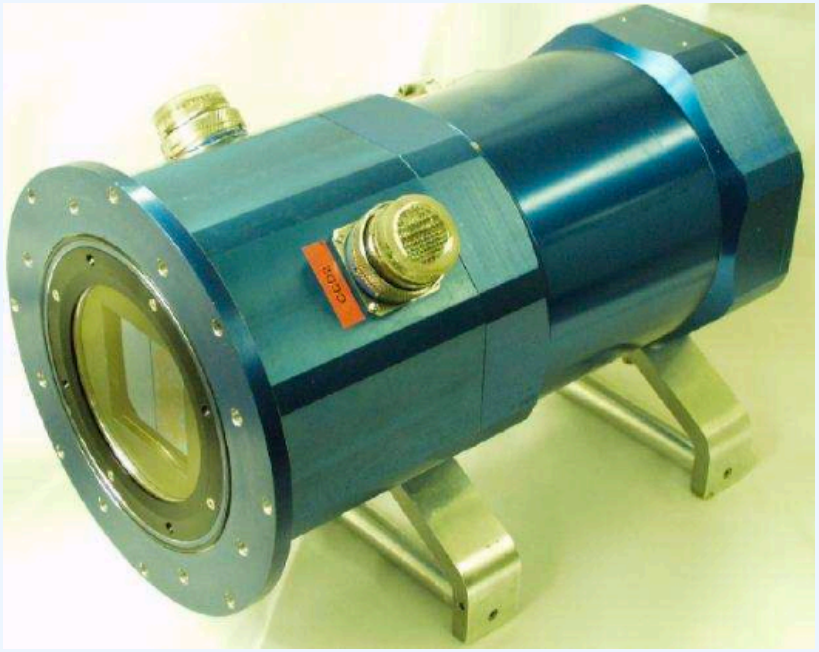
Electronic Image Motion Compensation

- Move *charge image* in detector to follow *optical image*.
  - Orthogonal Transfer CCD - CCD with special pixel structure.
  - Image motion sensing from nearby bright star.

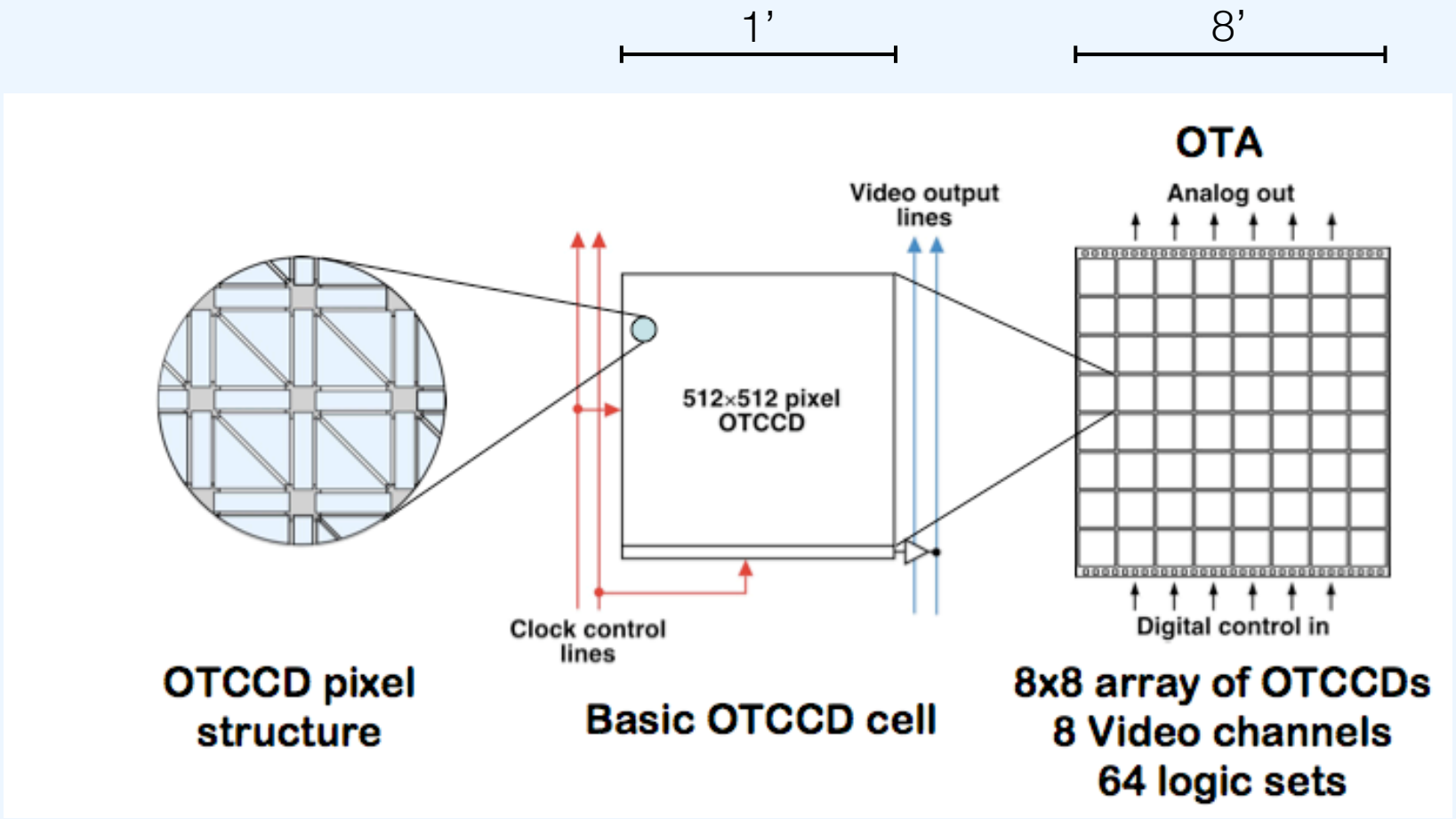
- Typical improvement by 0.05”-0.15” of image quality in the visual R band.
  - Isokinetic patch size ~ 4’

- Demonstrated at WIYN with precursor OPTIC
  - Loan from John Tonry (IfA).

- **Orthogonal Transfer Array (OTA) next evolutionary step of technology.**



Orthogonal Transfer **Array** CCD



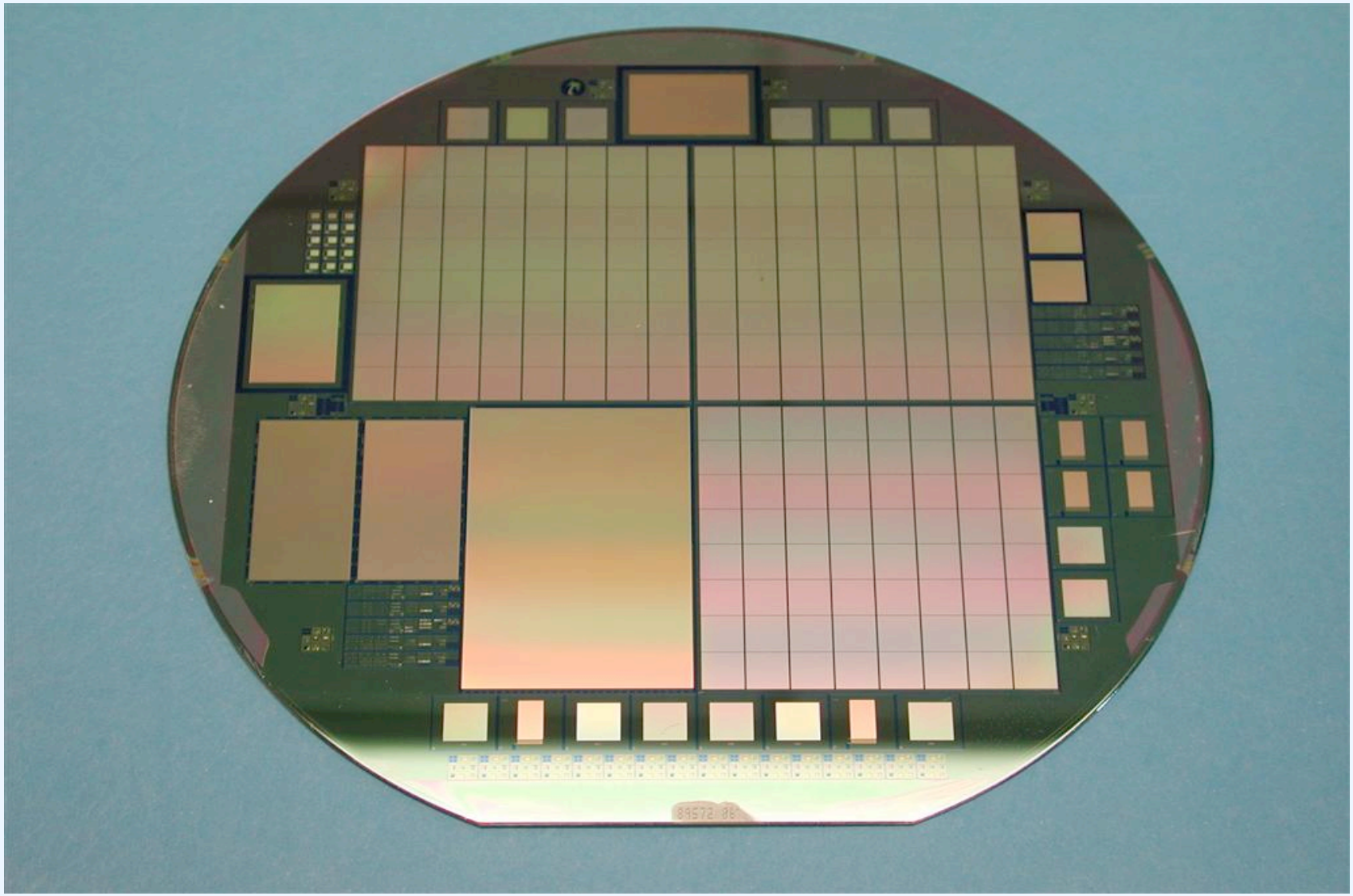
each cell is an independent[1] CCD ~1’ on sky

each cell can be read out in video mode

each cell is either imaging or obtaining guiding information at up to 30Hz

tip/tilt correction can be applied to each individual cell

OTA Wafer (Lot 2)



