SNAP technical design highlights

Physics Discoveries

Launch

Assembly

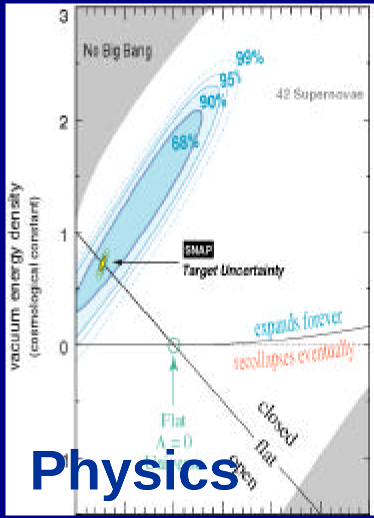
Configuration

Development

2001

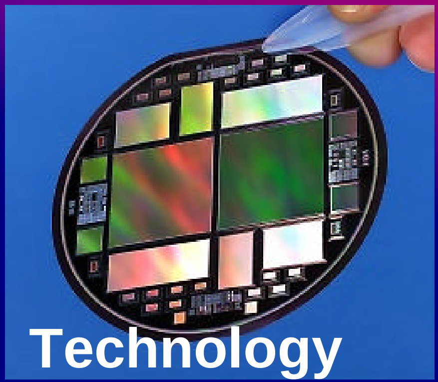
Supernova Acceleration Probe

2010

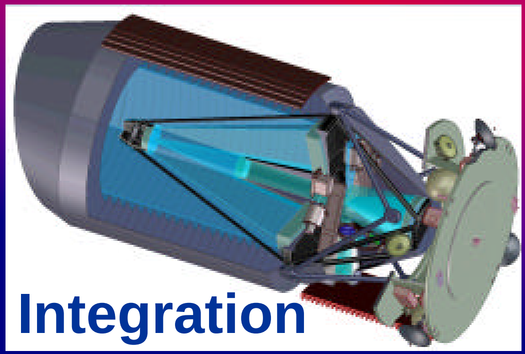


Physics

Engineering



Technology



Integration

Michael Levi July 14, 2001

From Science Goals to Project Design

Science

- Measure Ω_M and Λ
- Measure w and $w(z)$

Statistical Requirements

- Sufficient (~2000) numbers of SNe Ia
- …distributed in redshift
- …out to $z < 1.7$

Systematics Requirements

Identified and proposed systematics:

- Measurements to eliminate / bound each one to +/–0.02 mag

Data Set Requirements

- Discoveries 3.8 mag before max
- Spectroscopy with S/N=10 at 15 Å bins
- Near-IR spectroscopy to 1.7 μm

⋮

Satellite / Instrumentation Requirements

- ~2-meter mirror
- 1-square degree imager
- Spectrograph (0.35 μm to 1.7 μm)

Derived requirements:

- High Earth orbit
- ~50 Mb/sec bandwidth

⋮

Mission Requirements

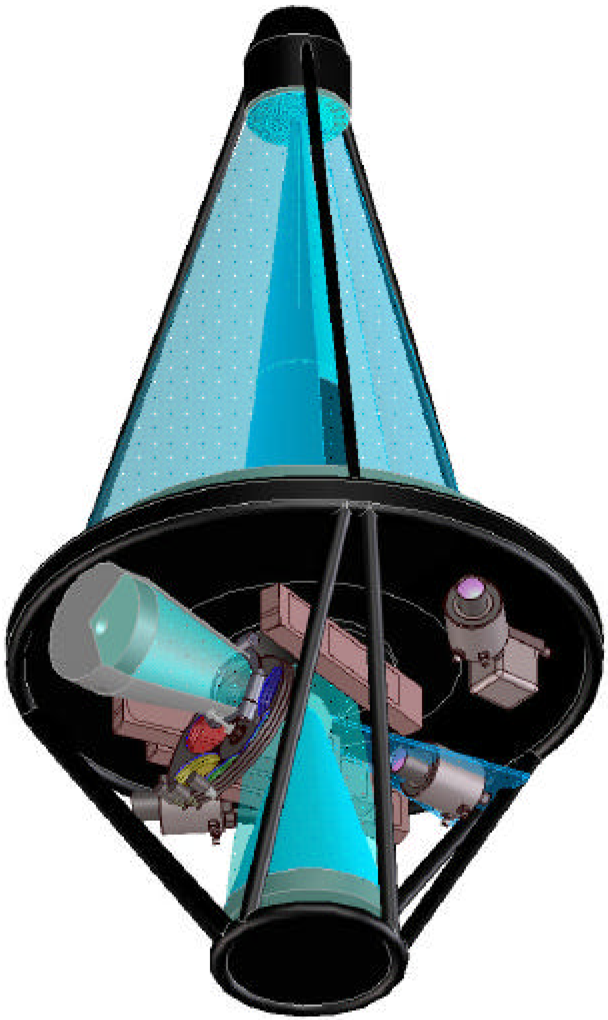
- **Minimum data set criteria:**
  - **Discovery within 2 days (rest frame) of explosion (peak + 3.8 magnitude),**
  - **Ten high S/N photometry points on lightcurve,**
  - **Lightcurve out to plateau (2.5 magnitude from peak),**
  - **High quality peak spectrophotometry**

- **How to obtain both data quantity AND data quality?**
  - **Batch processing techniques with wide field -- large multiplex advantage,**
  - **Wide field imager designed to repeatedly observe an area of sky**
  - **Mostly preprogrammed observations, fixed fields**
  - **Very simple experiment, passive expt.**

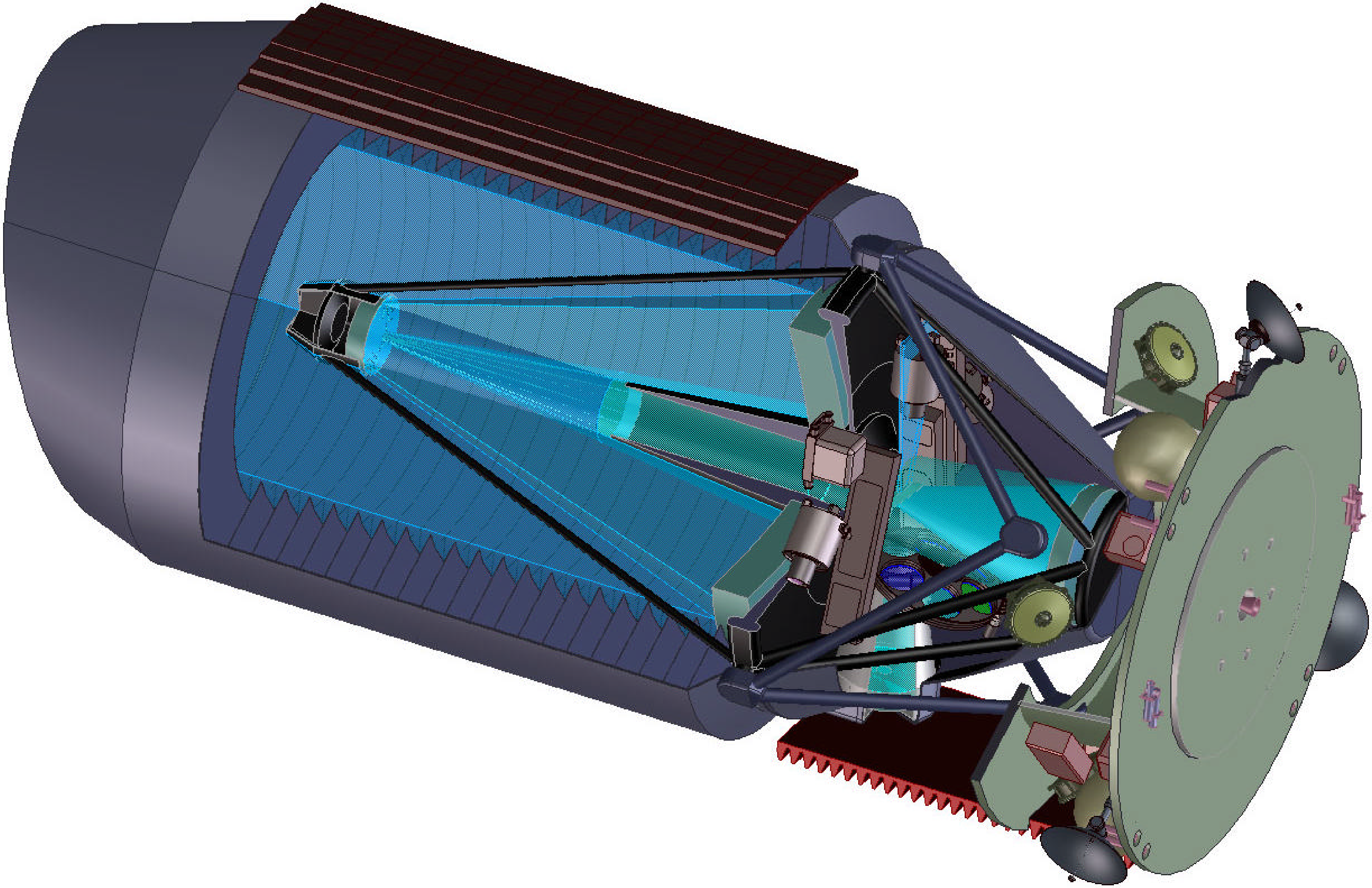
Mission Design

SNAP a simple dedicated experiment to study the dark energy

- — **Dedicated instrument, essentially no moving parts**
- — **Mirror: 2 meter aperture sensitive to light from distant SN**
- — **Optical Photometry: with 1°x 1° billion pixel mosaic camera, high-resistivity, rad-tolerant p-type CCDs sensitive over 0.35-1mm**
- — **IR photometry: 0.25 sq. degree FOV,**
  HgCdTe array (1-1.7 mm)
- — **Integral field optical and IR spectroscopy:**
  0.35-1.7 mm, 2"x2" FOV



Cut away View of Structure



Telescope Assembly

Movie courtesy of Hytec

Observatory Parameters

Primary Mirror

diameter= 200 cm

Secondary Mirror

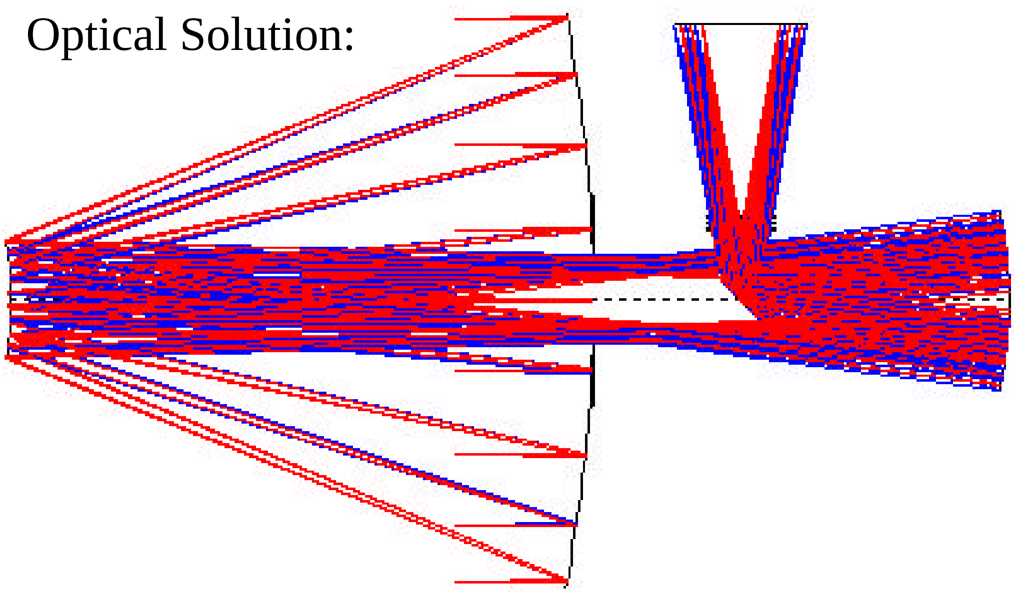
diameter= 42 cm

Tertiary Mirror

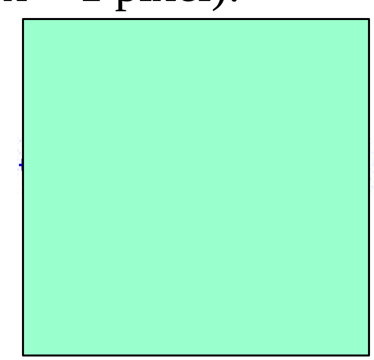
diameter=64 cm

Aperture	~ 2.0 meter
Field-of-view	1° x 1°
Optical resolution	diffraction-limited at I-band
Wavelength	350nm - 1700nm
Solar avoidance	70°
Temperature	Telescope 270-290K (below thermal background)
Fields of study	North and South Ecliptic Caps
Image Stabilization	Focal Plane Feedback to ACS
Plate Scale	~ 0.1 arcsec/pixel

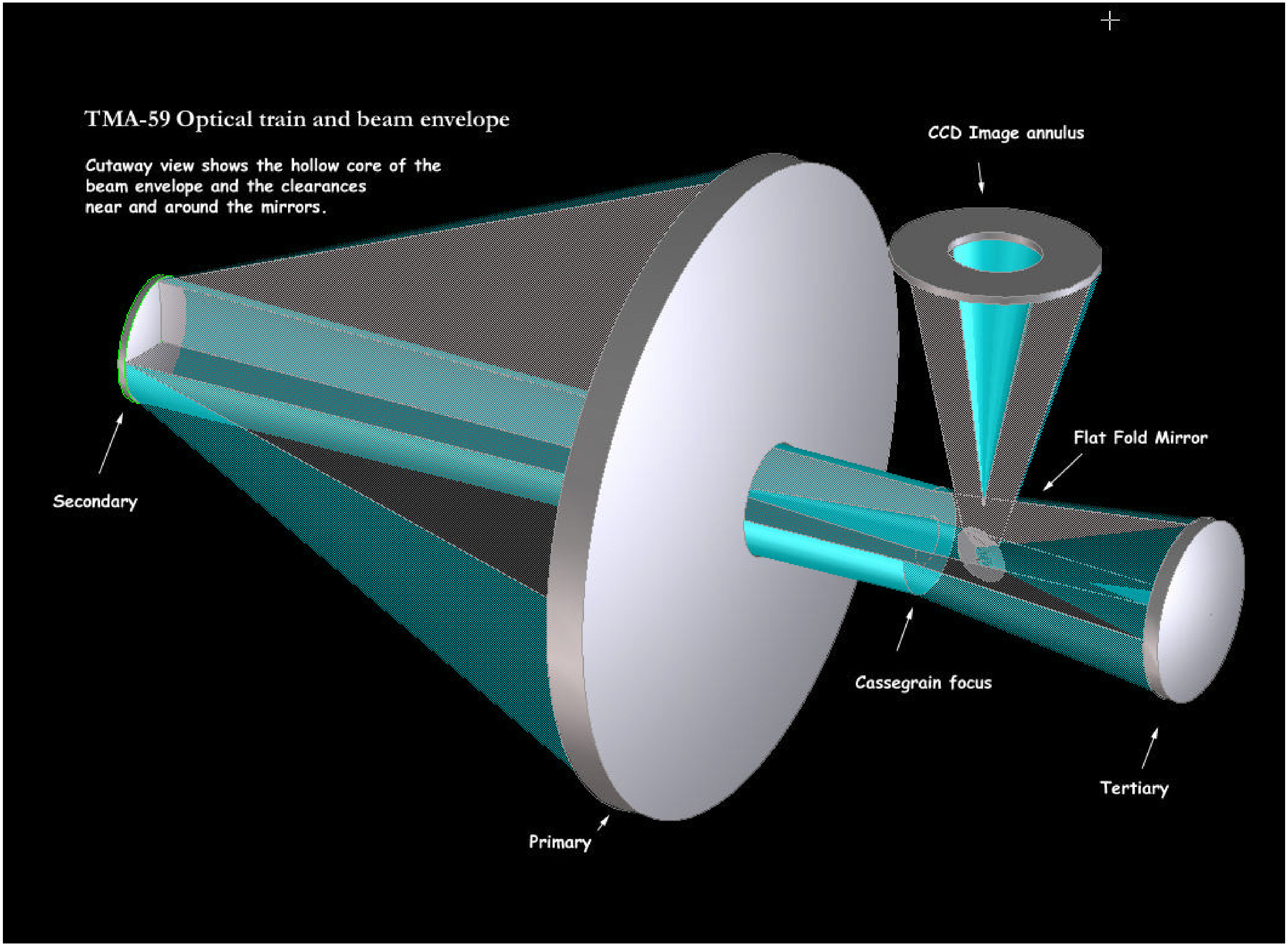
Optical Solution:



