SPIcam: an overview

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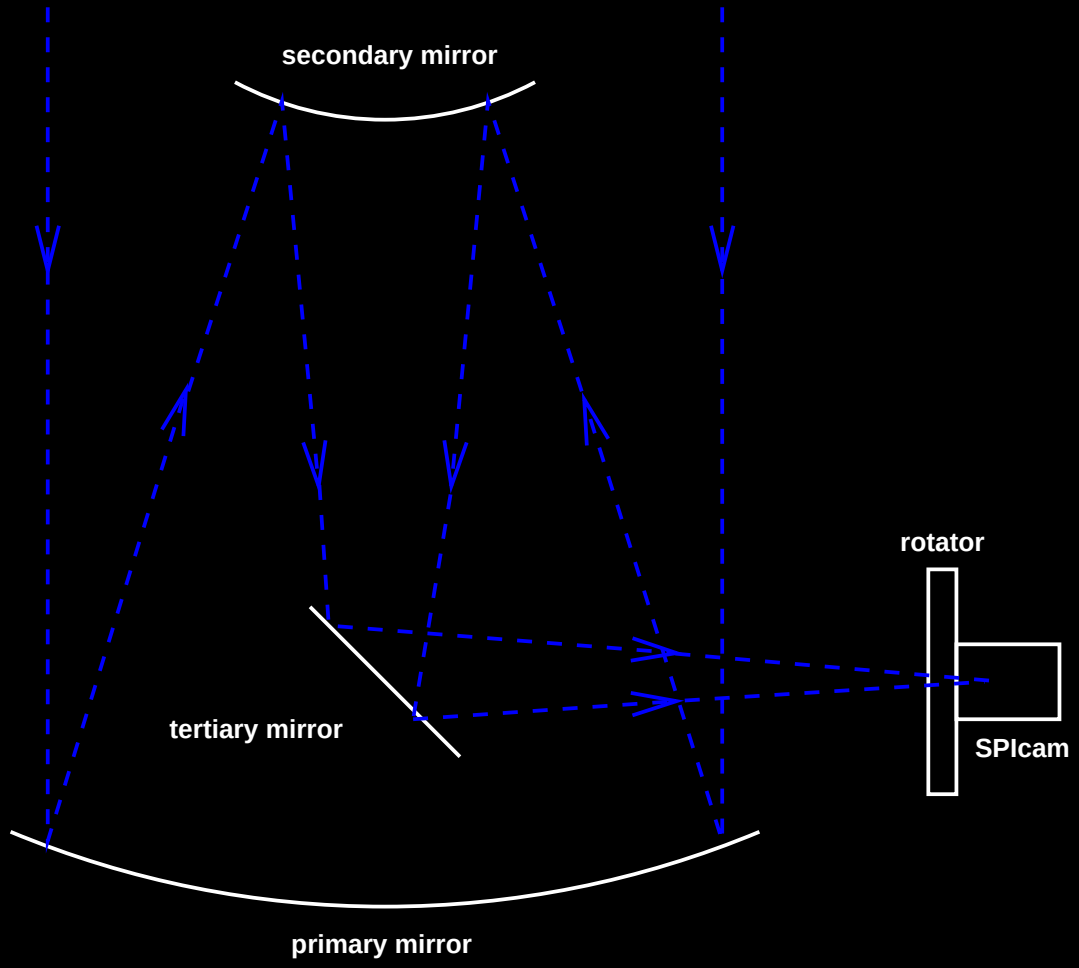
Outline