Detector Development Program

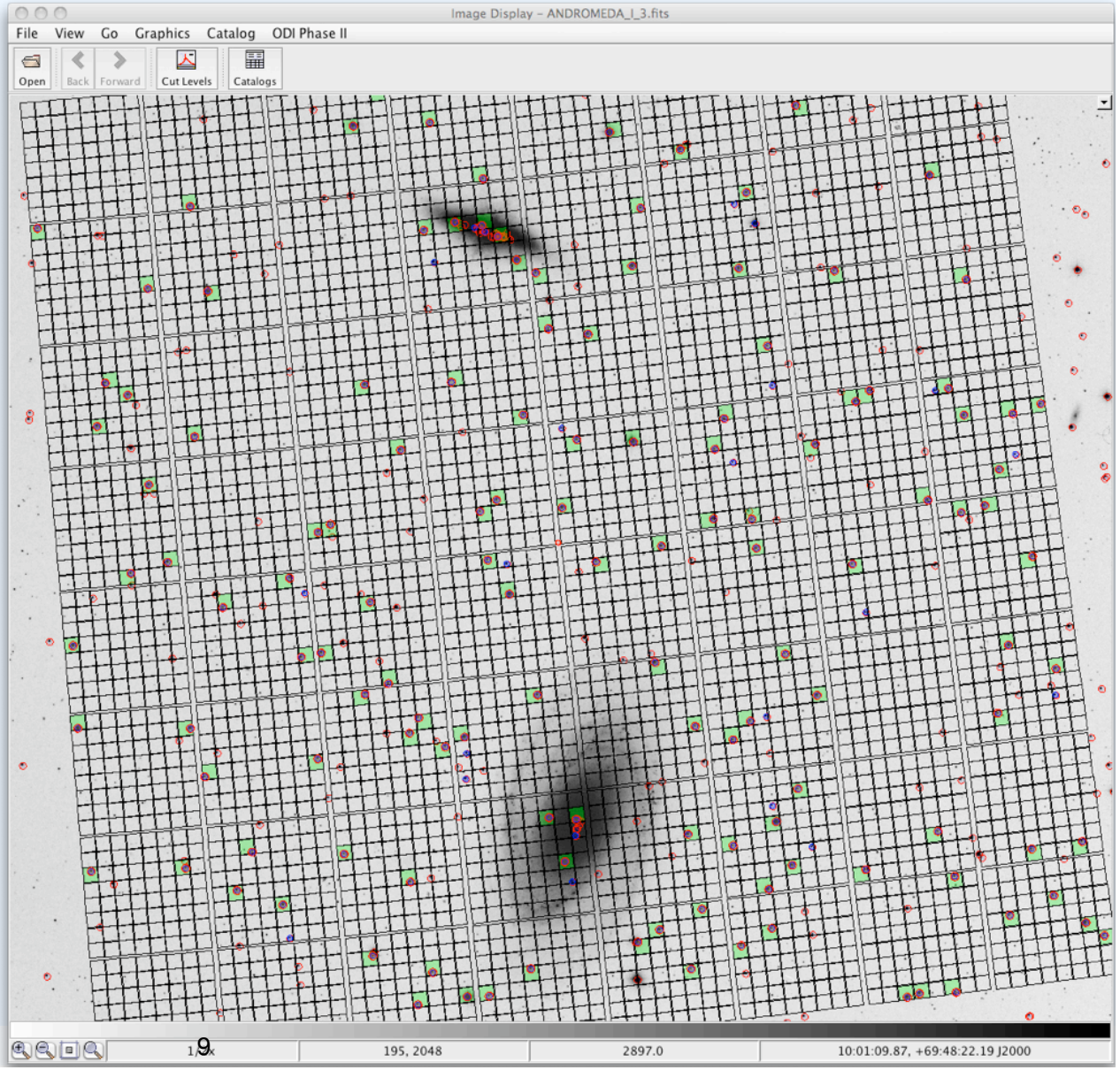
- **Program coordinated with PanSTARRS**
  - PanSTARRS: MIT / LLNL
  - WIYN: STA / DALSA / ITL (Design / Foundry / Package & Thinning)

- 4 foundry runs so far:
  - Lot 1: not working.
  - Lot 2: yielded operational detectors, 3W/detectors, amplifier glow.
  - Lot 3: yielded improved detectors, ~2W/detectors, design frozen.
  - Lot 4: **final production run; finished**; 1000 Ωcm material for red response.

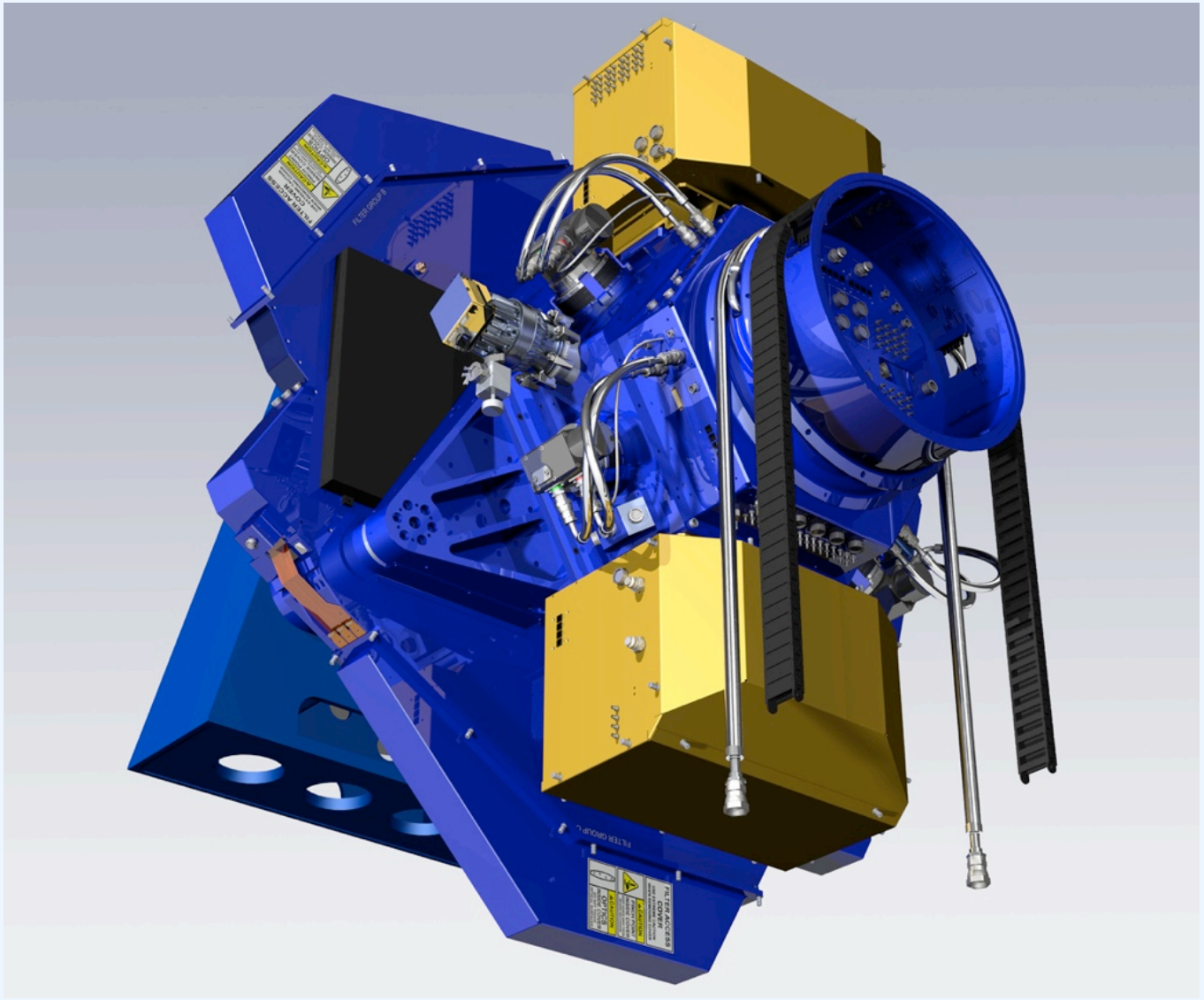
- Lot 4 detectors currently packaged, thinned @ ITL, delivery May 2010.
  - Yield on wafer level ~ 80/192; 42% for excellent devices.
  - Packaging yield TBD.
  - Focal plane population also done by ITL.

64 OTAs on a 1° Field Of View

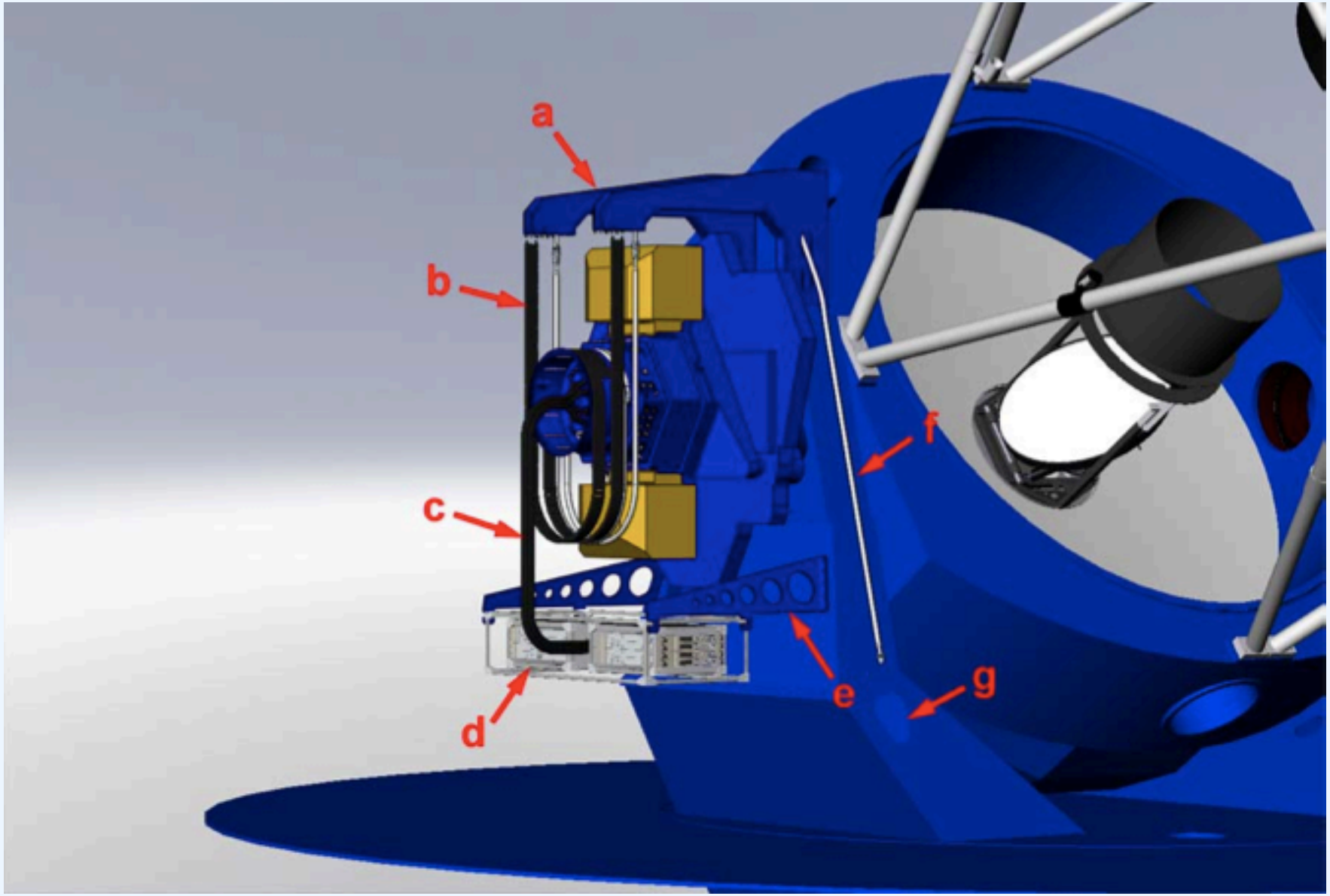
- 8x8 Array of detectors.
  - ~85% Filling Factor
- Predict location of bright guide stars
  - limit is ~14-15 mag_{AB}
- Operational modes:
  - Static imaging.
  - Coherent correction only.
  - Local correction:
    1 guide star per 4'x4',
    4 per detector.