Edge Ray Spot Diagram
(box = 1 pixel):

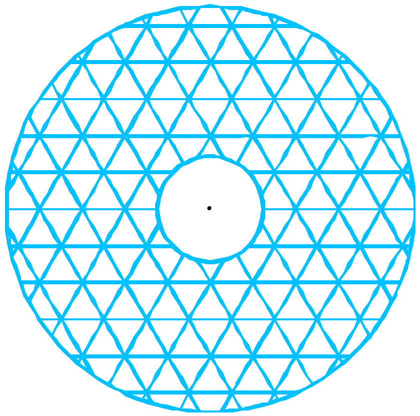


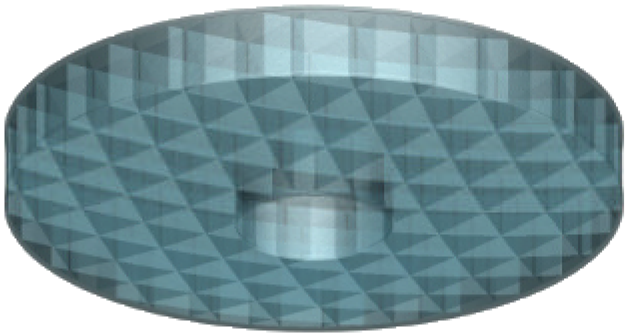
Optical Train



Primary Mirror Substrate

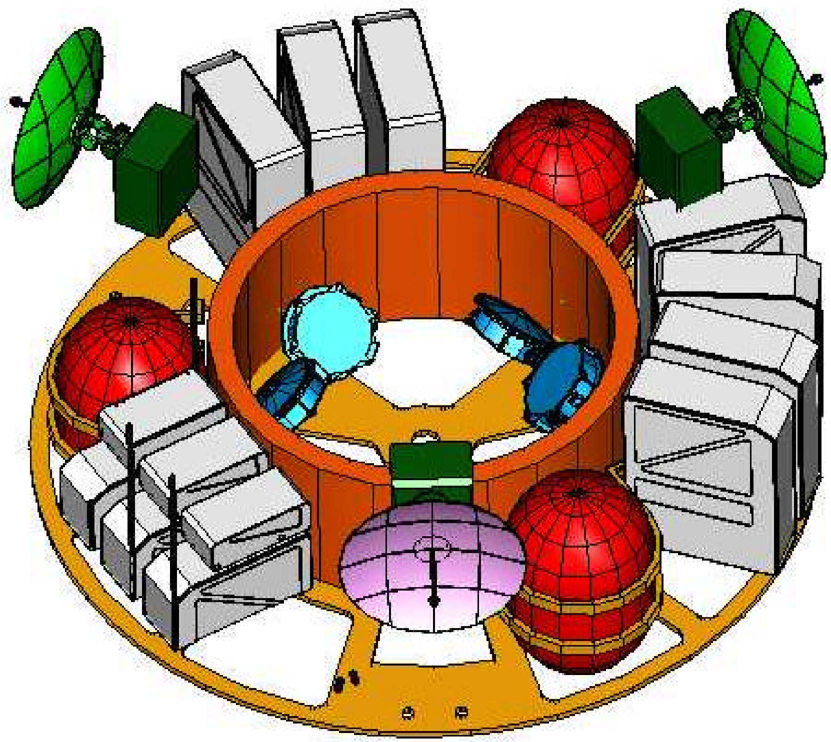
- **Key requirements and issues**
  - — **Dimensional stability**
  - — **High specific stiffness (1g sag, acoustic response)**
  - — **Stresses during launch**
  - — **Design of supports**
- **Baseline technology**
  - — **Multi-piece, fusion bonded, with egg-crate core**
  - — **Meniscus shaped**
  - — **Triangular core cells**
- **Material**
  - — **Baseline = ULE Glass (Corning)**

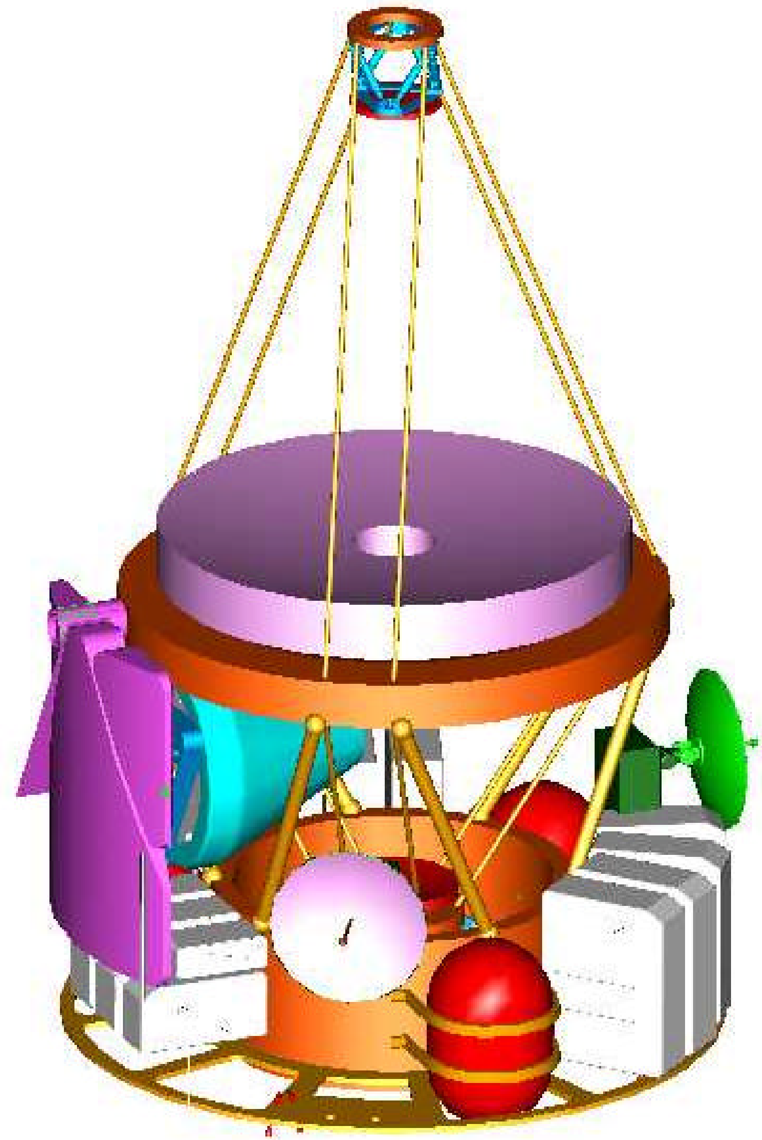




Initial design for primary mirror substrate: 120 kg

Goddard Designed Spacecraft

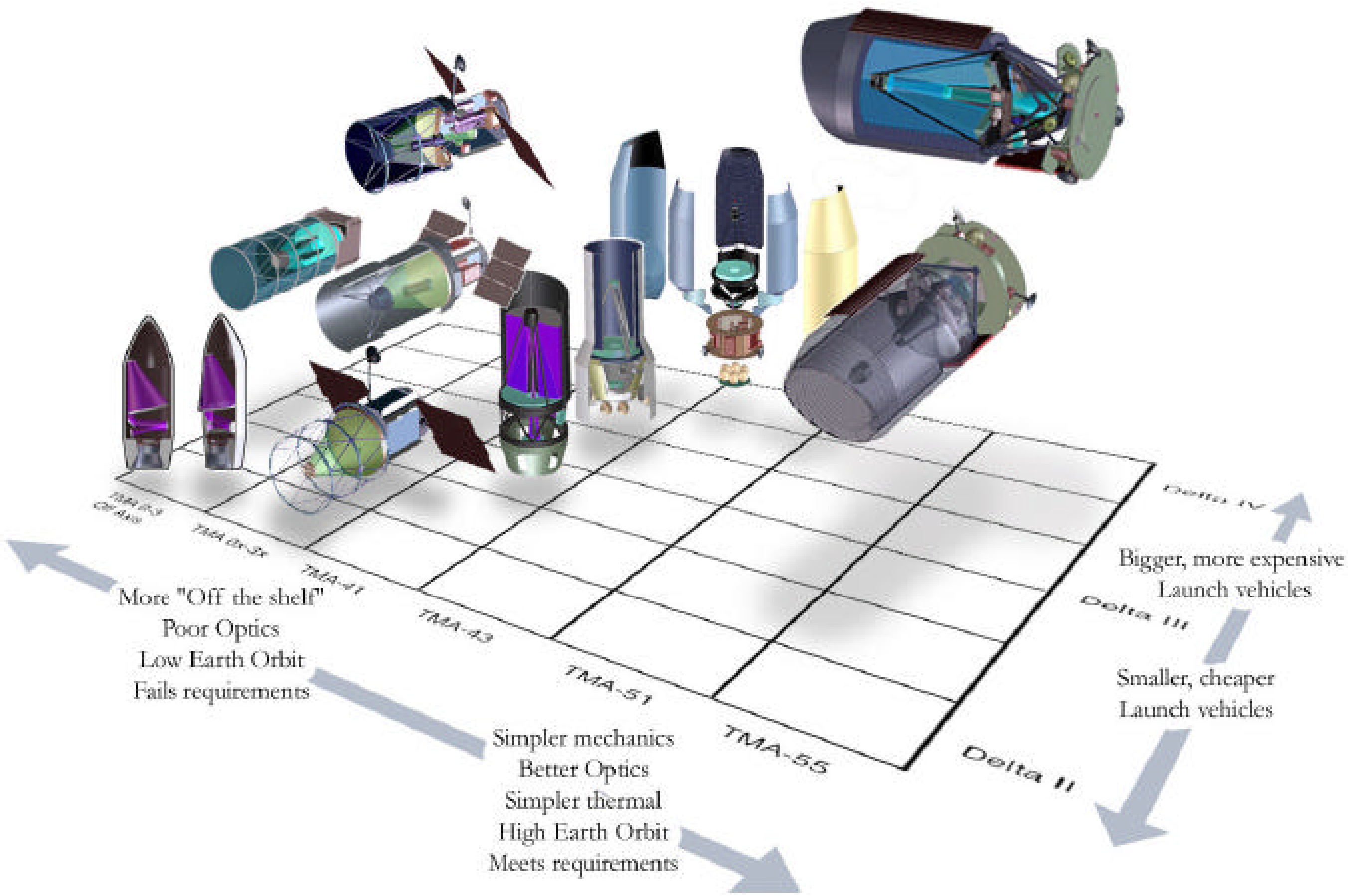


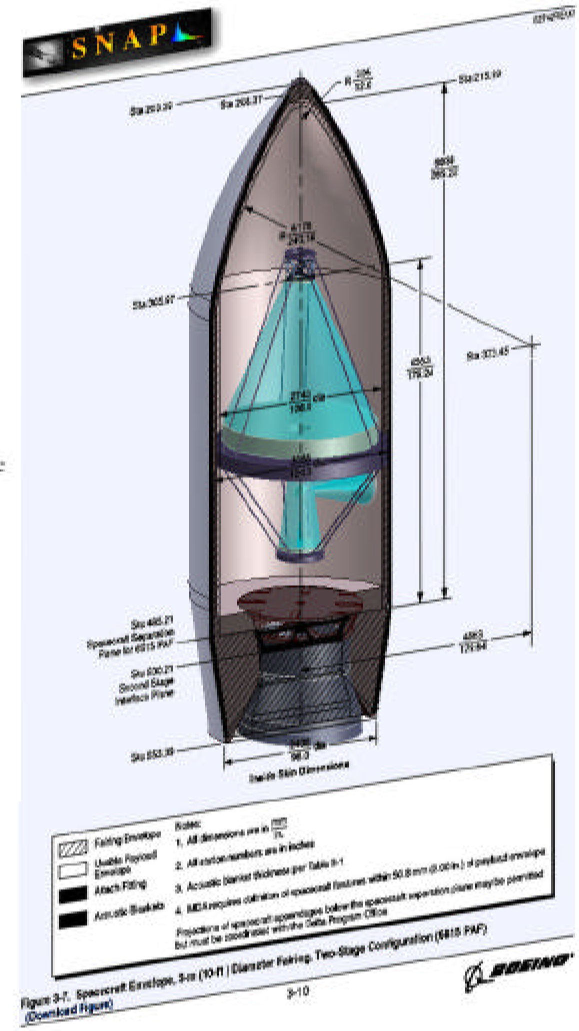


Spacecraft Assembly

Movie courtesy of Hytec

Launch Vehicle Study





Launch Vehicle Study

Space Transportation System	24,000 Kg	$ 500 M
Titan IVB/Centaur/SRMU	8600 Kg	$ 250 M
Ariane 5	6800 Kg	$ 200 M
EELV-Heavy	6120 Kg	
H2-A	6000 Kg	
Proton	4800 Kg	$ 50-70 M
H2	4000 Kg	$ 150 M
Sea Launch I/Zenit 3	3300 Kg	$ 50-70 M
Atlas II ARS	3100 Kg	
Delta IV	2800 Kg	$ 100 M
Delta III	2700 Kg	$ 80 M
Atlas II AR	2100 Kg	$ 95 M
Delta II 7920 H-10L	900 Kg	$ 80 M
Delta II 7925	1260	$ 70 M