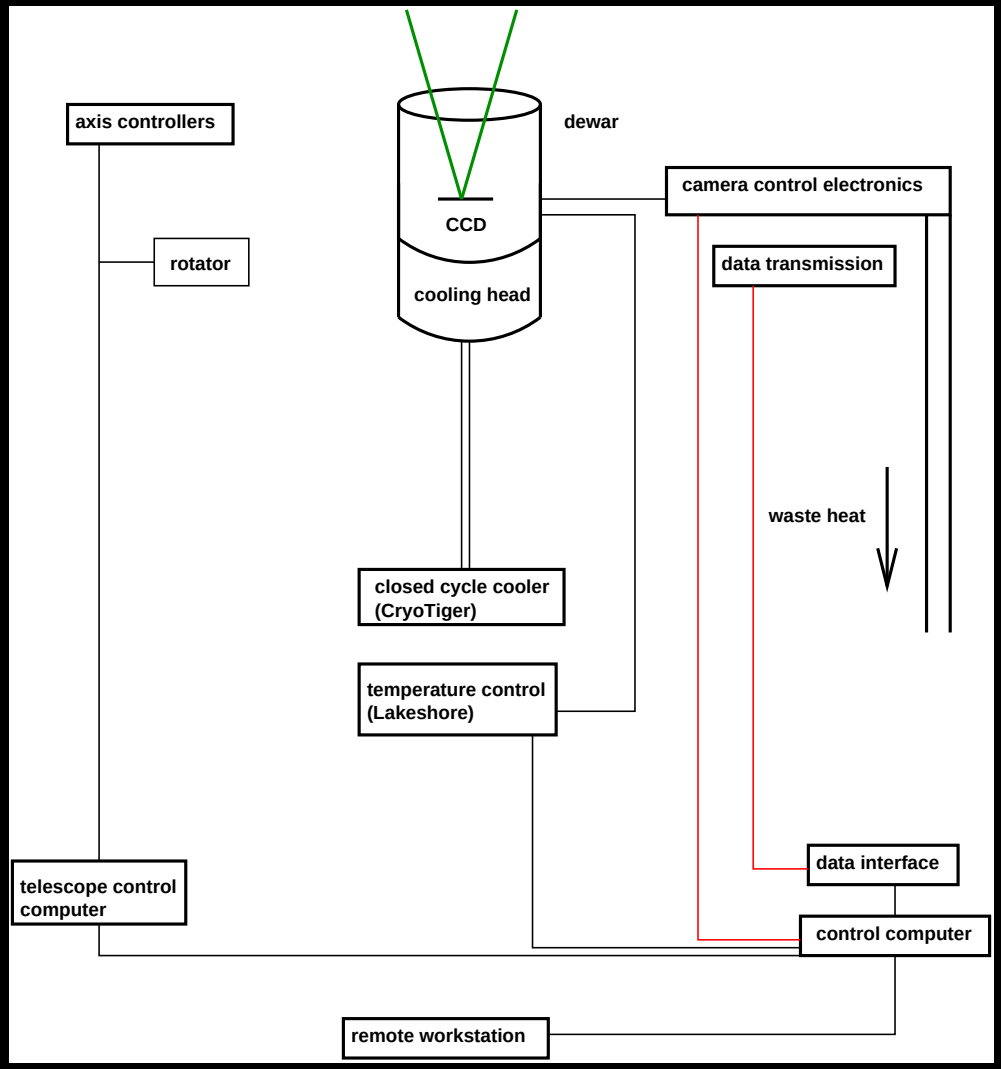
- Overview of instrument
- CCDs
- mechanics
- instrument control
- performance
- construction anecdotes