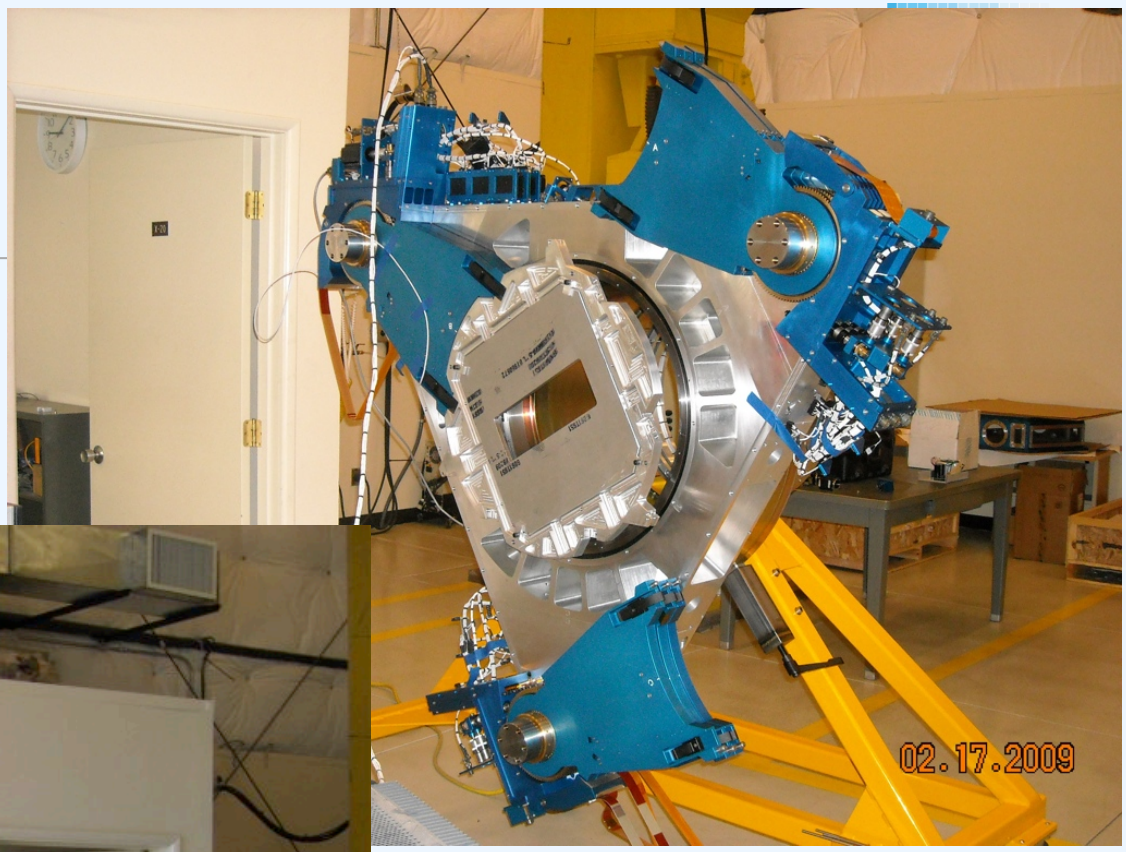


Instrument Highlights



Instrument at the Nasmyth Port

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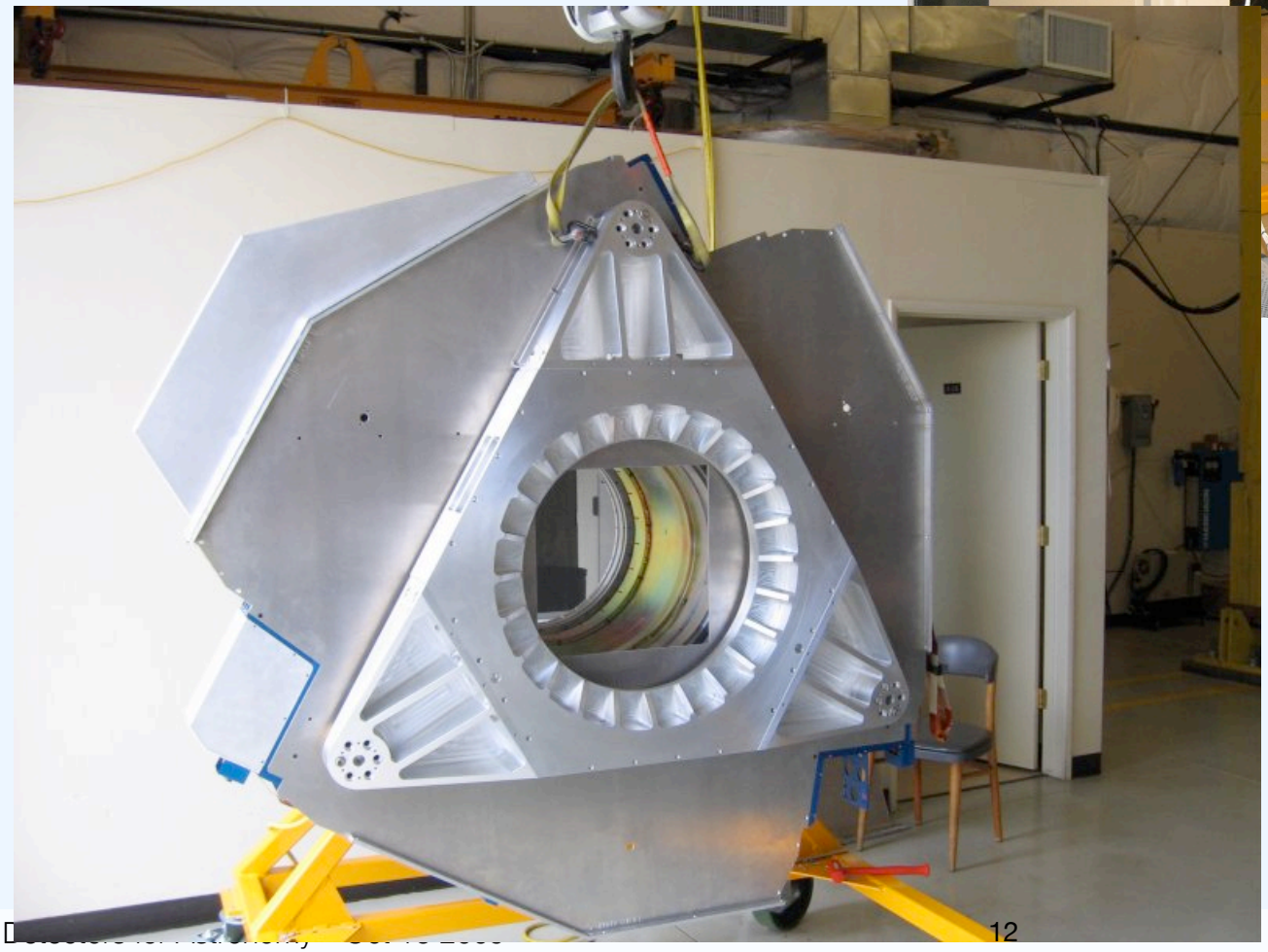
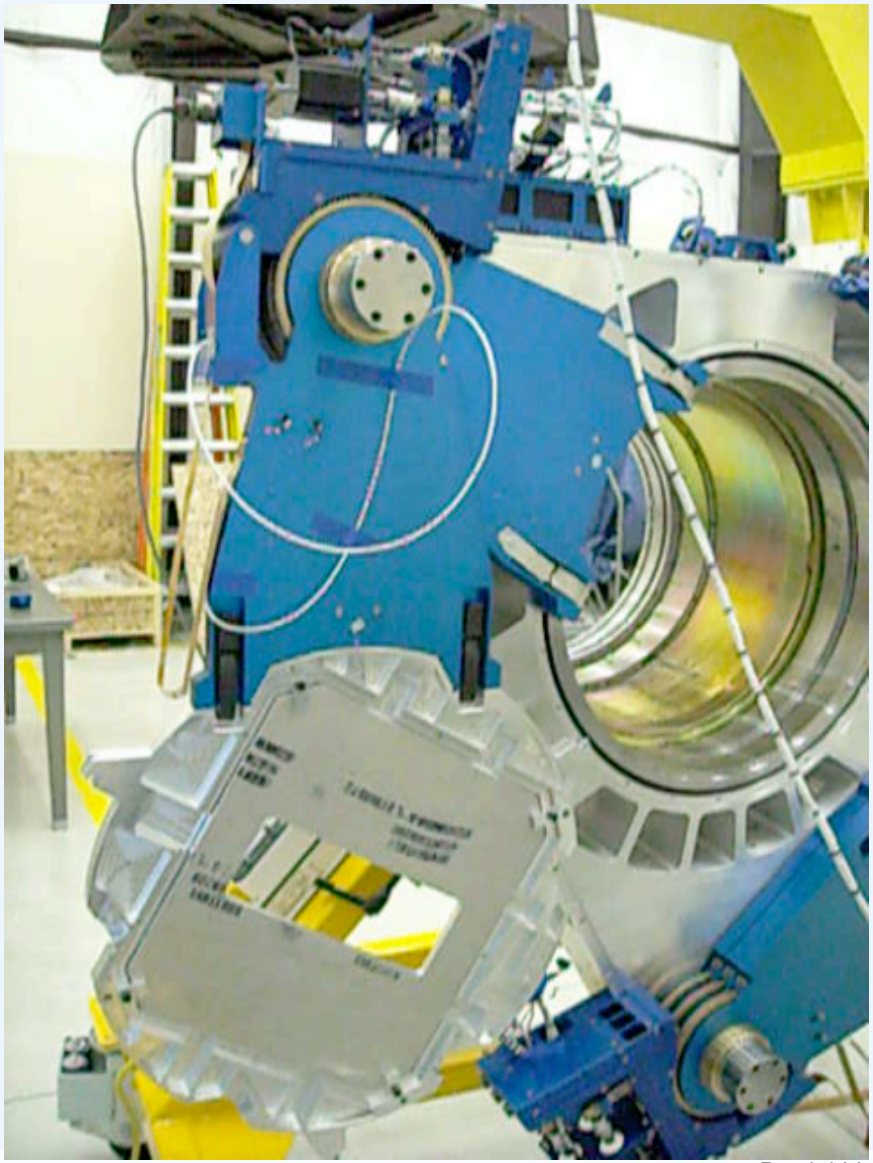


Filter Mechanism

- Design challenge:
  - Filter size (42cm)
  - **Filter cost ($65k-$100k est.)**
  - Filter weight
  - Safe handling

- 9 Filter positions available.
  - ~30 seconds filter change time.



Bonn Shutter

- 2-blade design for accurate timing & short exposure times
- Designed and fabricated by the University of Bonn (Germany)
- Delivered and accepted.
  - Works.

ODI Dewar System Requirements

- Harbour 64 OTA detectors + 2 focus sensors
  - approx. 40cm x 40cm imaging area.
- P
- Detector surfaces flat within ±20μm.
  - Thermal cycling & T-gradients major drivers in flatness!
- **Protect detectors from overheating:**
  - Detectors can create runaway heating situation!
  - Indium bump bonding limits safe temperature range.
- Detector-limited instrument performance.