Sea Launch Fairing

Orbit Trade-Study

Feasibility & Trade-Study

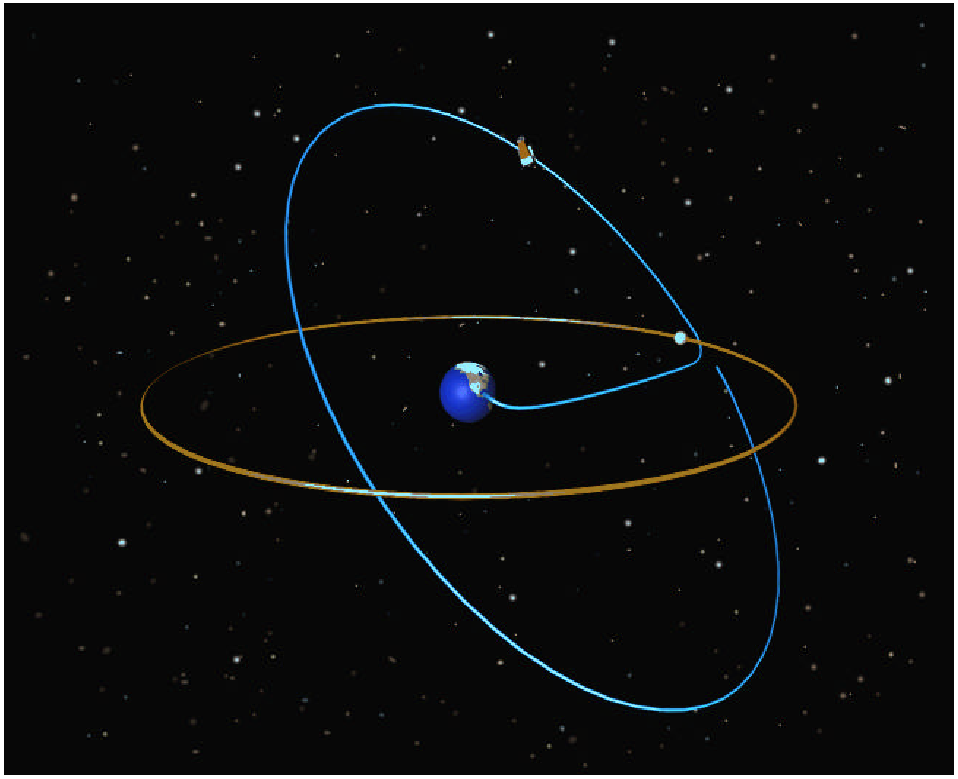
Orbit	Radiation	Thermal	Telemetry	Launch	Stray Light	Rank
HEO/ Prometheus	Very Good	Passive	Med. BW	Fair	Dark	1
HEO / L2	Very Good	Passive	Low BW	Fair	Dark	2
HEO / GEO	Poor	Passive	24 hr	Fair	Dark	3
LEO / Equator	Lowest Dose	Mechanical	High BW	Fair	Earth Shine	4
LEO / Polar	High at Poles	Mechanical	High BW	Excellent	Earth Shine	5
LEO / 28.5	Lowest Dose	Mechanical	High BW	Excellent	Earth Shine	6

Selected Lunar Assist “Prometheus” Orbit

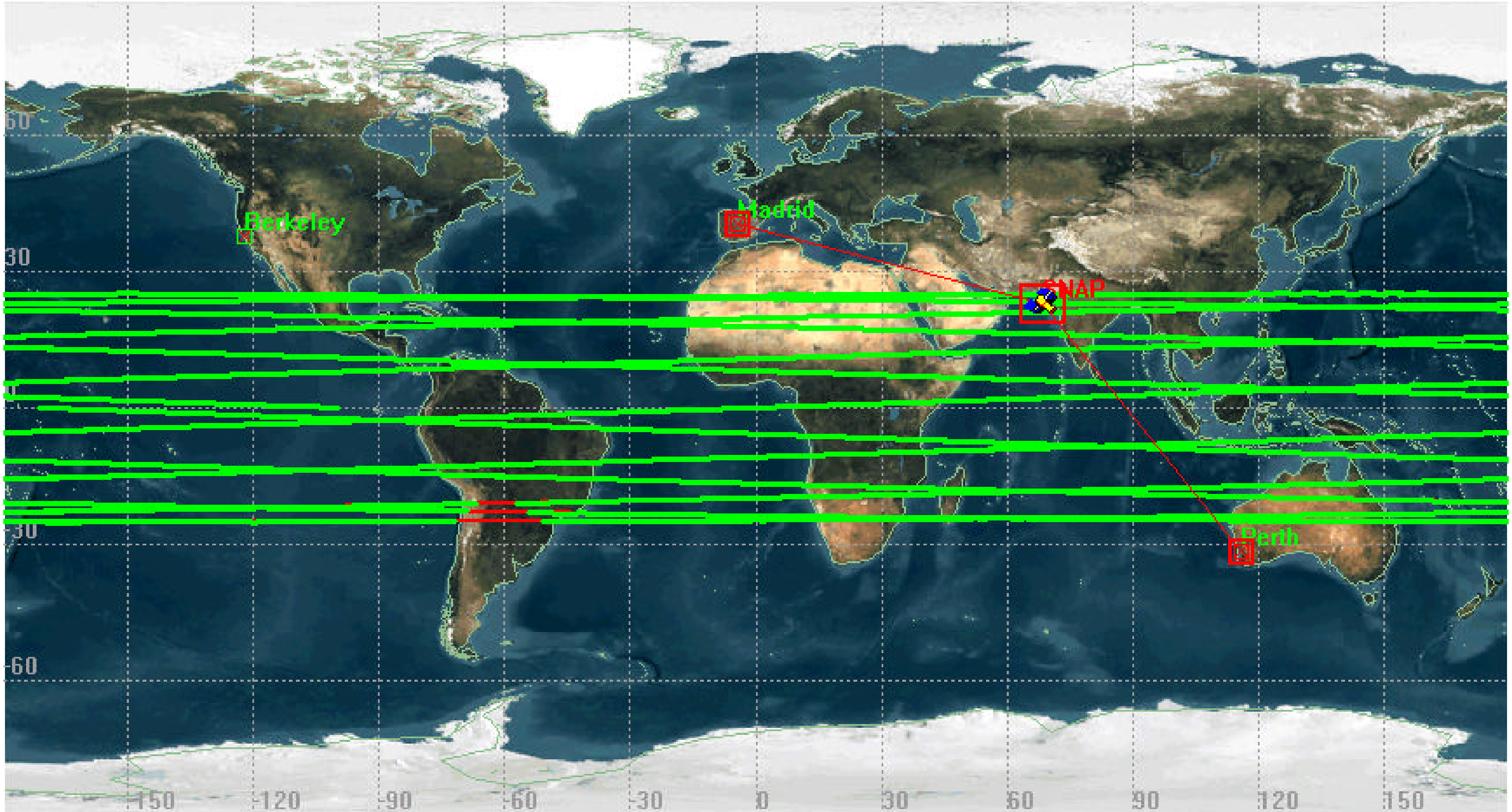
14 day orbit: 39 Re semi-major axis

Orbit Optimization

- Uses Lunar Assist to Achieve a 14 day Orbit, with a Delta III, Delta IV-M, Atlas III, or Sea Launch Zenit-3SL Launch Vehicle
- Good Overall Optimization of Mission Trade-offs
- Low Earth Albedo Provides Multiple Advantages:
  - Minimum Thermal Change on Structure Reduces Demand on Attitude Control
  - Minimum Thermal Change on Telescope – very stable PSF
  - Excellent Telemetry, reduces risk on satellite
  - Outside Radiation Belts
  - Passive Cooling of Detectors
  - Minimizes Stray Light
  - MAP currently proving orbit concept



Three Ground Stations



Mission Operations

Mission Operations Center (MOC) at Space Sciences Using Berkeley Ground Station

- Fully Automated System Tracks Multiple Spacecraft
  - 11 meter dish at Space Sciences Laboratory
  - Science Operations Center (SOC) closely tied to MOC

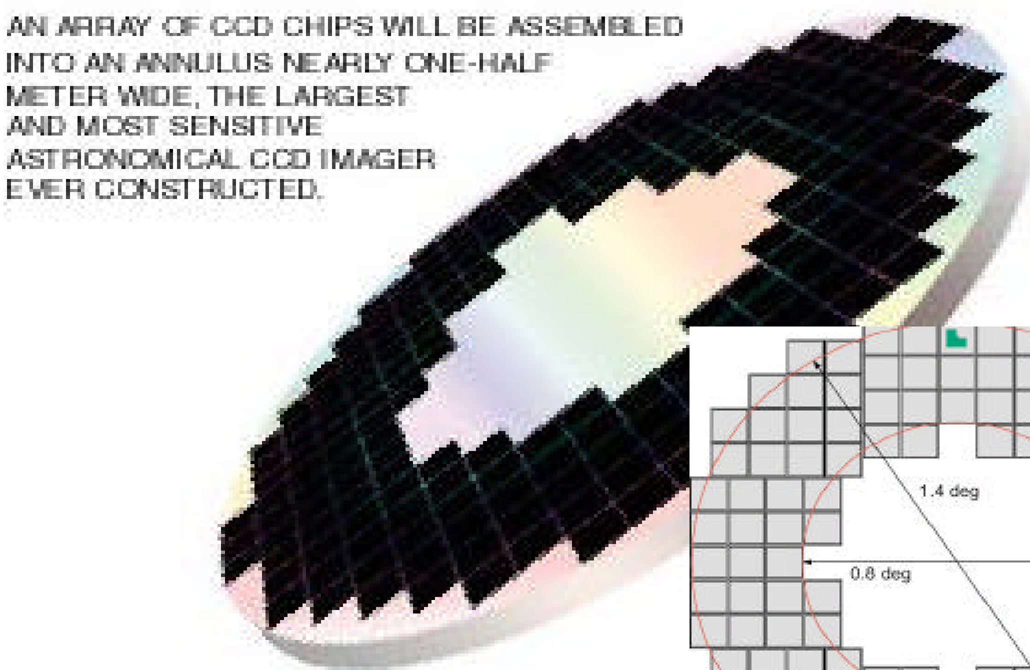
Operations are Based on a Four Day Period

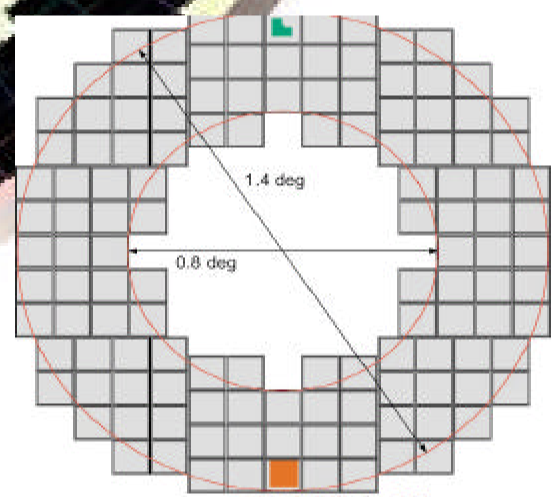
- Autonomous Operation of the Spacecraft
- Coincident Science Operations Center Review of Data with Build of Target List
- Upload Instrument Configuration for Next Period

GigaCAM

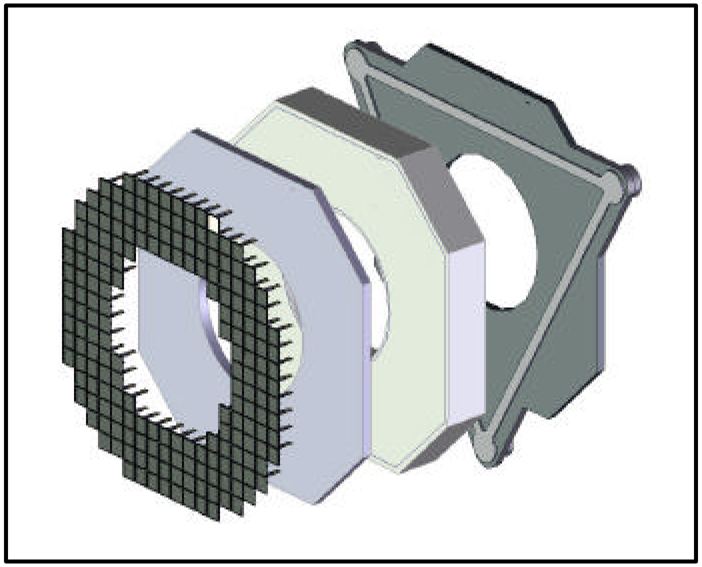
GigaCAM, a one billion pixel array

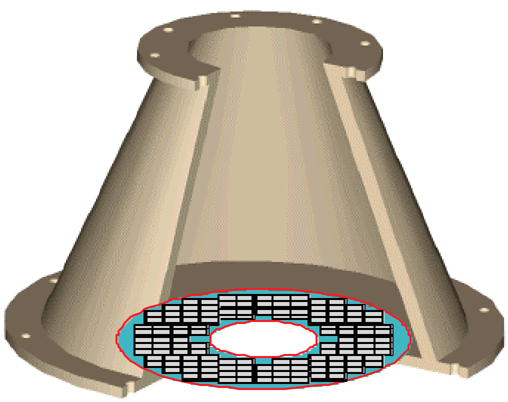
- Approximately 1 billion pixels
- ~132 Large format CCD detectors required
- Larger than SDSS camera, smaller than H.E.P. Vertex Detector (1 m^2)
- Approx. 5 times size of FAME (MiDEX)