Apache Point Observatory

3.5-meter telescope

Light Path


secondary mirror
rotator
tertiary mirror
SPIcam
primary mirror

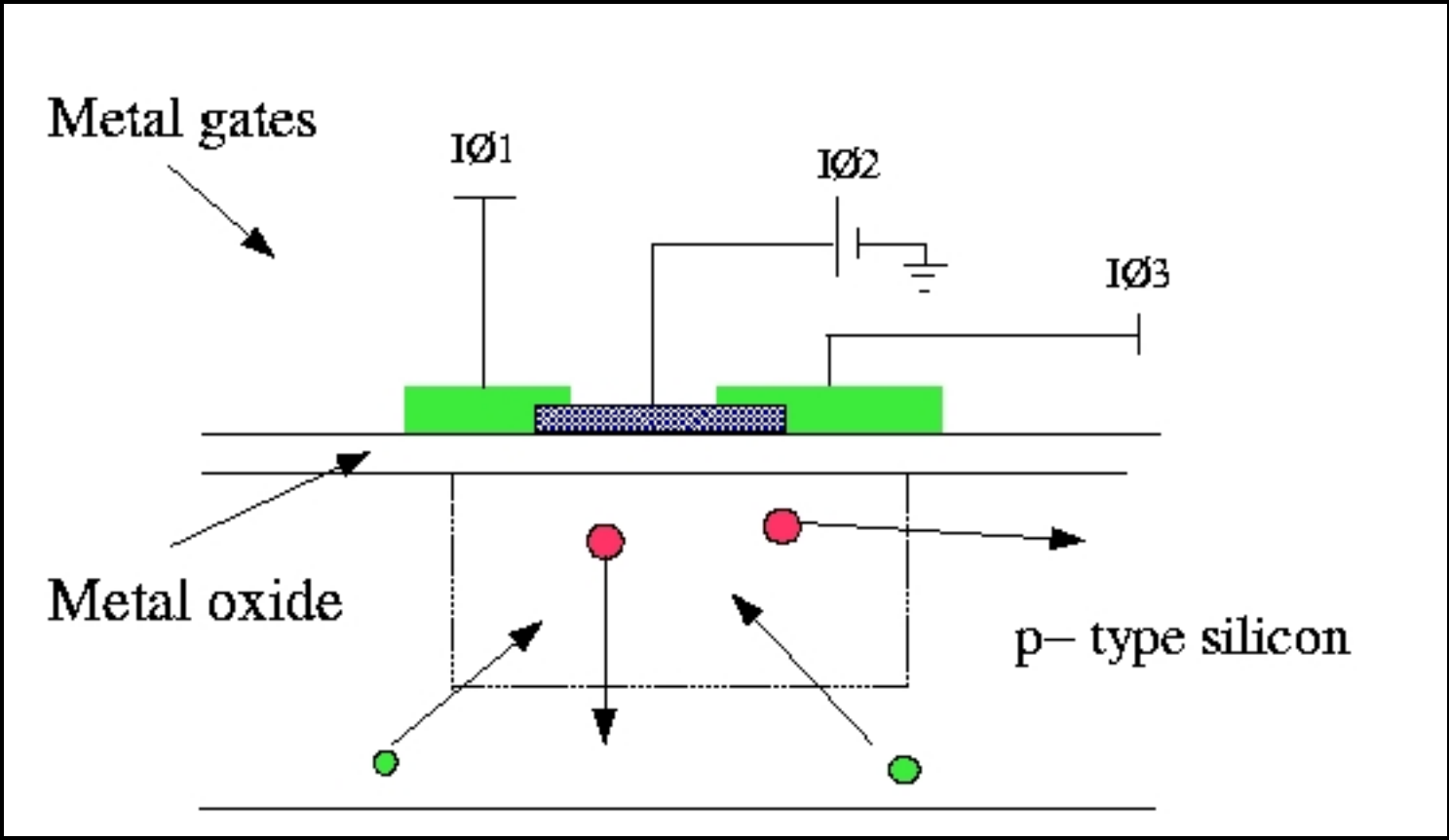

axis controllers
rotator
dewar
CCD
cooling head
camera control electronics
data transmission
waste heat
closed cycle cooler
(CryoTiger)
temperature control
(Lakeshore)
telescope control
computer
data interface
control computer
remote workstation

Charge-Coupled-Devices (CCDs)

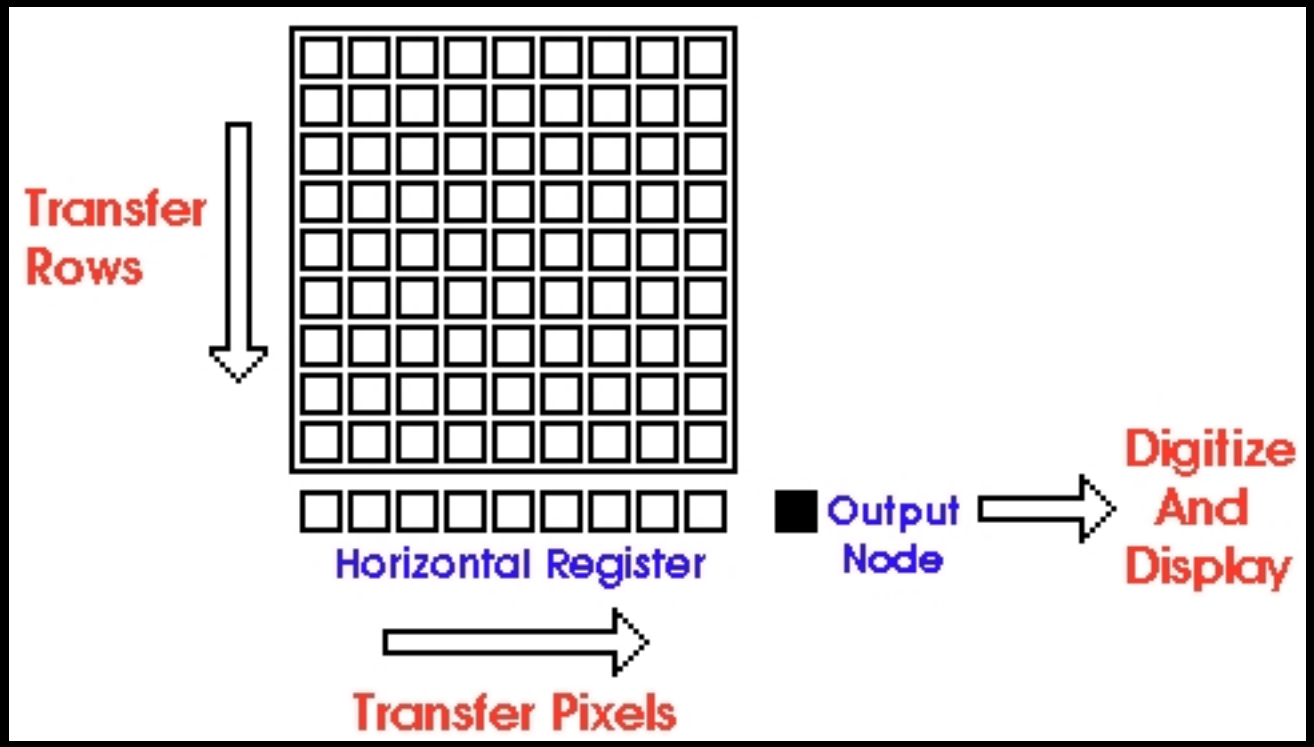
near-perfect detectors for optical radiation