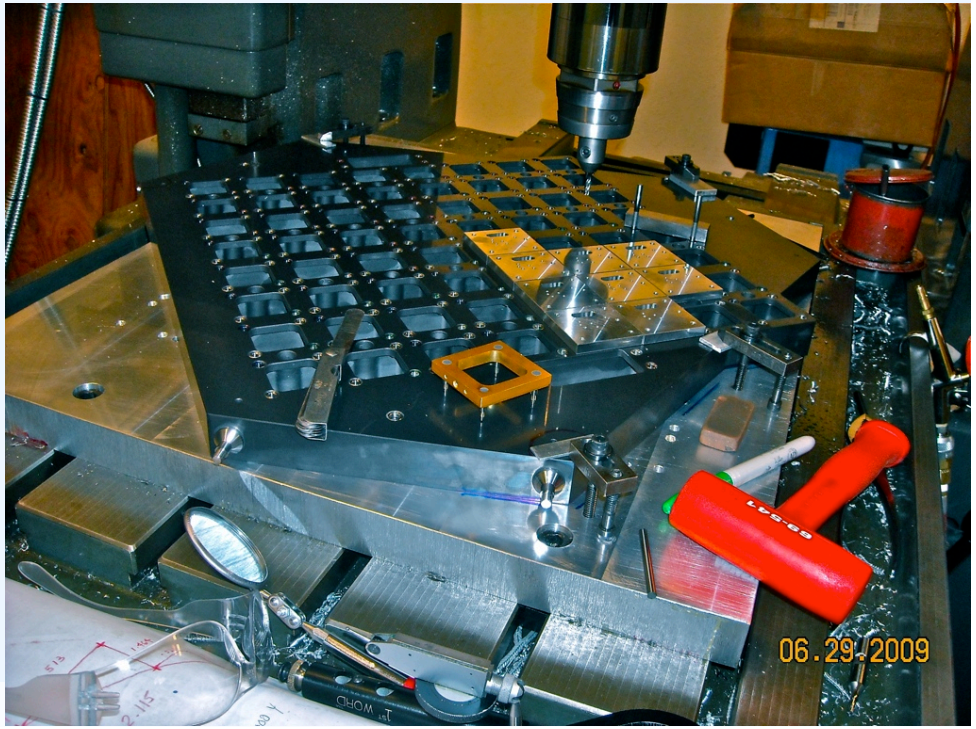
End-to-end engineering required.

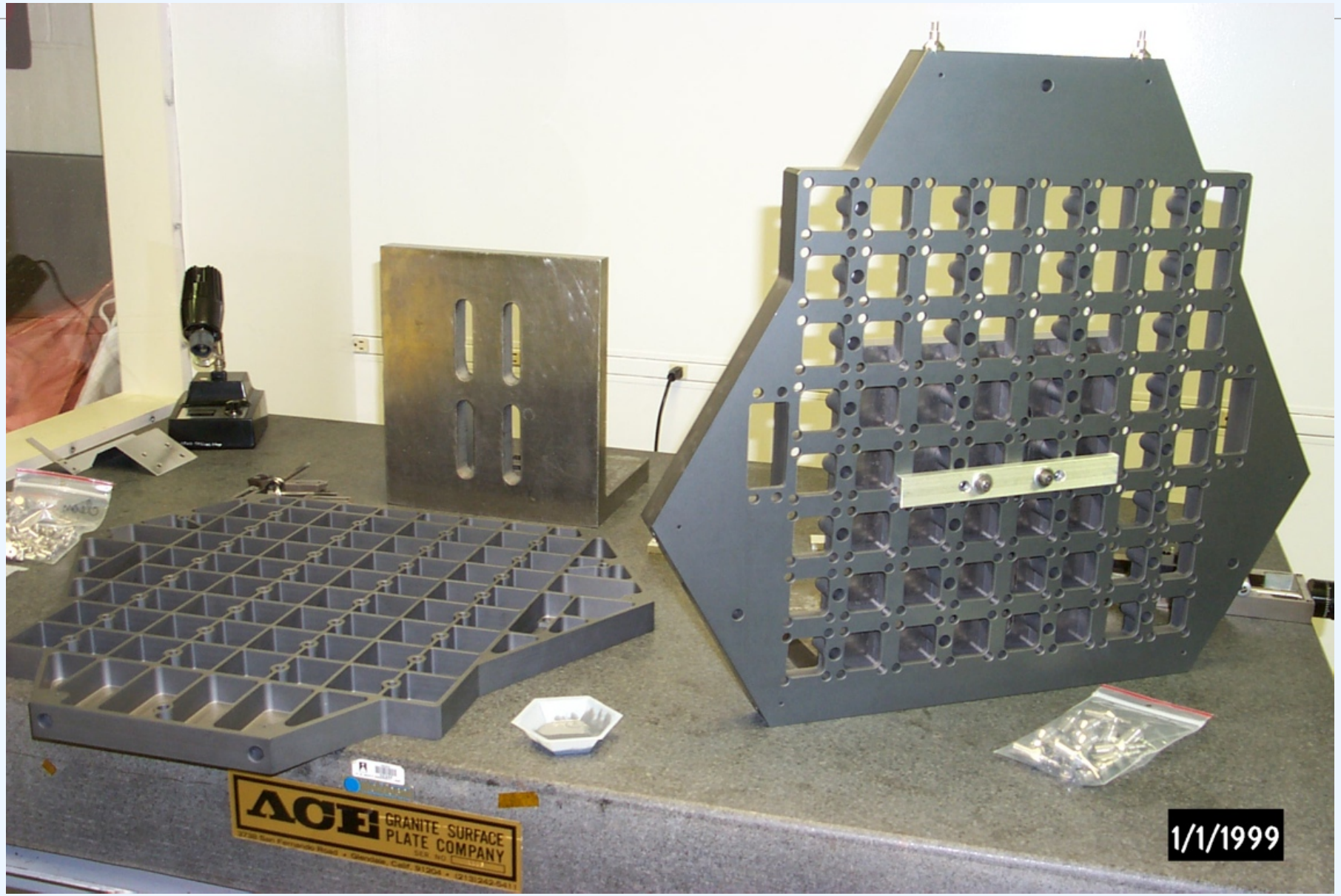
Focal Base Plate

- Matched material design (Thermal expansion, thermal conductivity)
  - Silicon Carbide for base plate.
  - Detector package design to match thermal properties.

- Silicon Carbide material of choice:
  - Thermal conductivity and expansion.
  - ,,Bimetalic" bending with thermal gradient important.
  - Polished flat within 10µm (like glass).

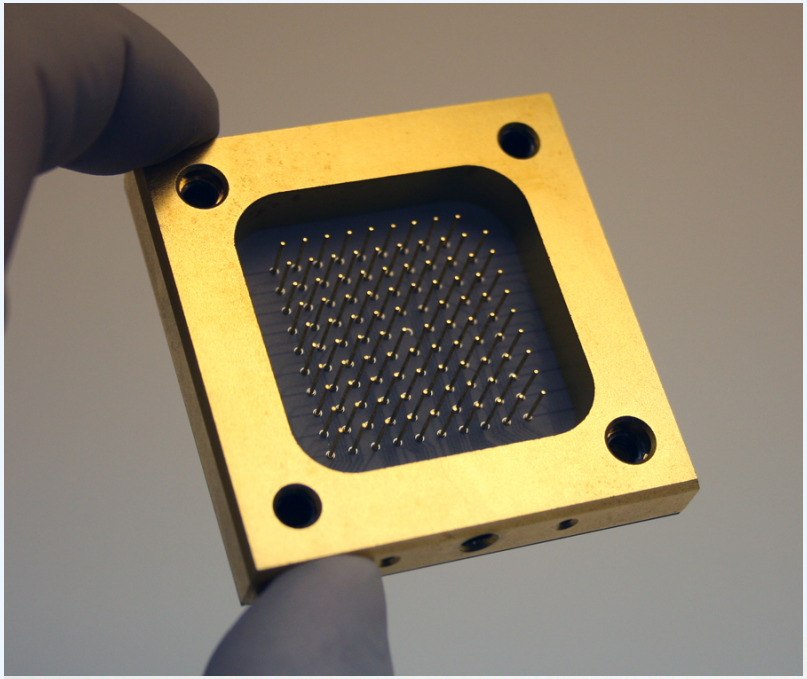
- *Detectors mount directly to base plate.*
  - No shimming or alignment required / forseen.