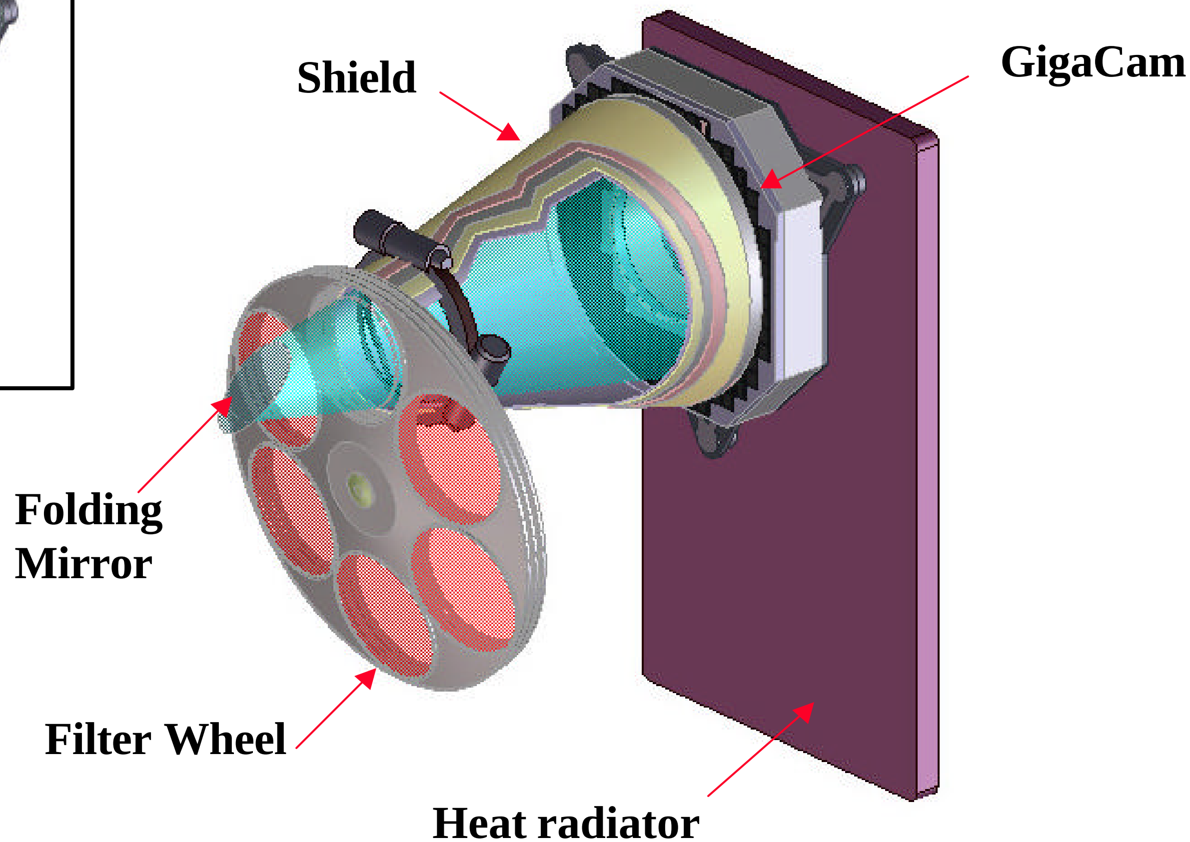




Camera Assembly



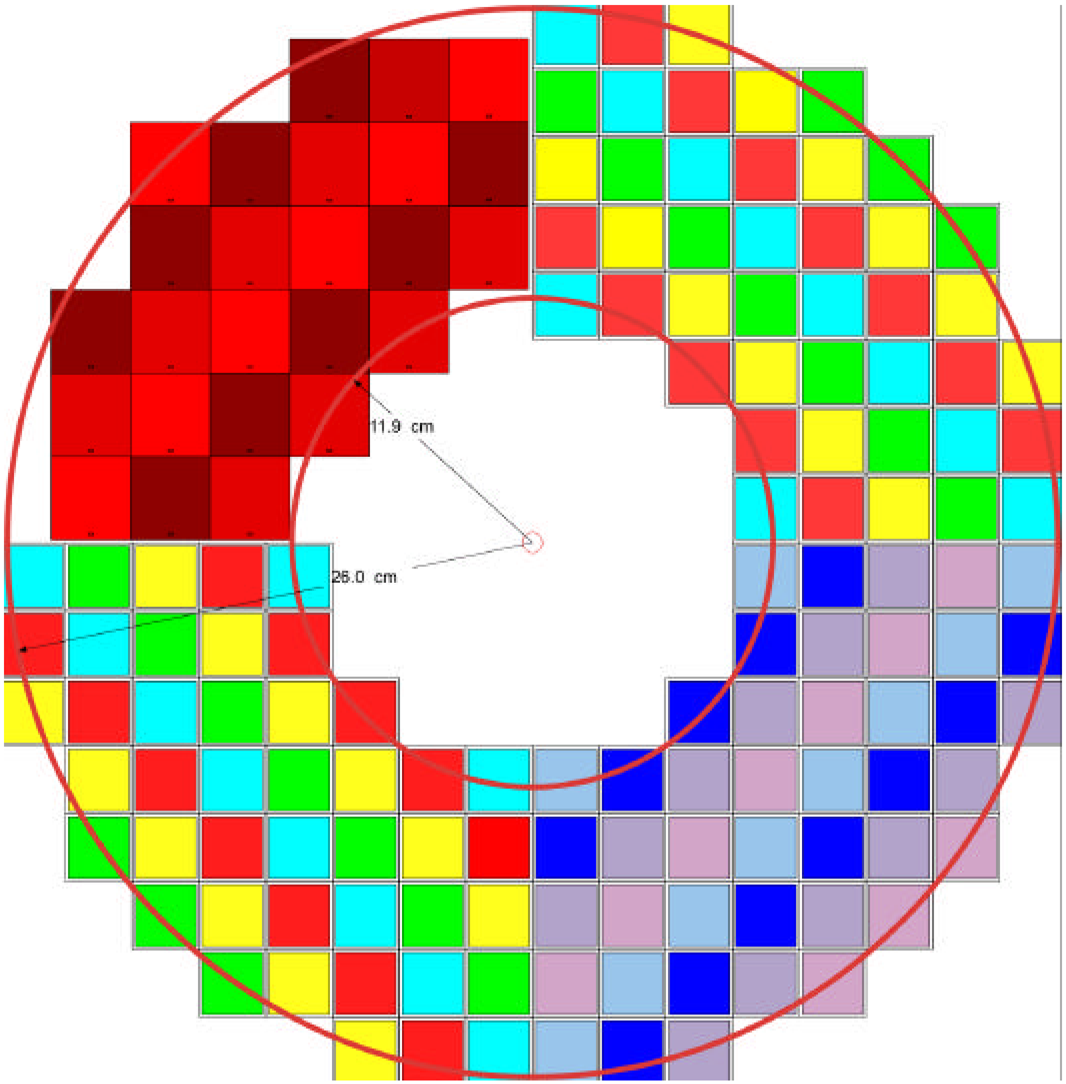




IR Enhanced Camera with Fixed Filter Set

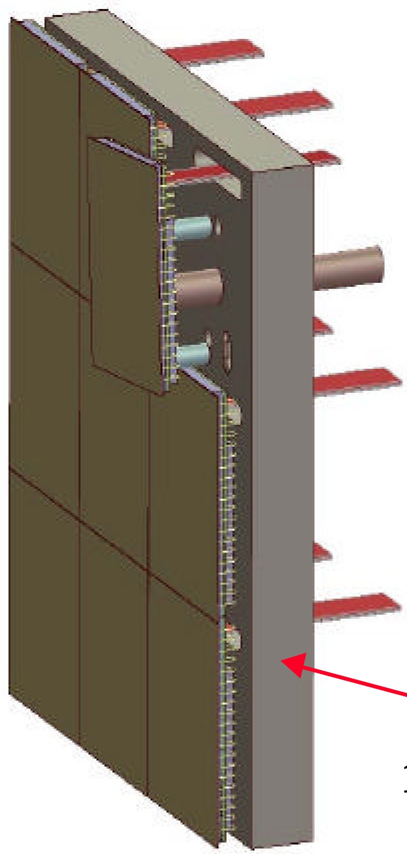
25 HgCdTe
132 CCD’s

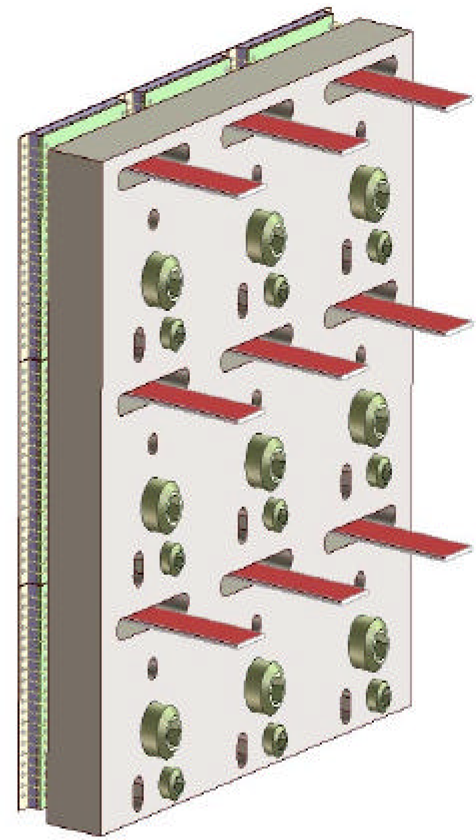
3 IR Filters
8 Visible Filters



Mosaic Packaging

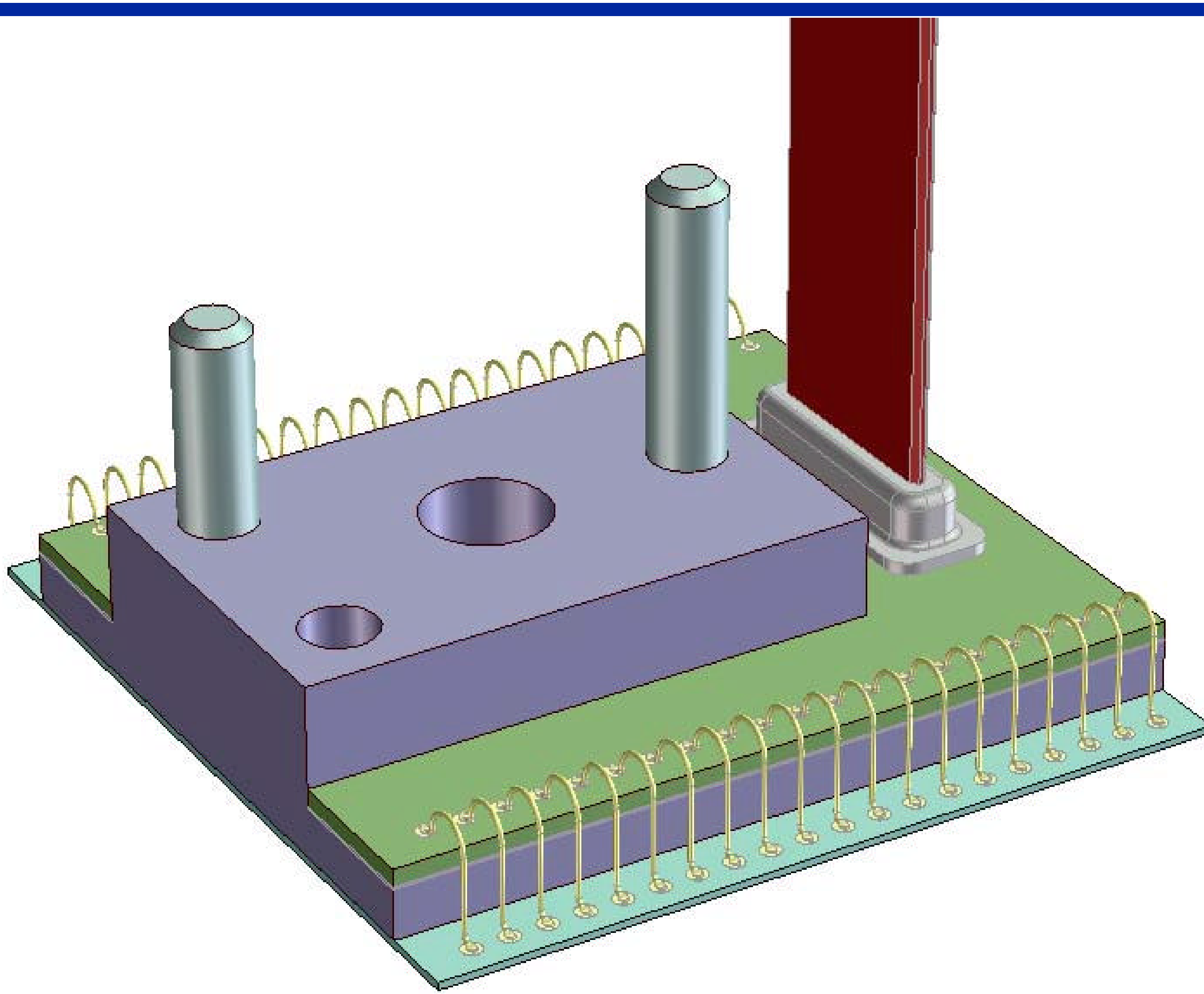
With precision CCD modules, precision baseplate, and adequate clearances designed in, the focal plane assemble is “plug and play.”



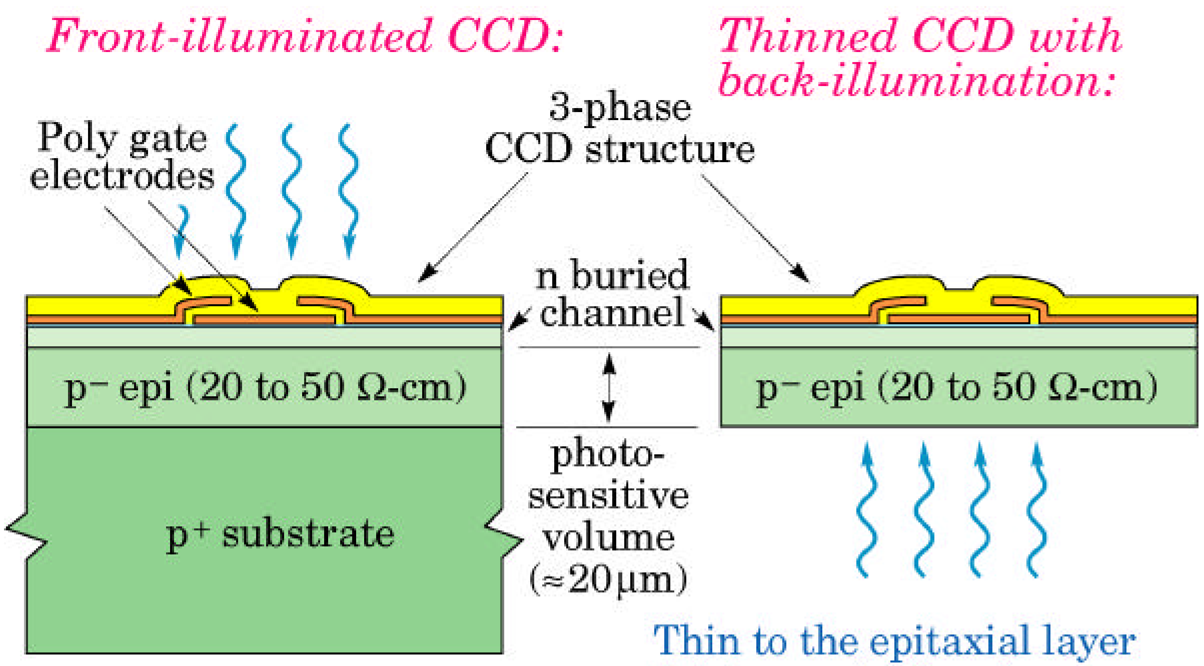


140 K plate attached to space radiator.

CCD Subassembly



Typical CCD's



Thin to the epitaxial layer thickness (≈20µm)

Drawbacks:

1) Poor blue response due to absorption in polysilicon gate electrodes
2) Poor near-IR response due to thinness of the epitaxial layer
3) Interference patterns due to gate structure