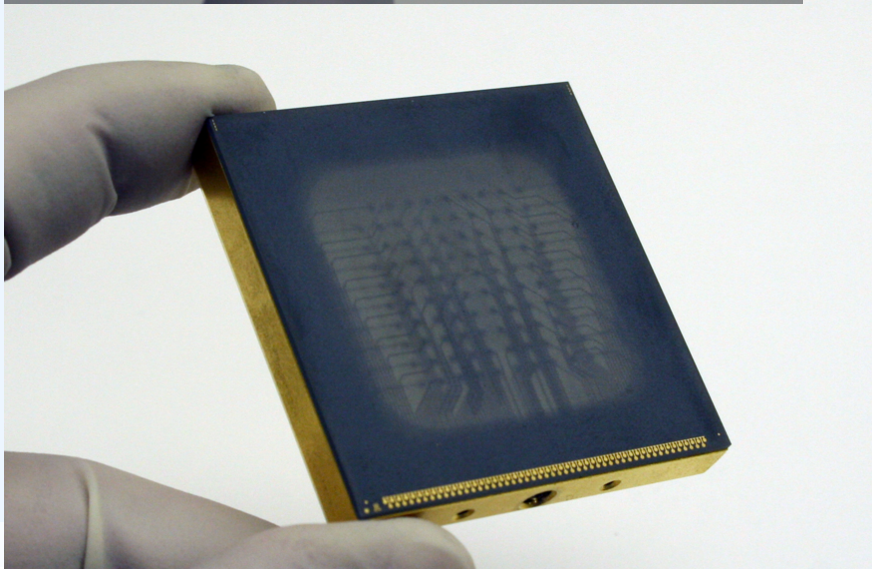



ACE
GRANITE SURFACE
PLATE COMPANY
1/1/1999

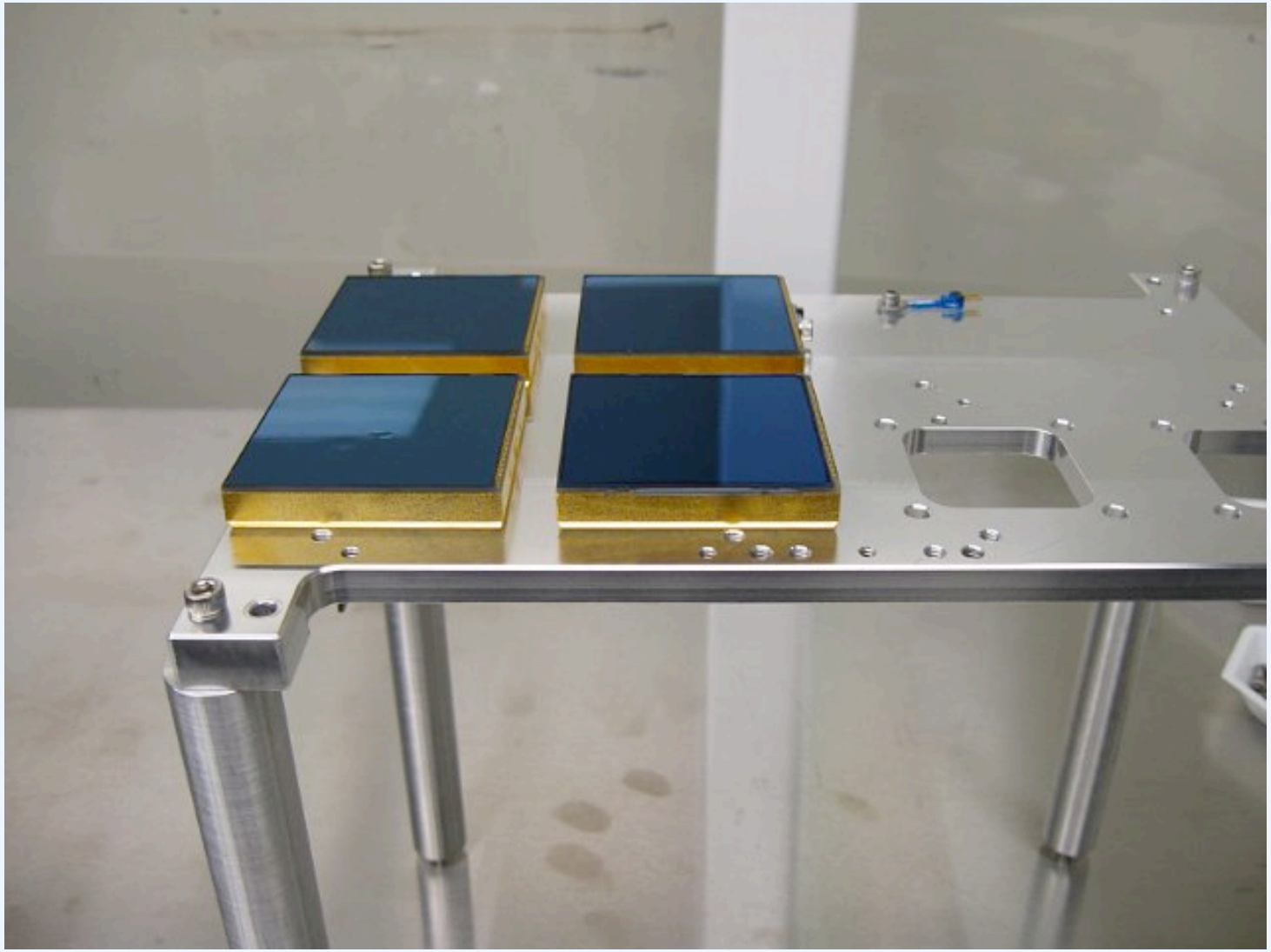
OTA Package Design

- Matched thermal/mechanical design:
  - Osprey CE-5 compound for frame
  - AlN interface (detector, epoxy, wiring).
  - Matched to focal base plate & Si.
  - 4-side buttable design
- Indium bump bonding for electrical contact.
  - No gold wire bonding!
  - Vacuum deposition of indium bumps.
  - 100 pin grid array.
- *Detector front side and package || to ±10μm*
- See Lesser et al. 2009, SPIE 7249-12.



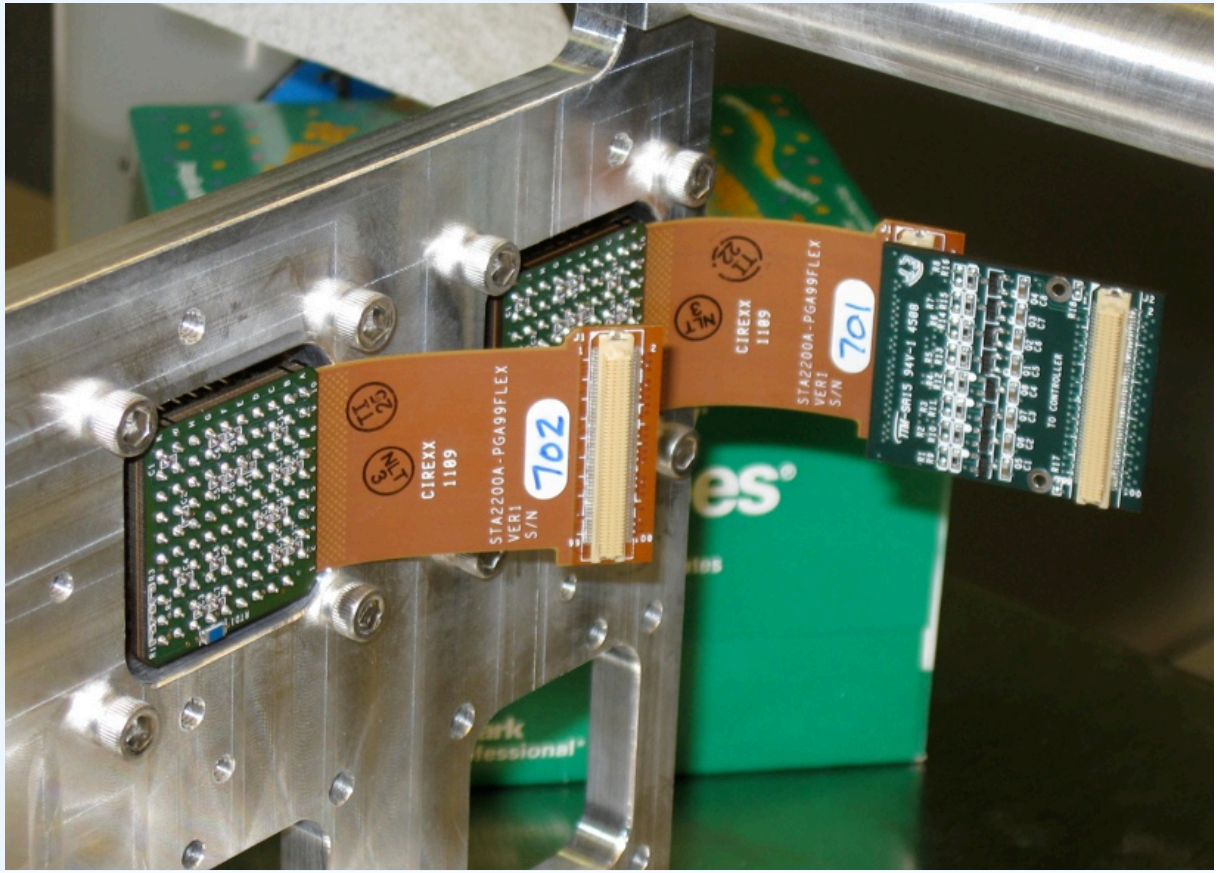


Detectors on IfA Test Focal Plane.



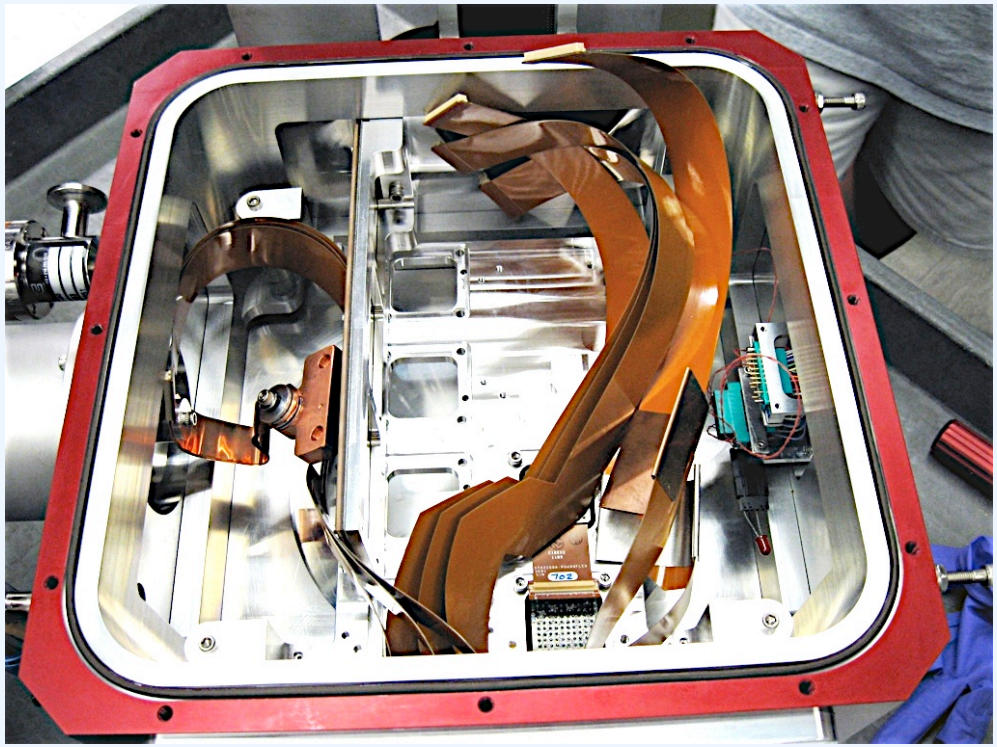
Electro-Mechanical Interfaces

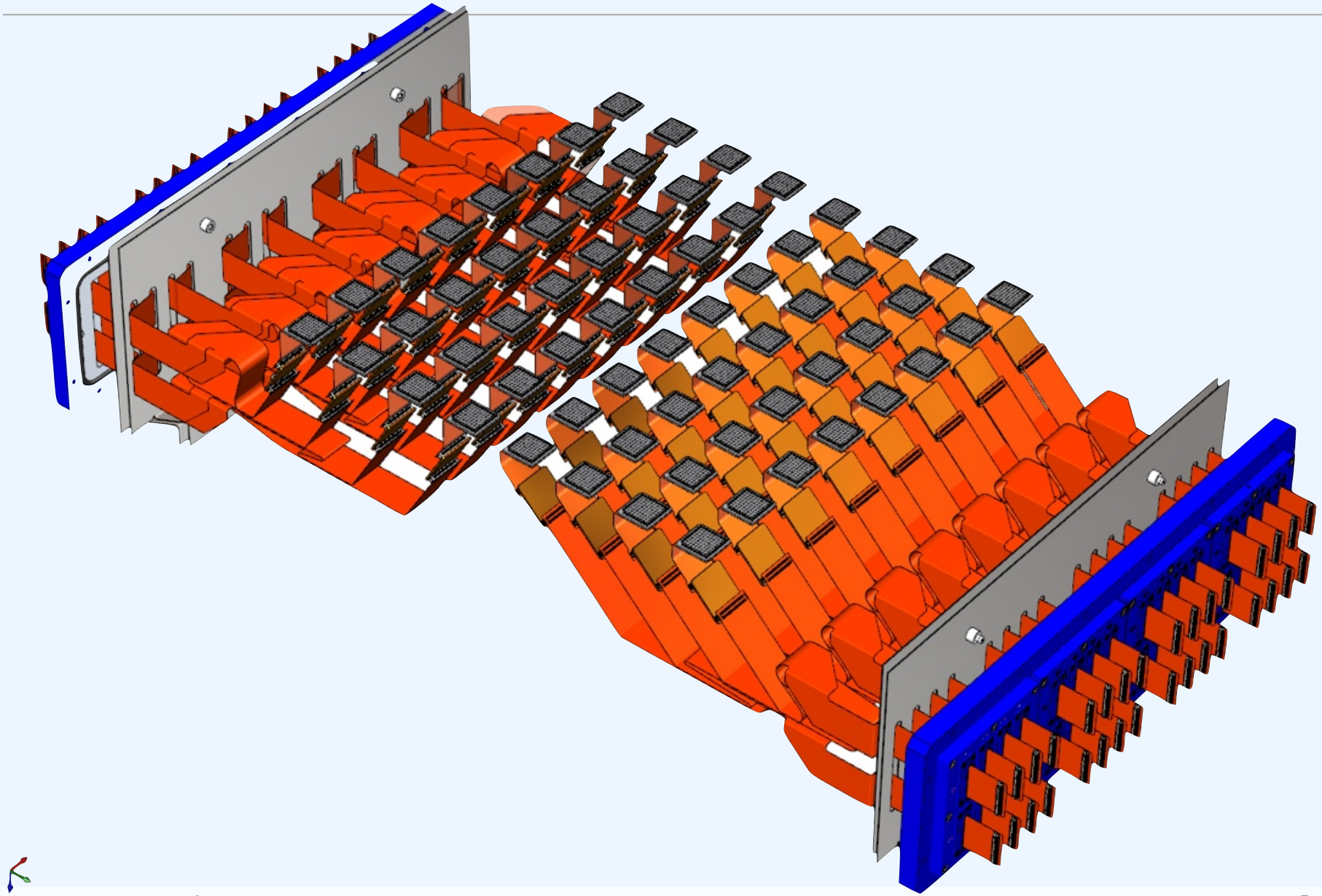
- Pin grid array connection on detector.
  - Pre-amplifier (JFET) interface attaches to connector.
- Joint development with PanSTARRS/Stargrasp group.
- Lessons from PS1 implemented.
- Modular design to be used in PanSTARRS PS2.