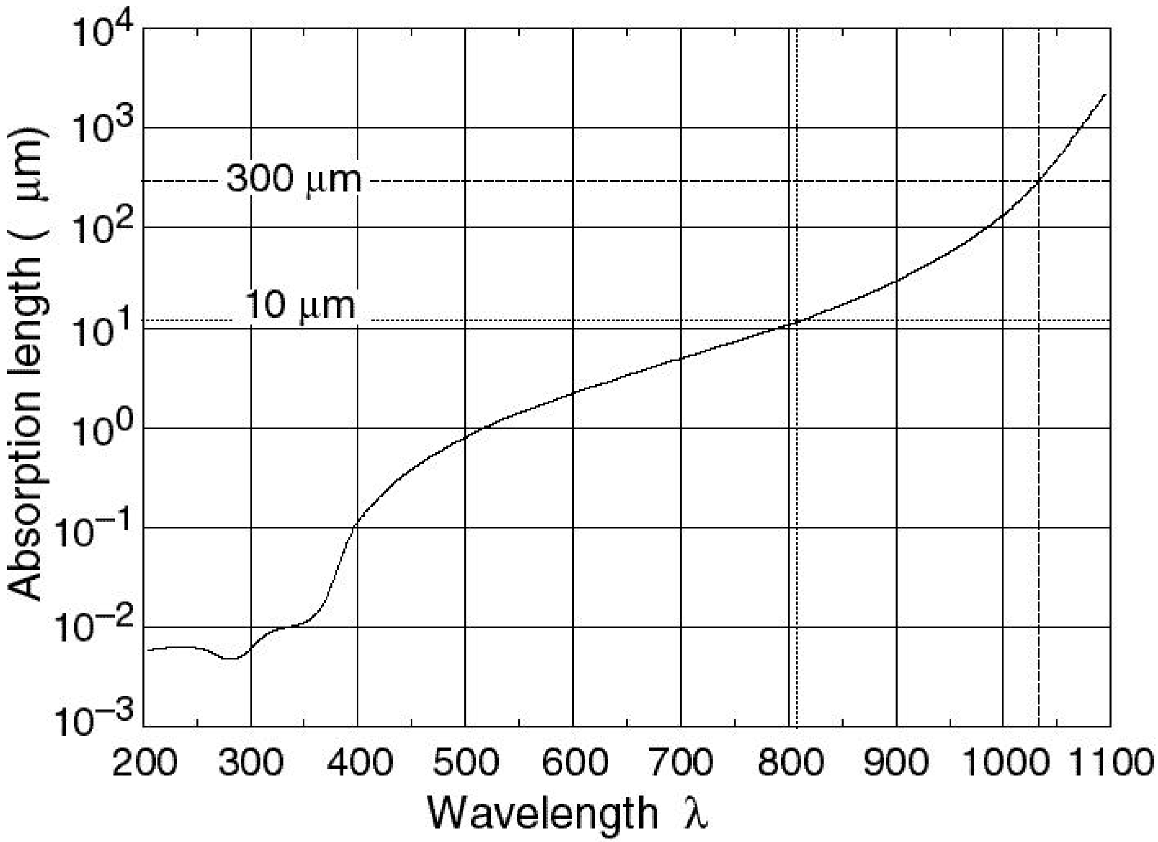
Drawbacks:

1) Thinning is difficult and expensive
2) Poor near-IR response
3) Interference (fringing)
4) Lateral diffusion in field-free region (degraded PSF)

Silicon Absorption Length

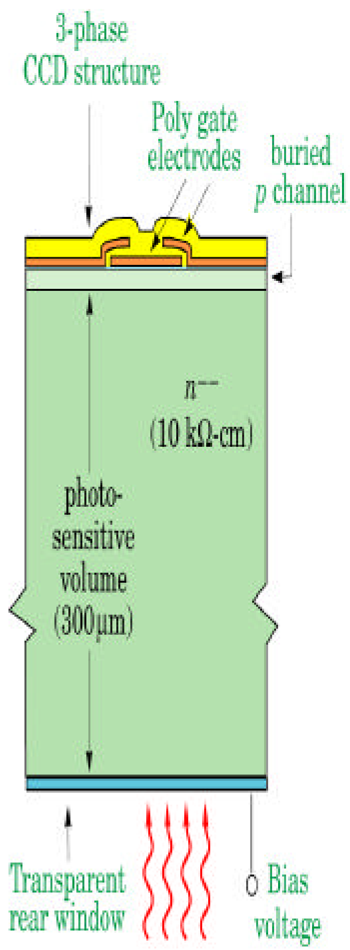
Photoactive region of standard CCD’s are 10-20 microns thick

Photoactive region of LBNL CCD’s are 300 microns thick



High-Resistivity CCD’s

- Broad technology patent for high-resistivity CCD technology
- Better overall response than more costly “thinned” devices in use
- High-purity silicon has better radiation tolerance for space applications
- The CCD’s can be abutted on all four sides enabling very large mosaic arrays
- Measured Quantum Efficiency at Lick Observatory (R. Stover):

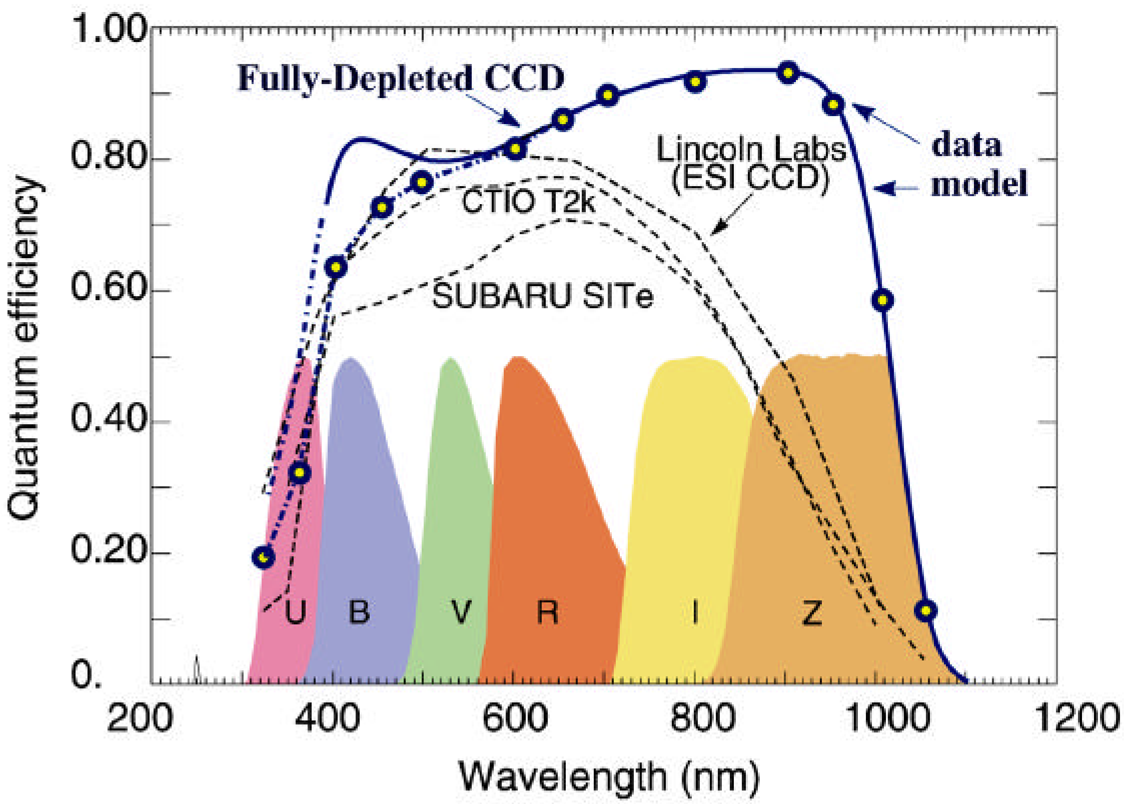


Advantages:

1) Conventional MOS processes with no thinning => "inexpensive"
2) Full quantum efficiency to > 1 μm => no fringing
3) Good blue response with suitably designed rear contact
4) Radiation tolerant

Disadvantages:

1) Enhanced sensitivity to radiation (x-rays, cosmic rays, radioactive decay)



LBNL 2k x 2k results

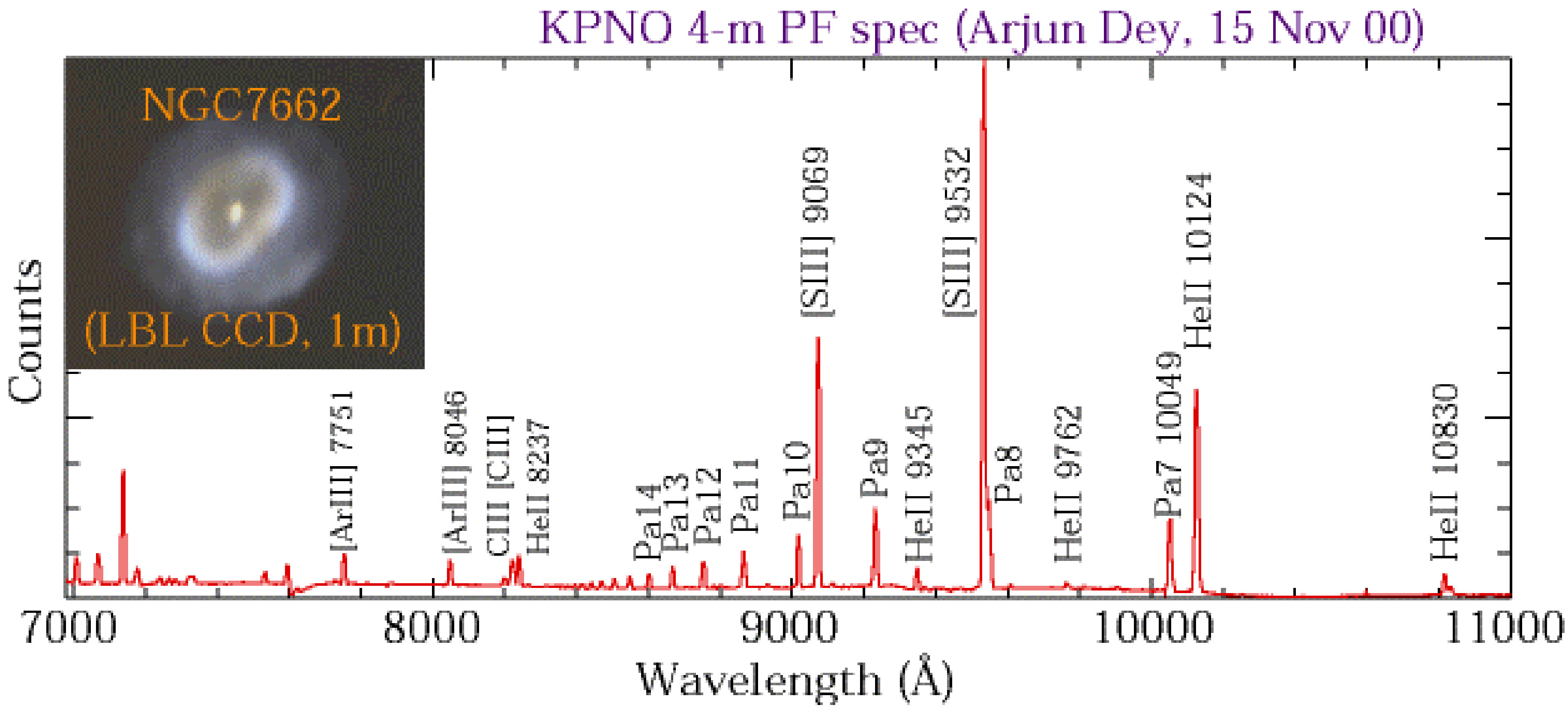
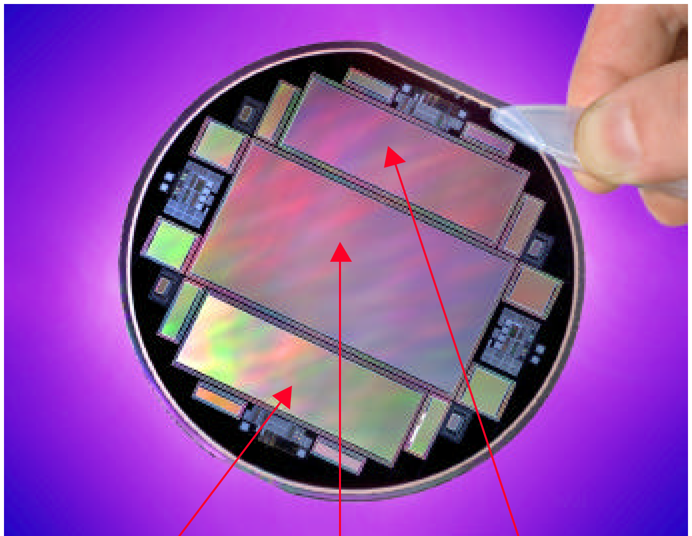


Image: 200 x 200 15 mm LBNL CCD in Lick Nickel 1m.
Spectrum: 800 x 1980 15 mm LBNL CCD in NOAO KPNO spectrograph.
Instrument at NOAO KPNO 2nd semester 2001 (http://www.noao.edu)

LBNL 2k x 4k



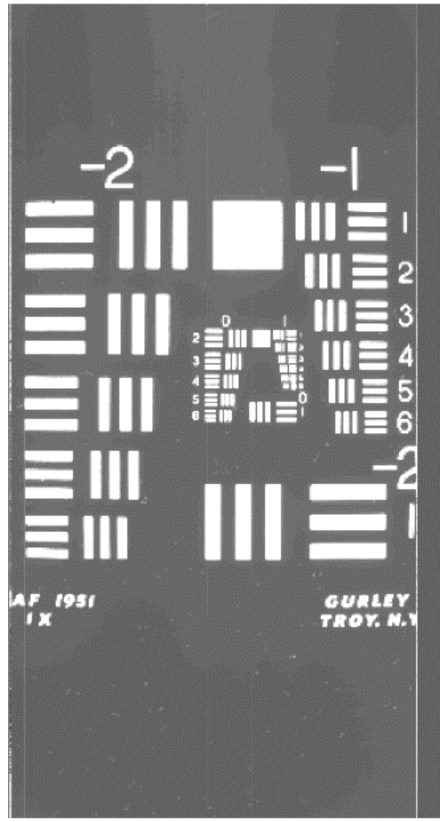
1478 x 4784
10.5 mm

2k x 4k
15 mm

1294 x 4186
12 mm

USAF test pattern.

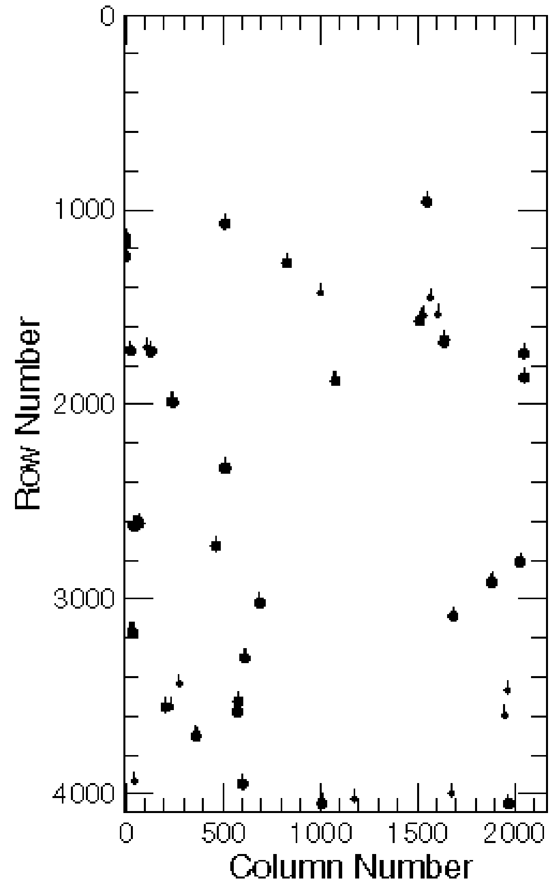
LBNL 2KX4K #1 R(17) -135c image



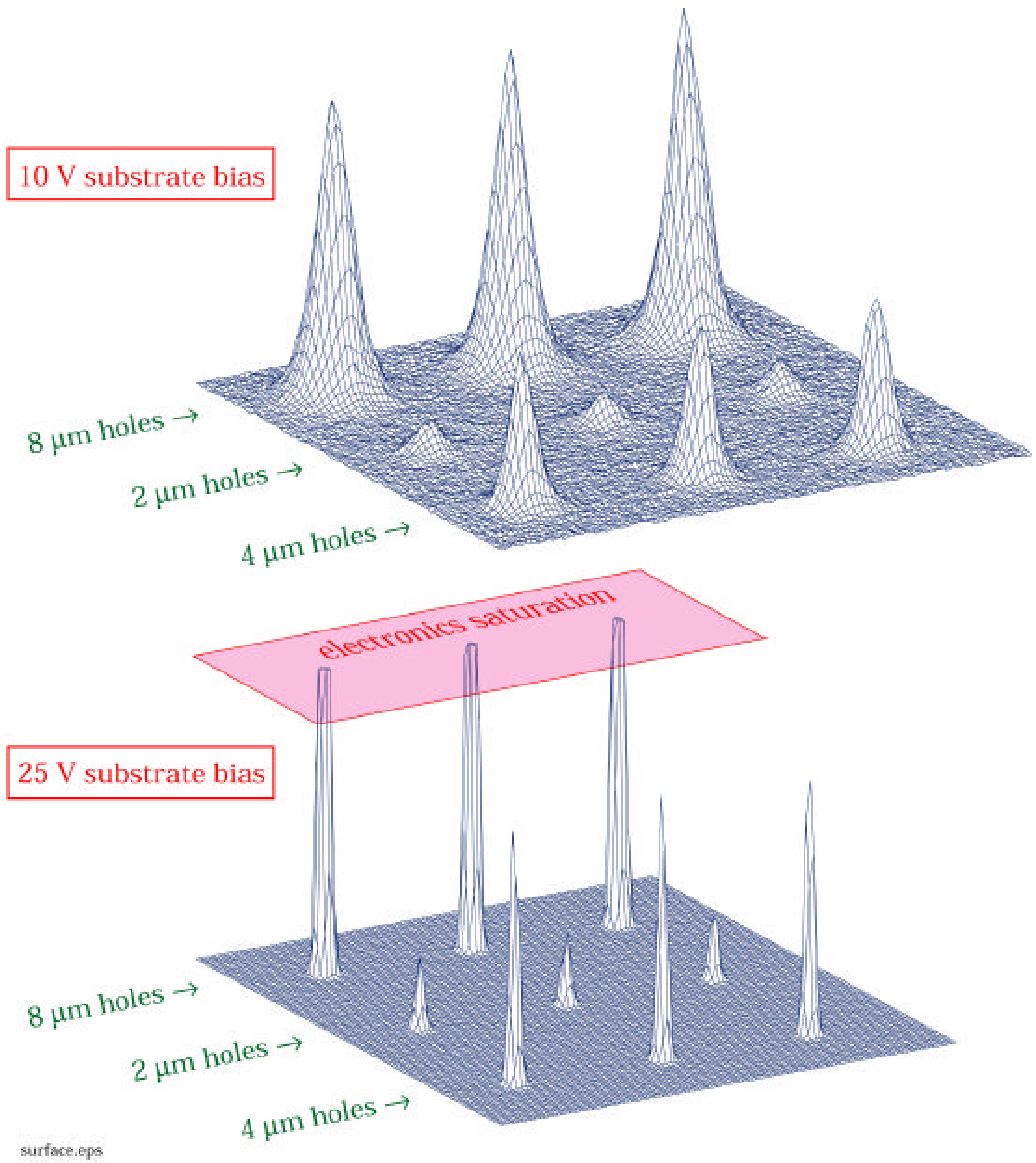
Size: 512 Rows, 272 Cols Origin (0,0)

Trap sites found by pocket pumping.

LBNL 2KX4K #1 R(17) -135c pol



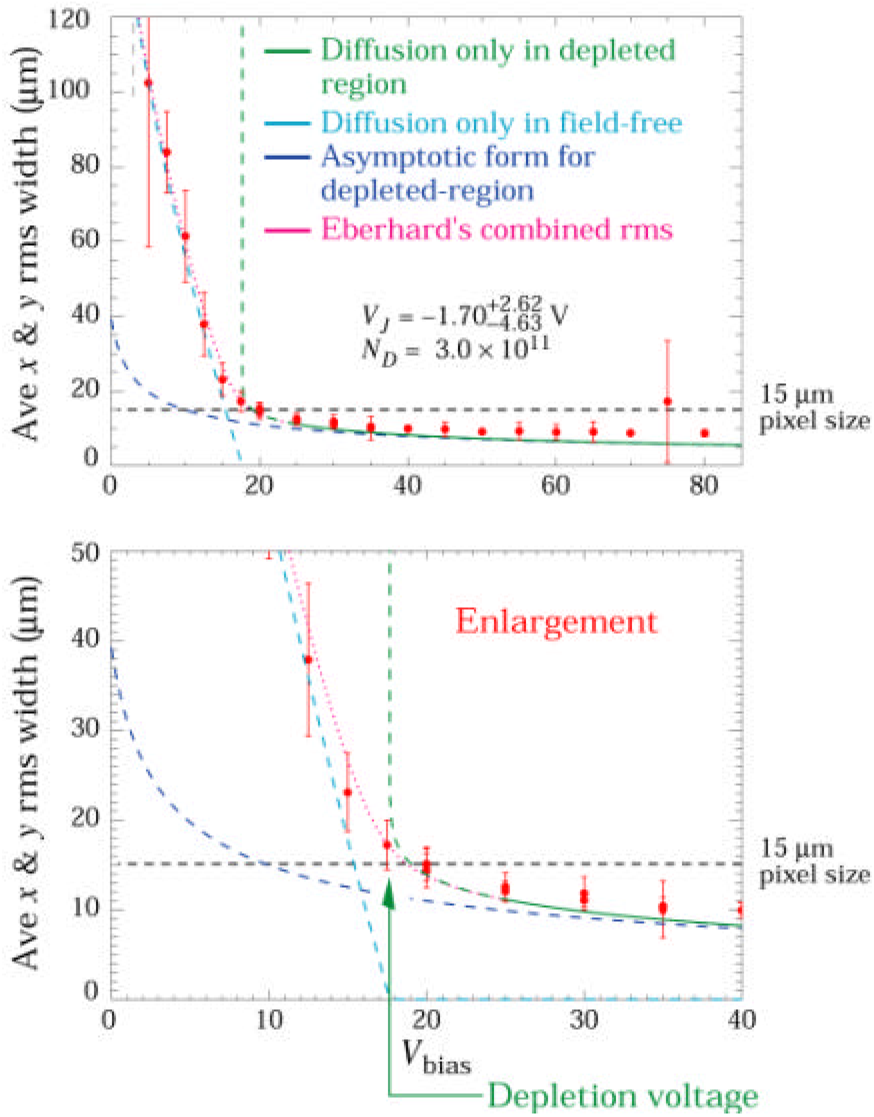
Measurement of PSF with pinhole mask



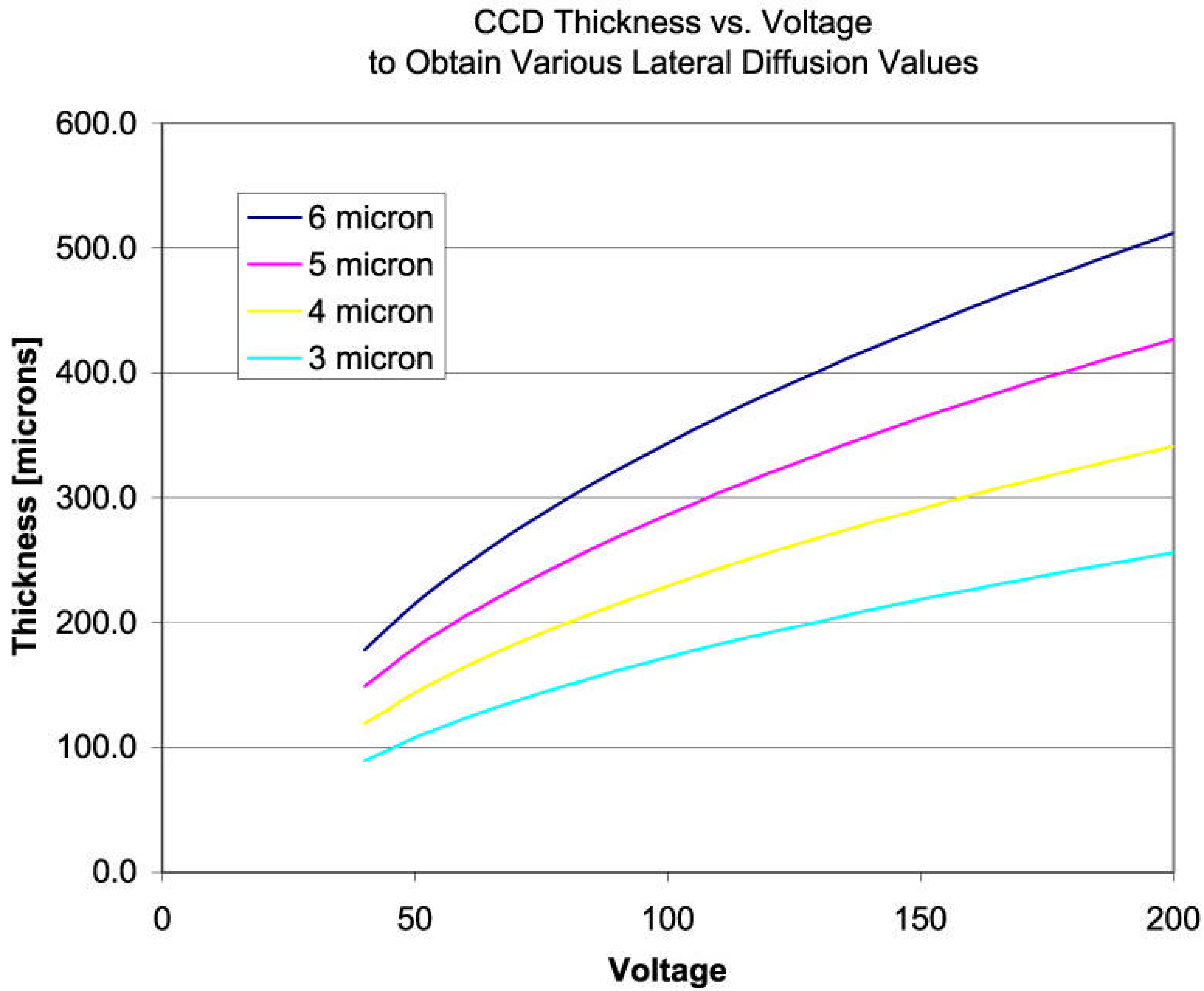
Measurement of PSF with pinhole mask

SNAP

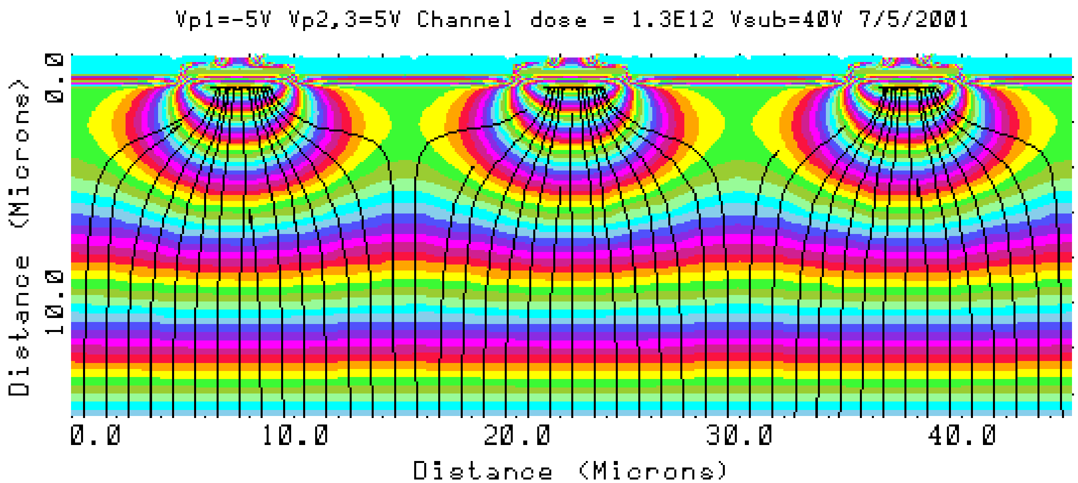
Measurements at Lick Observatory

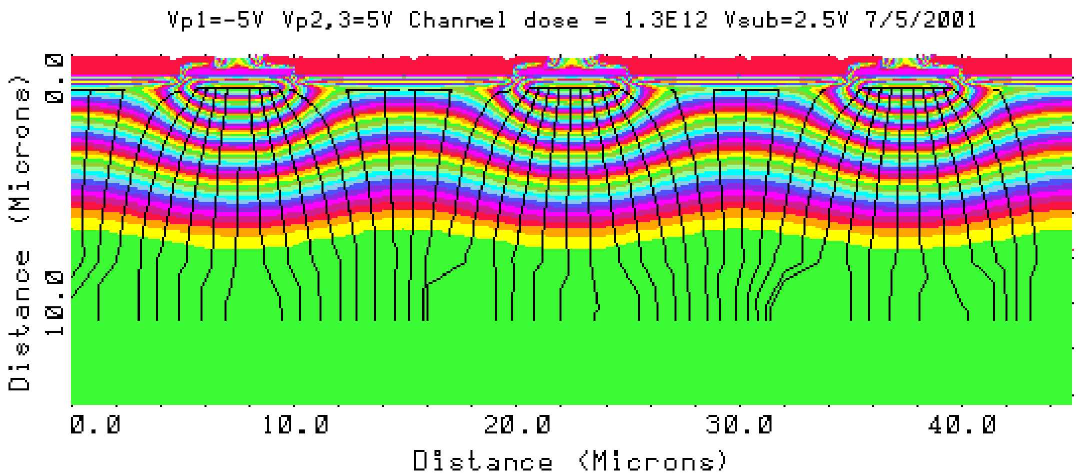


CCD Diffusion



Intra-pixel variation





Radiation Damage

Solar protons are damaging to CCDs.