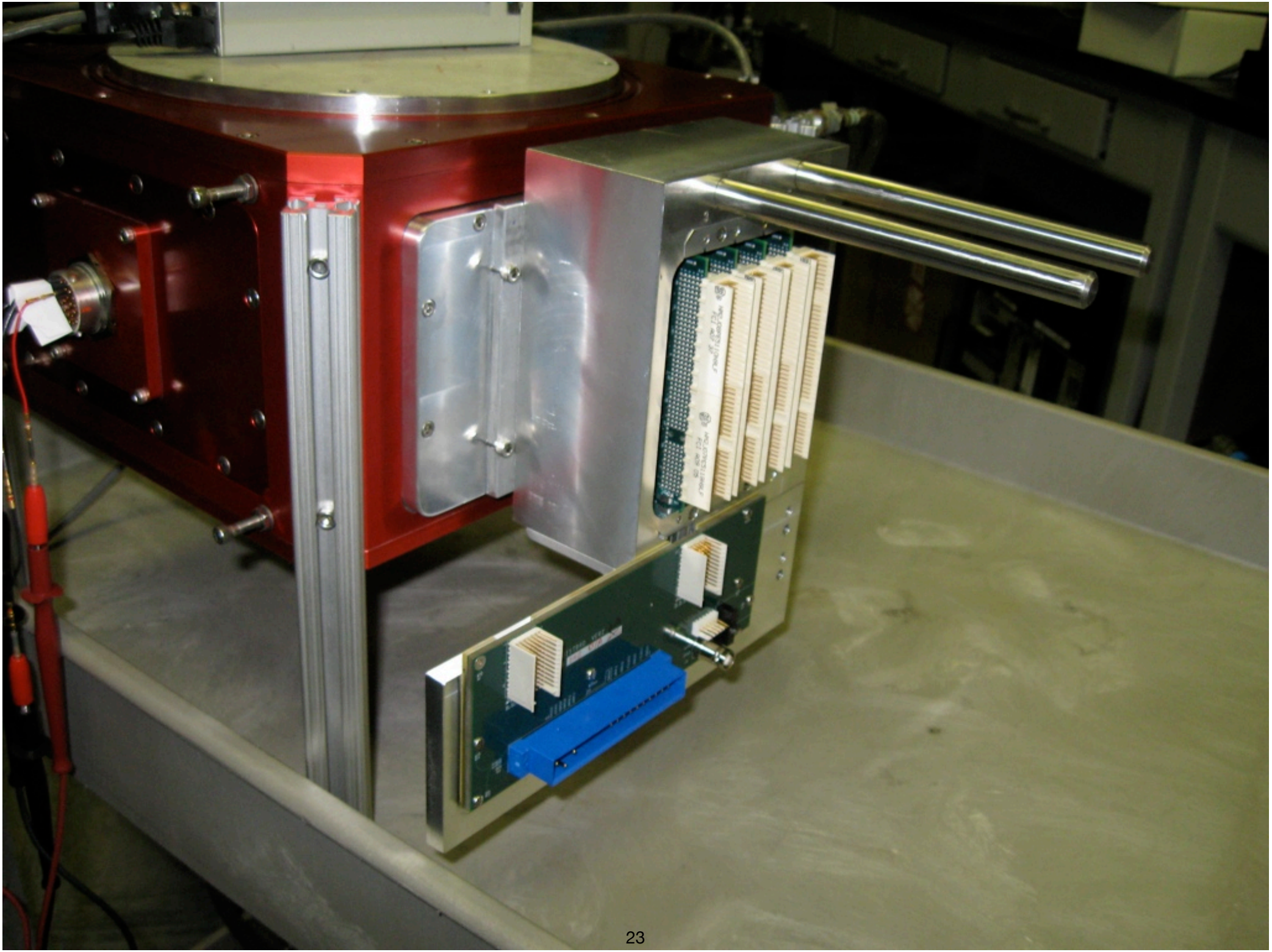


Electromechanical Interfaces II

- 64 point-to-point flex circuit connections.
  - To be folded and located in Dewar.
  - Equal cable length for each detector (equal impedance, time delay)





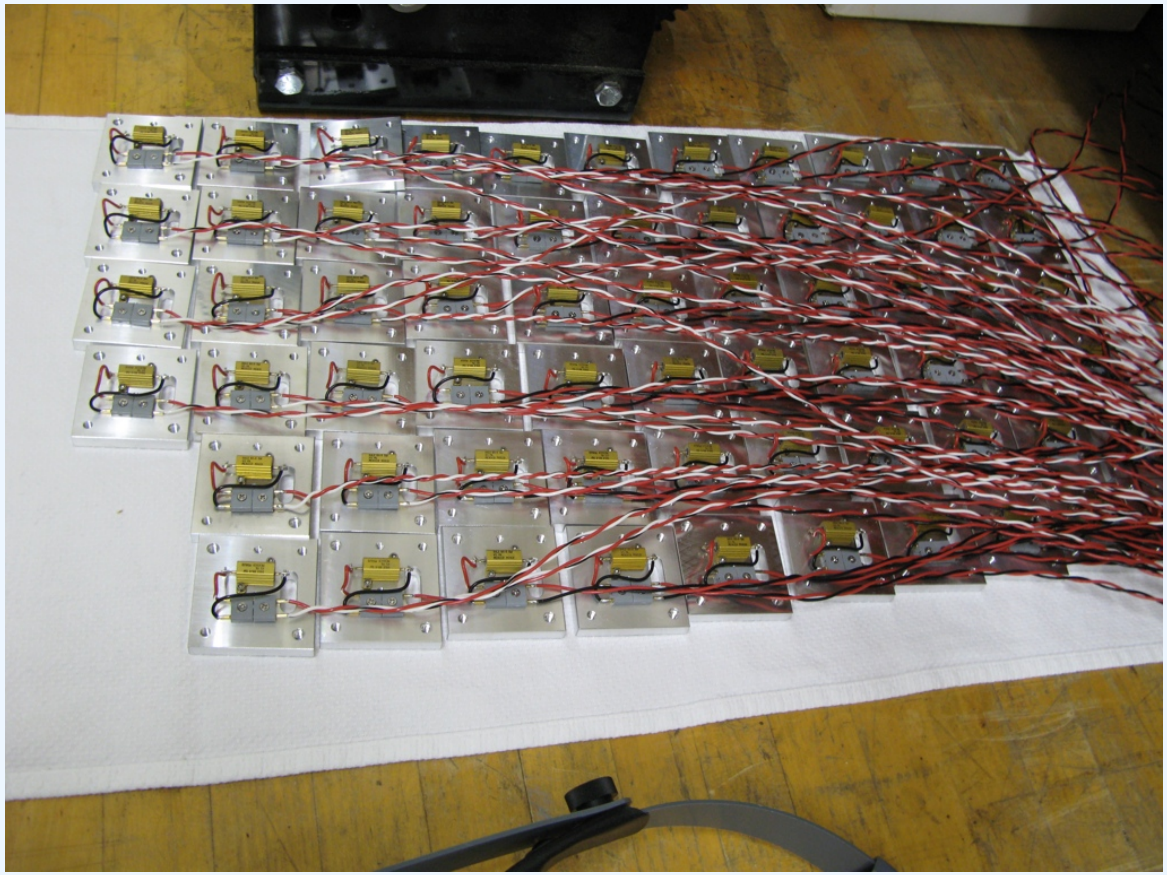


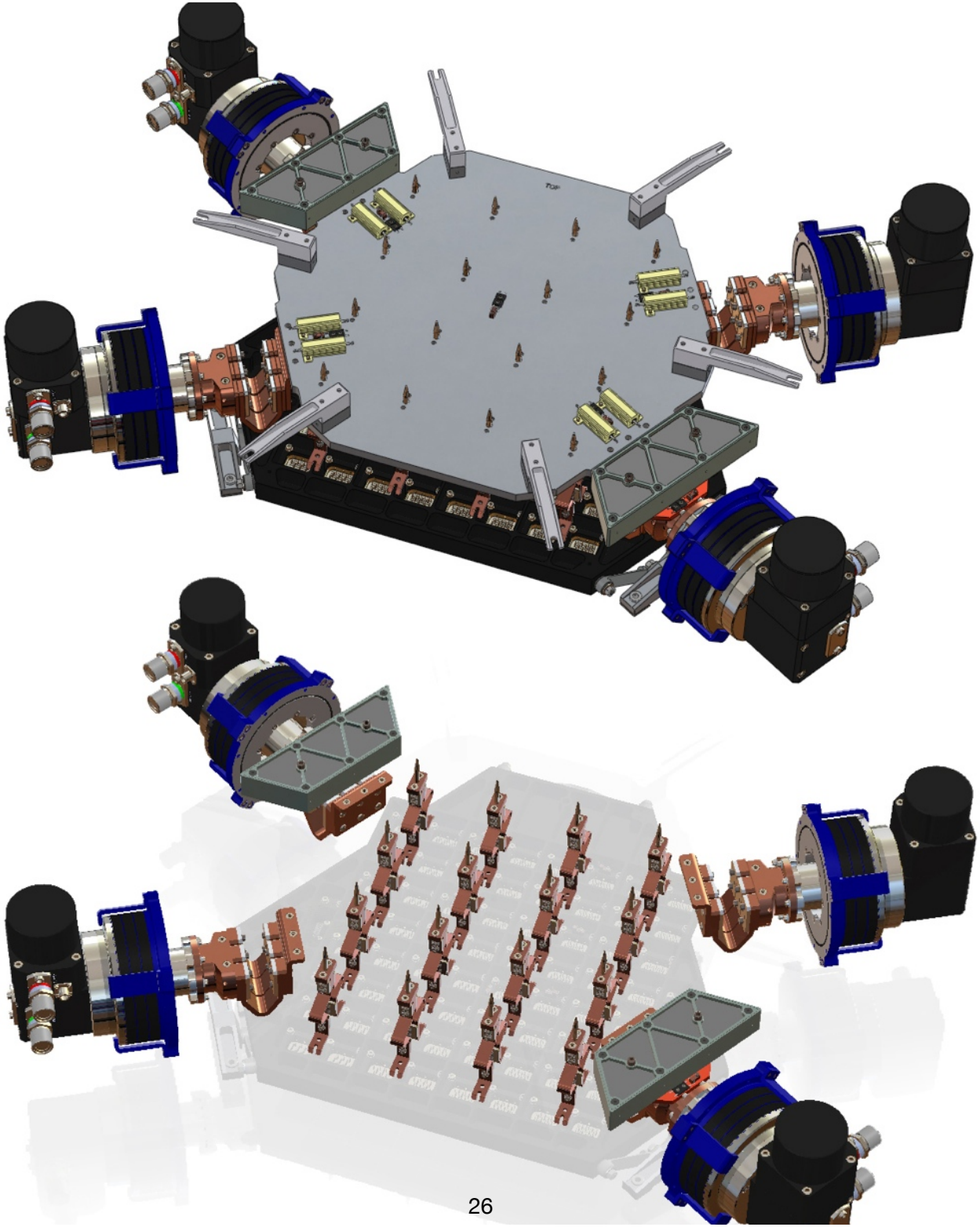
CCD Controllers

- Stargrasp controllers,
  - 2 detectors/board, 1GB ethernet/board.
  - TCP/UPD interface; network oriented architecture.
- Dissipate 1200W!
  - Remove heat from dome
- Crossbar switched ethernet
- 4 16 CPU-core computers
  - SAN 25TB Raid storage
  - 10GB internal network.
- Readout <<10sec.

Verification of Thermal Design

- Simulate heat load of 64 detectors.
  - Test response to pon/pof.
  - 120W variation to control.
- Test failure scenarios.
  - Detectors could overheat themselves.
  - Indium bump bonding not fault tolerant.
- Multiple safety layers.



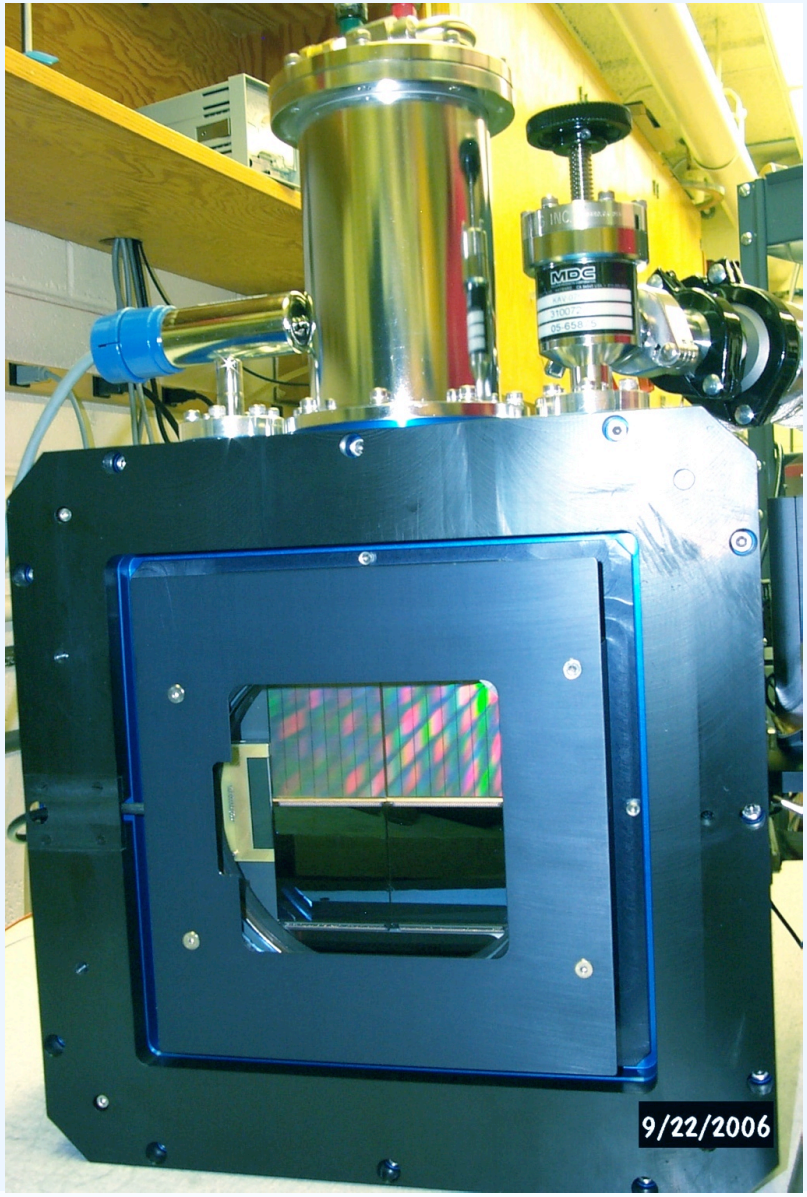


Thermal System

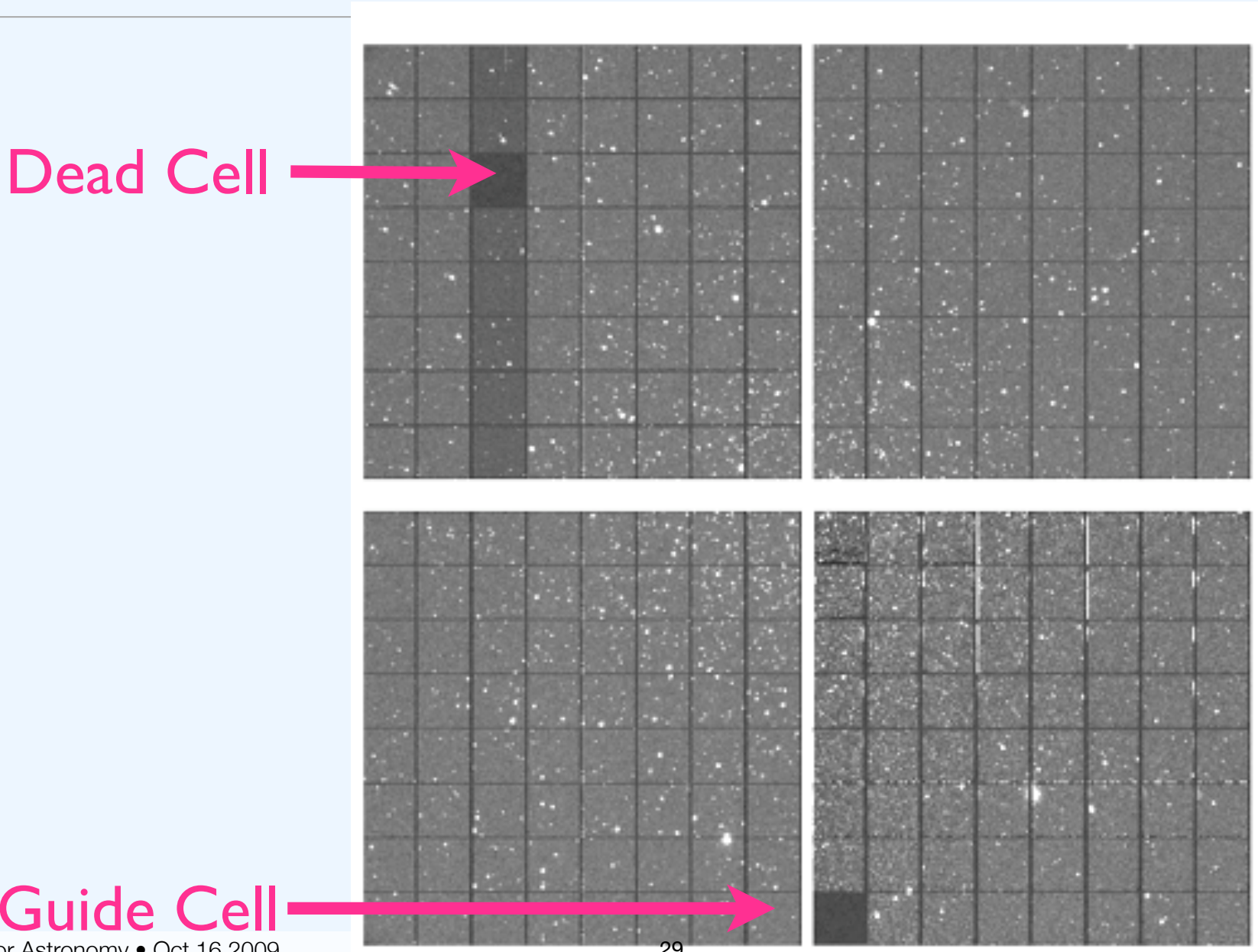
- Thermal & Vacuum System
  - 4 Ricor cryo cooling heads
  - Integrated Turbo molecular pump.

Prototype Camera QUOTA

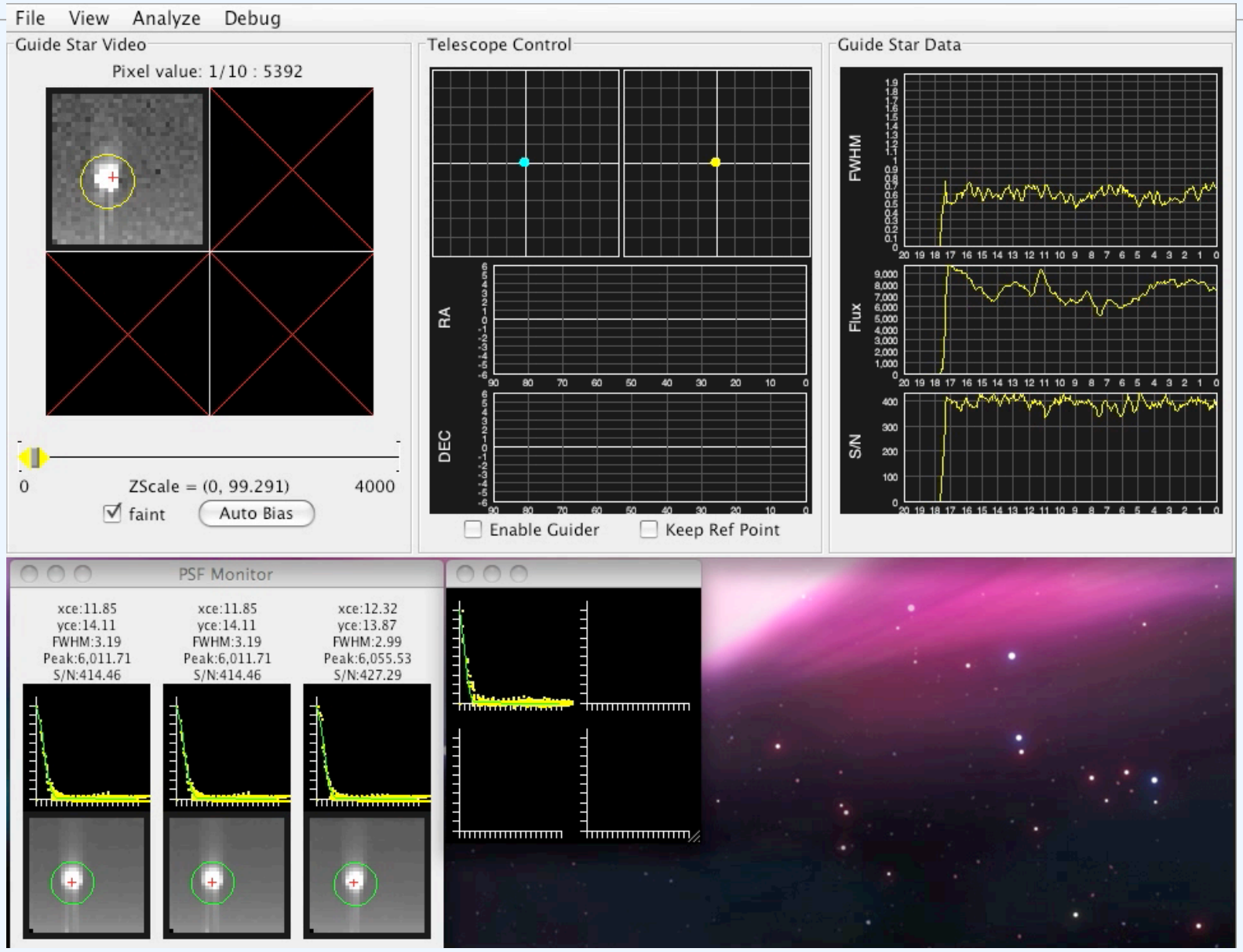
- 4 Detectors, different configurations over time.
- Prototype demonstrations at WIYN.
- First learning experience with OTA detectors.
- Demonstration of on-chip image correction.
- Decommissioned at this time.