- **WFPC2 on HST developed losses up to 40% across its CCD due to radiation damage.**

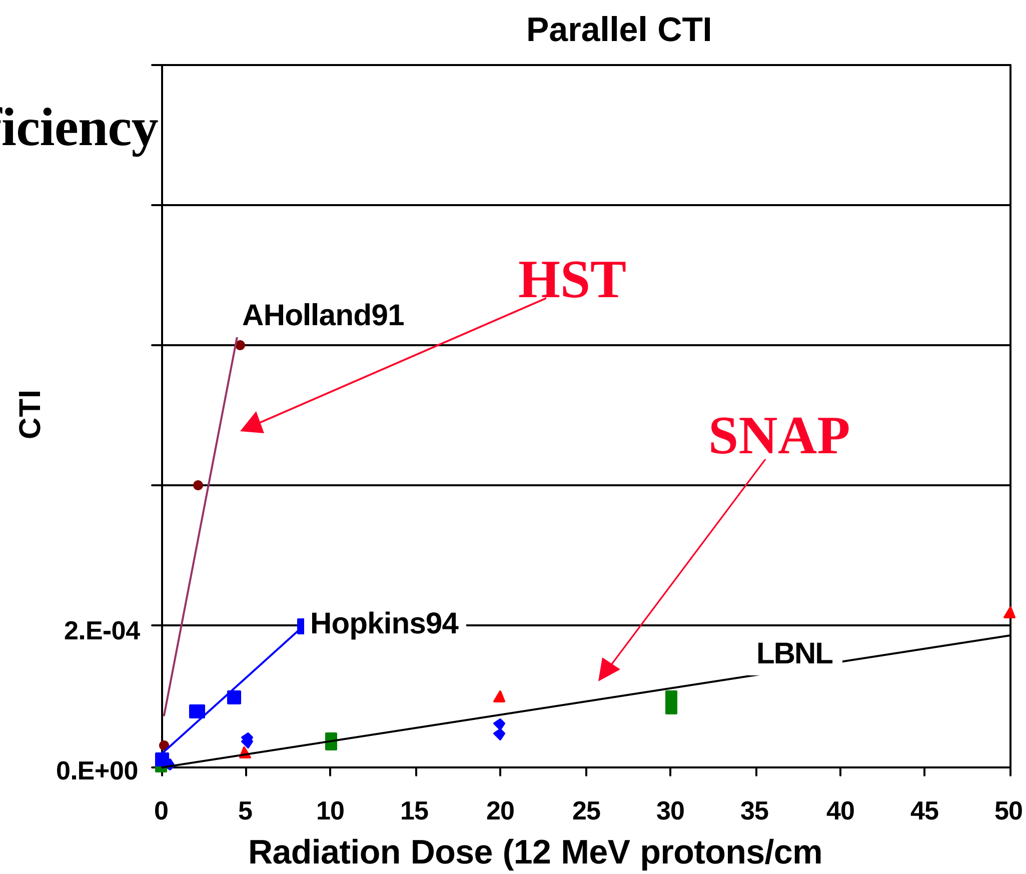
Radiation testing is done at the LBNL 88” Cyclotron with 12 MeV protons.