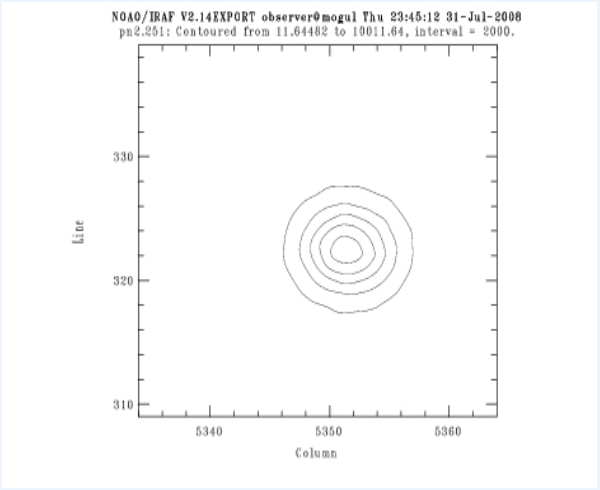
Open Cluster NGC 6791

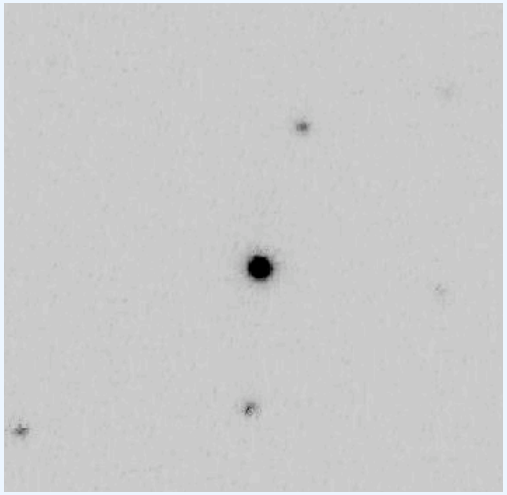


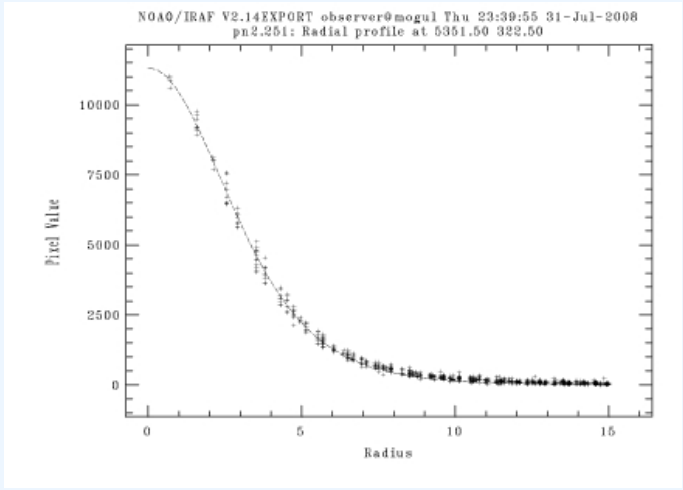
Demonstration of OTA Ops

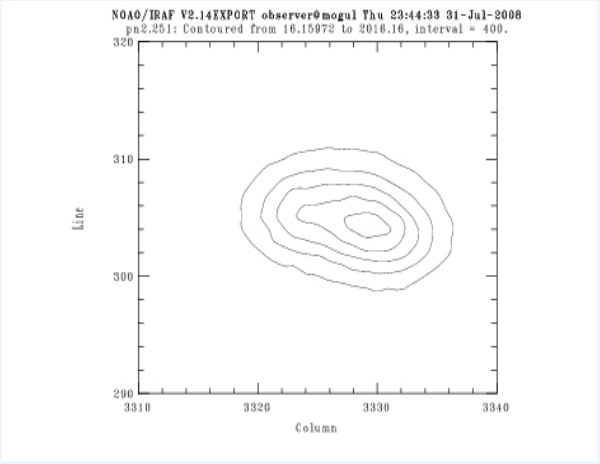


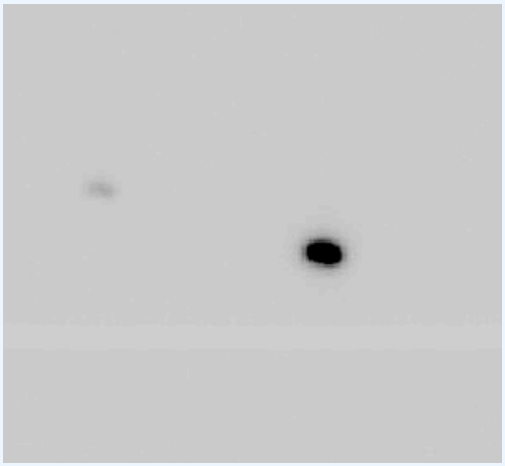
OT Image Correction Demonstrated

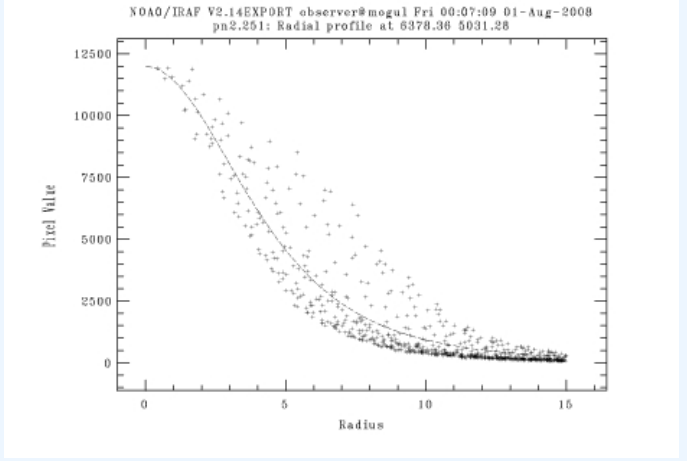








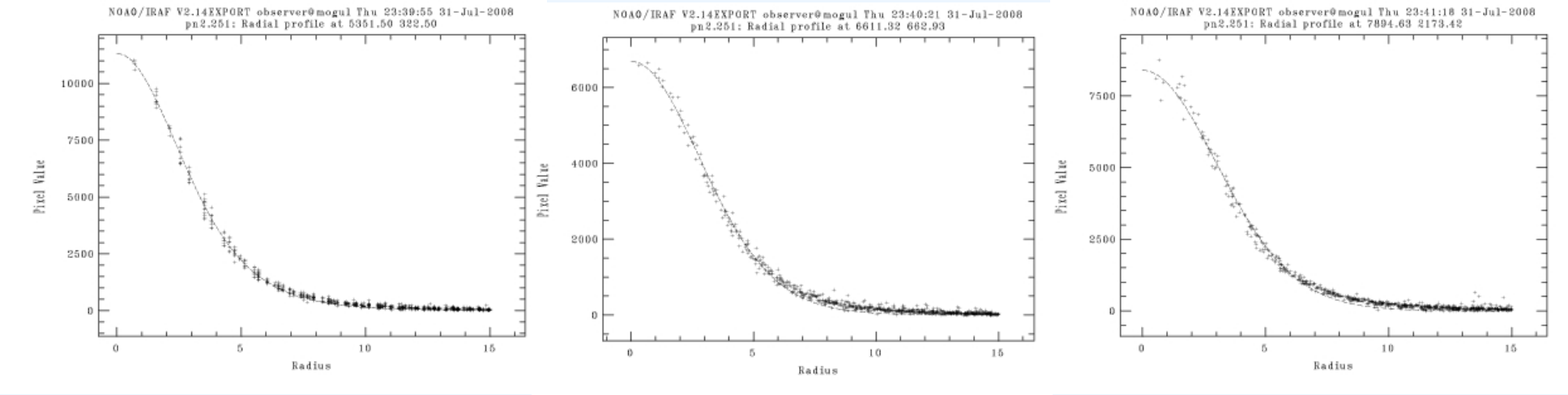




Guided Region - Top

Unguided Region - Bottom

FWHM vs. Distance from Guide Star



Distance: 2’
FWHM:
0.66”

Distance: 4’
FWHM:
0.72”

Distance: 8’
FWHM:
0.78”

Other QUOTA Demonstrations

- 16 guide stars in 2x2 detector array.

- OT correction modes
  - Common mode.
  - 1 correction per detector, nearest guide star.

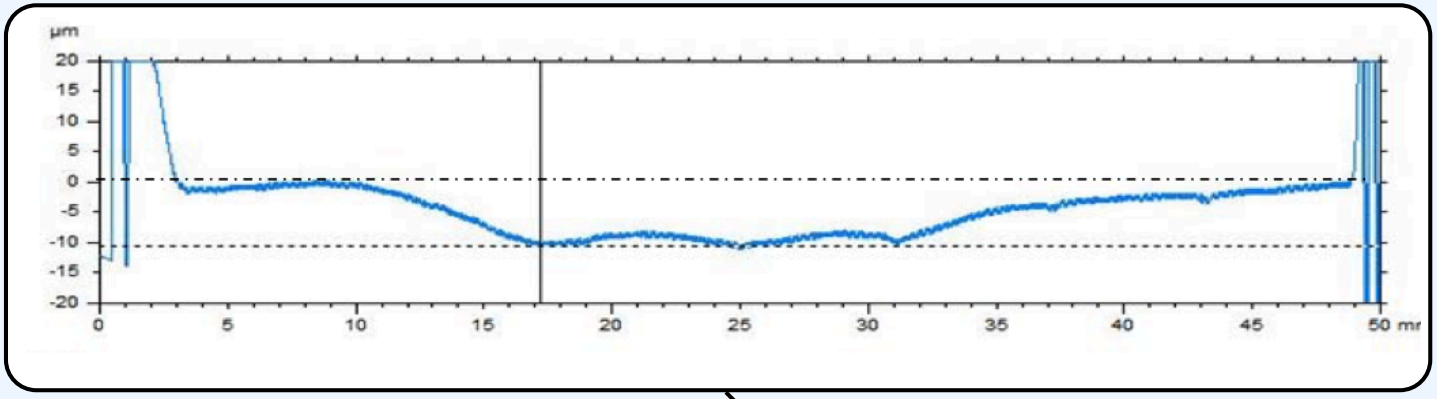
- Valuable lessons learned for ODI.
  - OTA operations.
  - Cooling system.

Summary

- Comprehensive, integrated design of
  - Detector & package
  - Focal plane & dewar
  - CCD Controller & network
  - Computer & storage infrastructure
- Testing of vacuum & thermal system has just started.
- OT mode successfully demonstrated with QUOTA.
- **Installation of ODI at WIYN in October 2010, scientific use in 2011.**


www.wiyn.org/ODI

Focal Plane stack



Detector surface flat ±20µm

Si

AlN

CE-5

CE-5

CE-5

SiC