SNAP expected lifetime dose 5 x 10^9 protons/cm^2

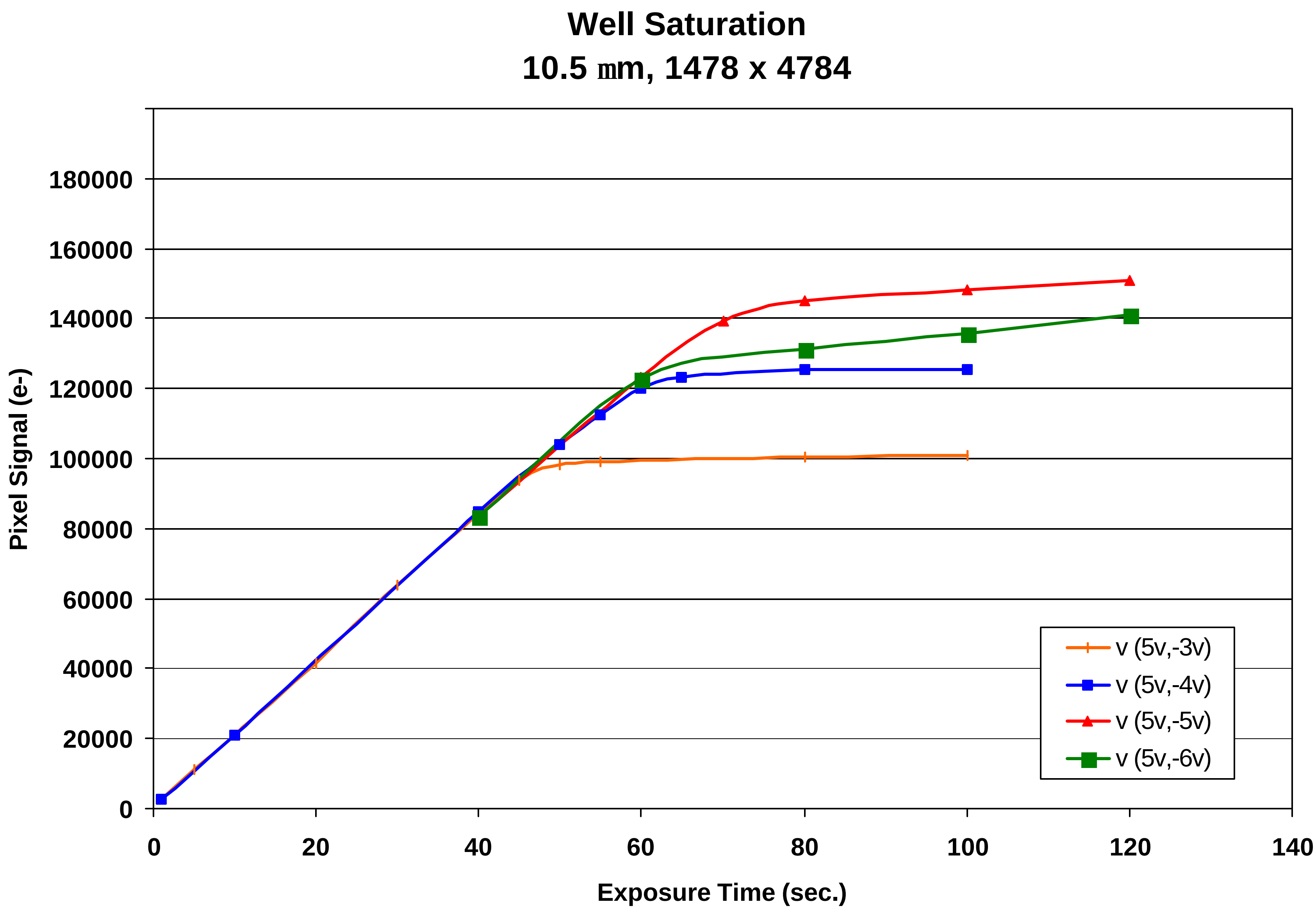
CTI is the charge transfer inefficiency

$$Q = Q_0^{(1-CTI)*N_{transfer}}$$

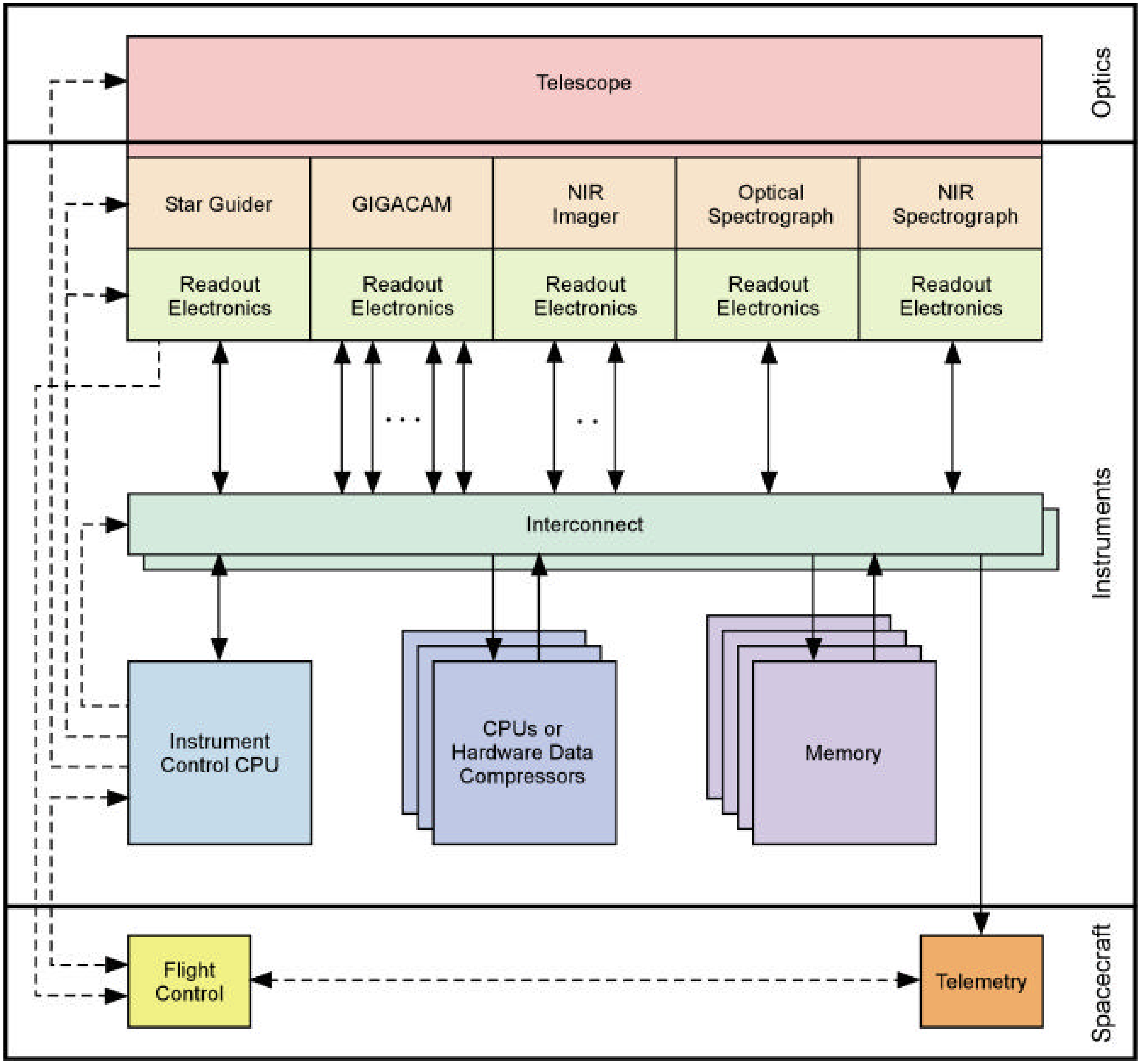
$$N_{transfer} \sim 2000$$



10.5 μm Well Depth

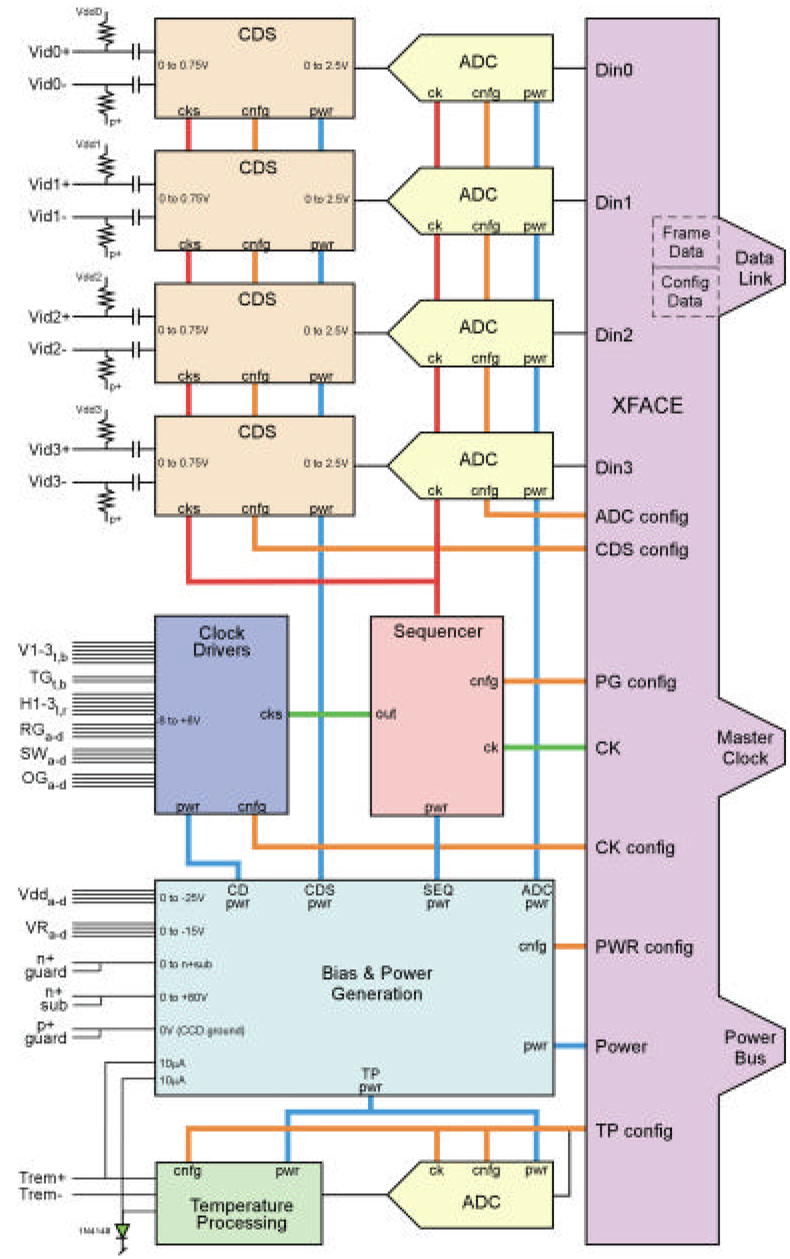


Instrument Electronics Context

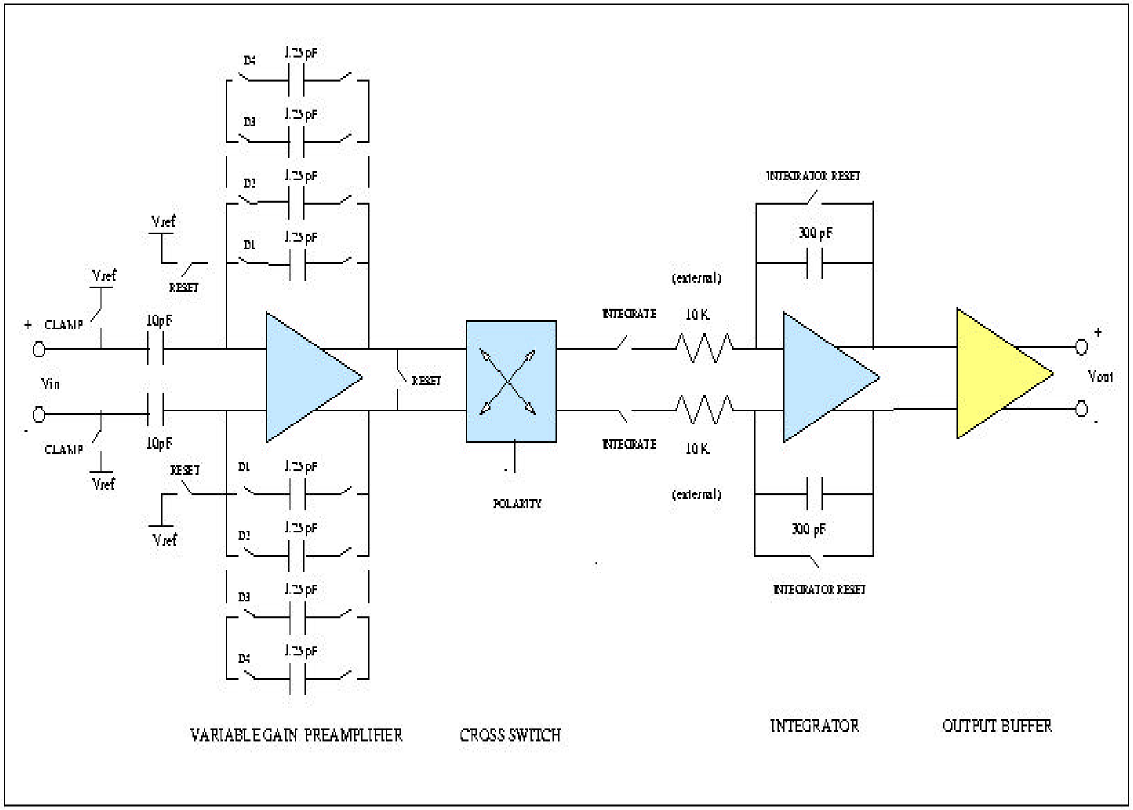


Readout Electronics Concept

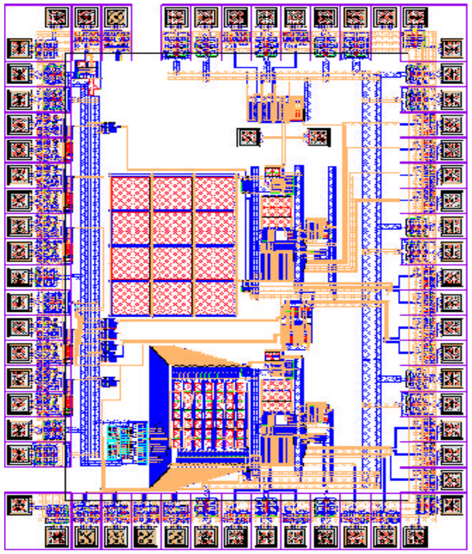
- **CDS – Correlated Double Samples is used for readout of the CCDs to achieve the required readout noise. Programmable gain receiver, dual-ramp architecture, and ADC buffer. HgCdTe compatible.**
- **ADC – 16-bit, 100 kHz equivalent conversion rate per CCD (could be a single muxed 400 kHz unit).**
- **Sequencer – Clock pattern generator supporting modes of operation: erase, expose, readout, idle.**
- **Clock drivers – Programmable amplitude and rise/fall times. Supports 4-corner or 2-corner readout.**
- **Bias and power generation – Provide switched, programmable large voltages for CCD and local power.**
- **Temperature monitoring – Local and remote.**
- **DAQ and instrument control interface – Path to data buffer memory, master timing, and configuration and control.**



CDS ASIC

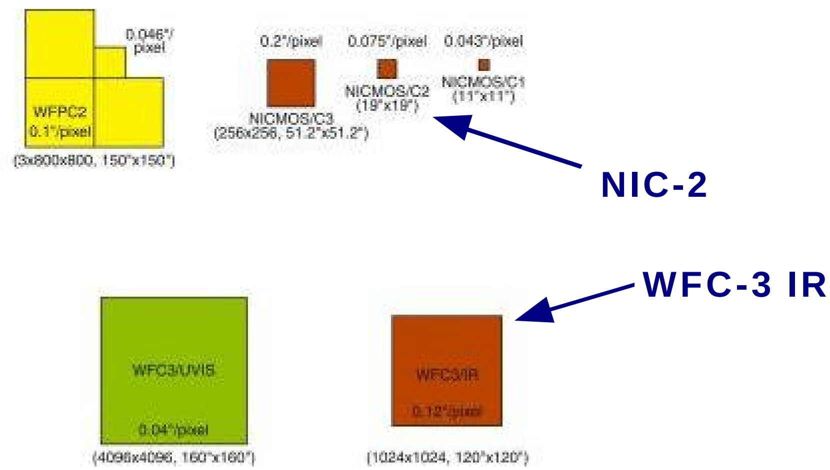


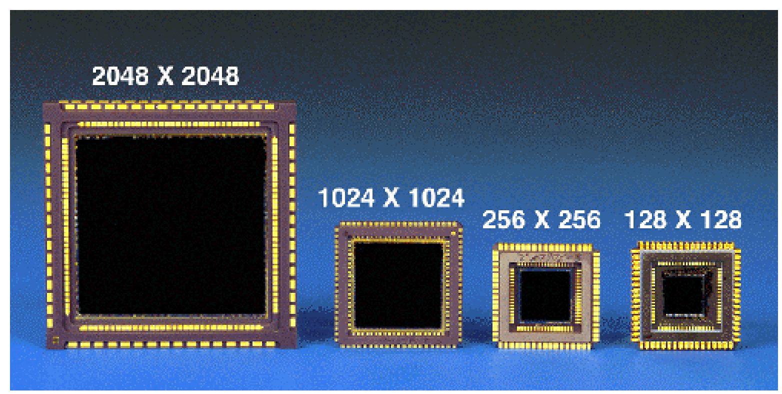
Vref
RESET
CLAMP
10pF
Vin
D4
D3
D2
D1
1.25 pF
RESET
POLARITY
INTEGRATE
10 K
(external)
INTEGRATOR RESET
300 pF
Vout
VARIABLE GAIN PREAMPLIFIER
CROSS SWITCH
INTEGRATOR
OUTPUT BUFFER



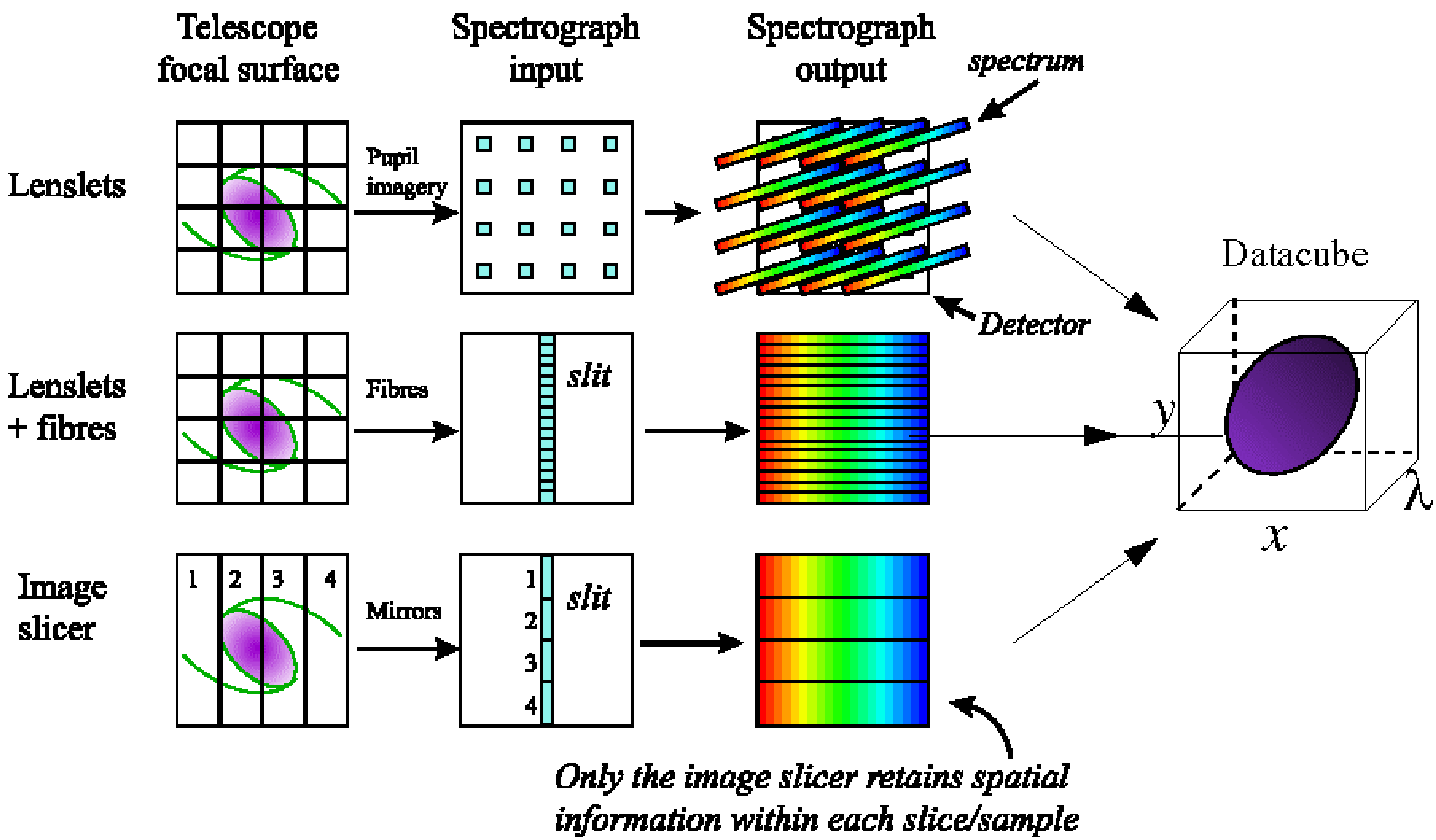
Shortwave HdCdTe Development

- *Hubble Space Telescope* Wide Field Camera 3
  - WFC-3 replaces WFPC-2
    - CCDs & IR HgCdTe array
    - Ready for flight July 2003
  - 1.7 mm cut off
  - 18 mm pixel
  - 1024 x 1024 format
    - Hawaii-1R MUX
  - Dark current consistent with thermoelectric cooling
    - < 0.5 e/s at 150 K
    - <0.05 e-/s at 140 K
  - Expected QE > 50% 0.9-1.7 mm
  - Individual diodes show good QE
    - Effective CdZnTe AR coating
    - No hybrid device with simultaneous good dark current & QE

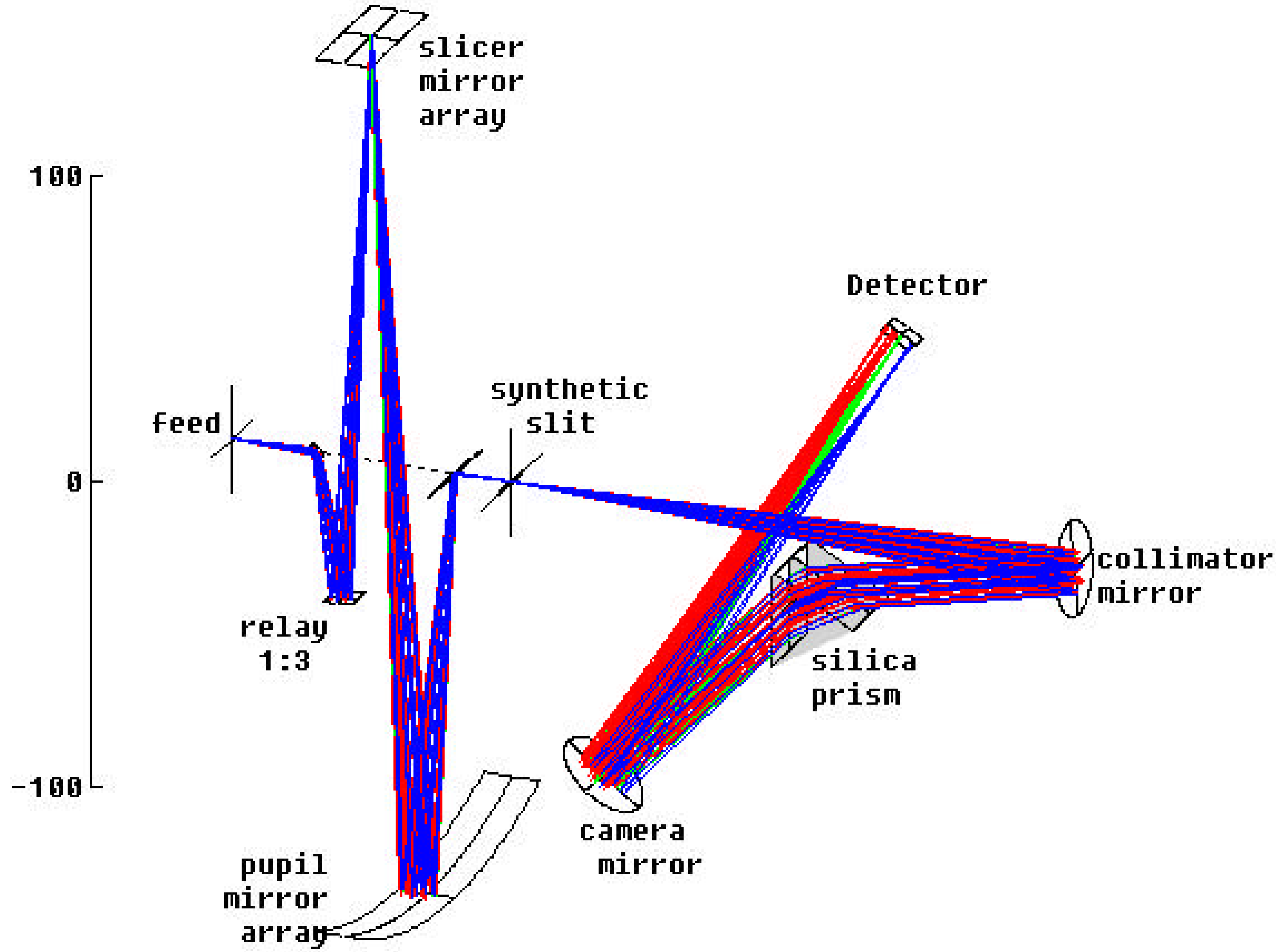




Spectroscopic Integral Field Unit Techniques



SNAP IFU/Spectrometer Concept



Current Work Areas

- Optical Telescope Assembly optics design, trade studies, risk assessment
- Instrument development
- Orbit analysis and study
- Structure design
- Thermal control system design
- Attitude Control System analysis and modeling
- Spacecraft systems refinement
- Integration and Test planning
- Data system layout
- Computational system definition

Technology readiness and issues

SNAP

NIR sensors

- **HgCdTe stripped devices are begin developed for NGST and are ideal in our spectrograph.**
- **"Conventional" devices with appropriate wavelength cutoff are being developed for WFC3 and ESO.**

CCDs

- **We have demonstrated radiation hardiness that is sufficient for the SNAP mission, but now need to extend to Co^{60} and commercial devices**
- **Extrapolation of earlier measurements of diffusion's effect on PSF indicates we can get to the sub 4 micron level. Needs demonstration.**
- **Industrialization of CCD fabrication has produced useful devices. More wafers have just arrived.**
- **Detectors & electronics are the largest cost uncertainty.**
- **ASIC development is required.**

Filters – we are investigating three strategies for fixed filters.

- **Suspending filters above sensors**
- **Gluing filters to sensors**
- Direct deposition of filters onto sensors.

Technology readiness and issues

On-board data handling

- **We have opted to send all data to ground to simplify the flight hardware and to minimize the development of flight-worthy software.**
- **50 Mbs telemetry, and continuous ground contact are required. Goddard has validated this approach.**

Calibration

- **There is an active group investigating all aspects of calibration.**

Pointing

- **The new generation HgCdTe multiplexor and readout IC support high rate readout of regions of interest for generating star guider information.**
- **Next generation attitude control systems may have sufficient pointing accuracy so that nothing special needs be done with the sensors.**

Telescope

- **Thermal and stray light**

Software

- **Data analysis pipeline architecture**

Conclusion

- **Fundamental science**
- **Lots of R&D going on right now**
- **Many areas that are uncovered or need very significant effort**
- **Collaboration still growing**
- **We need your help!**