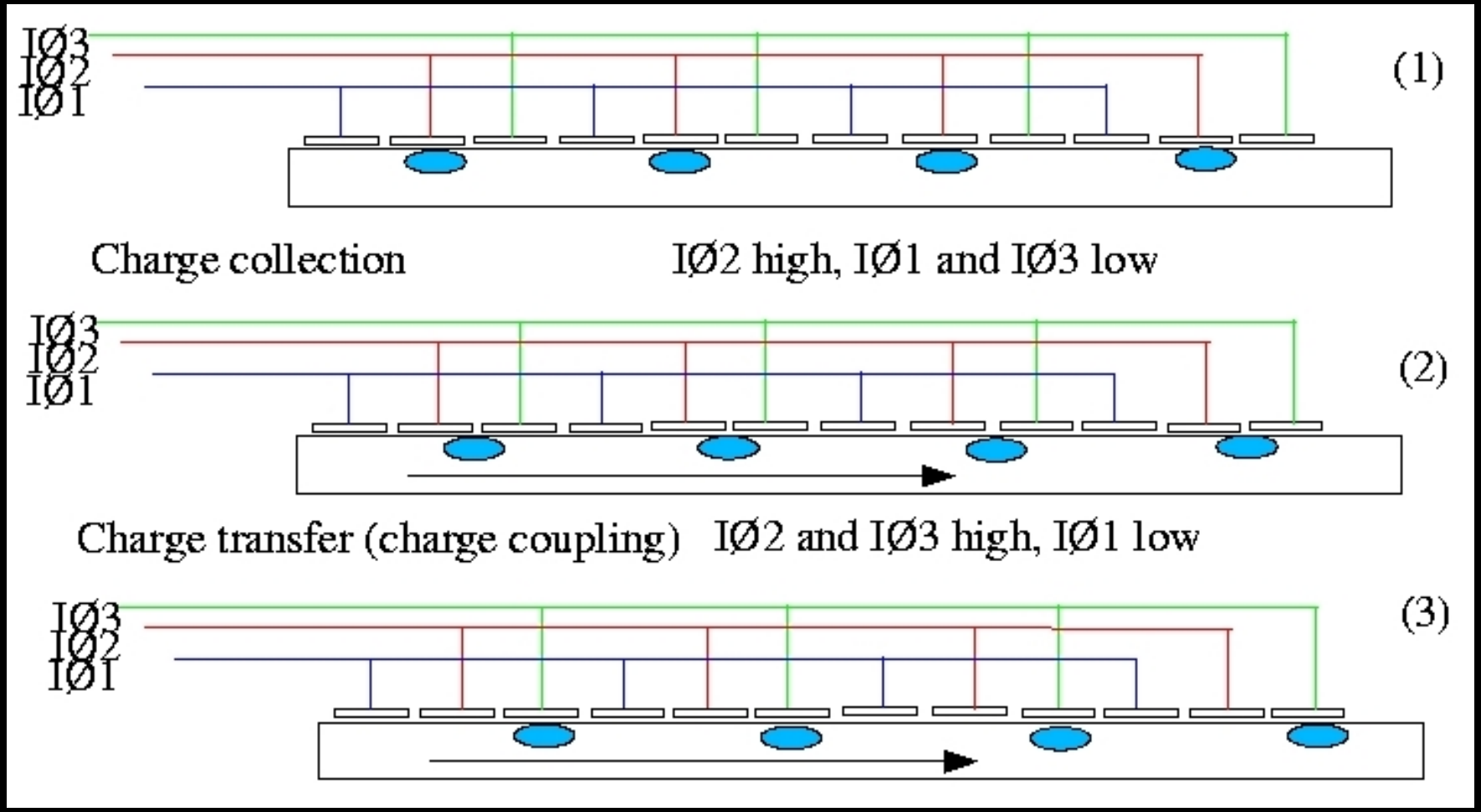
- high quantum efficiency
- 100% fill-factor
- large linear dynamic range
- $\sim$ few electrons (photons) read-noise
- negligible dark-current

CCD structure



CCD layout

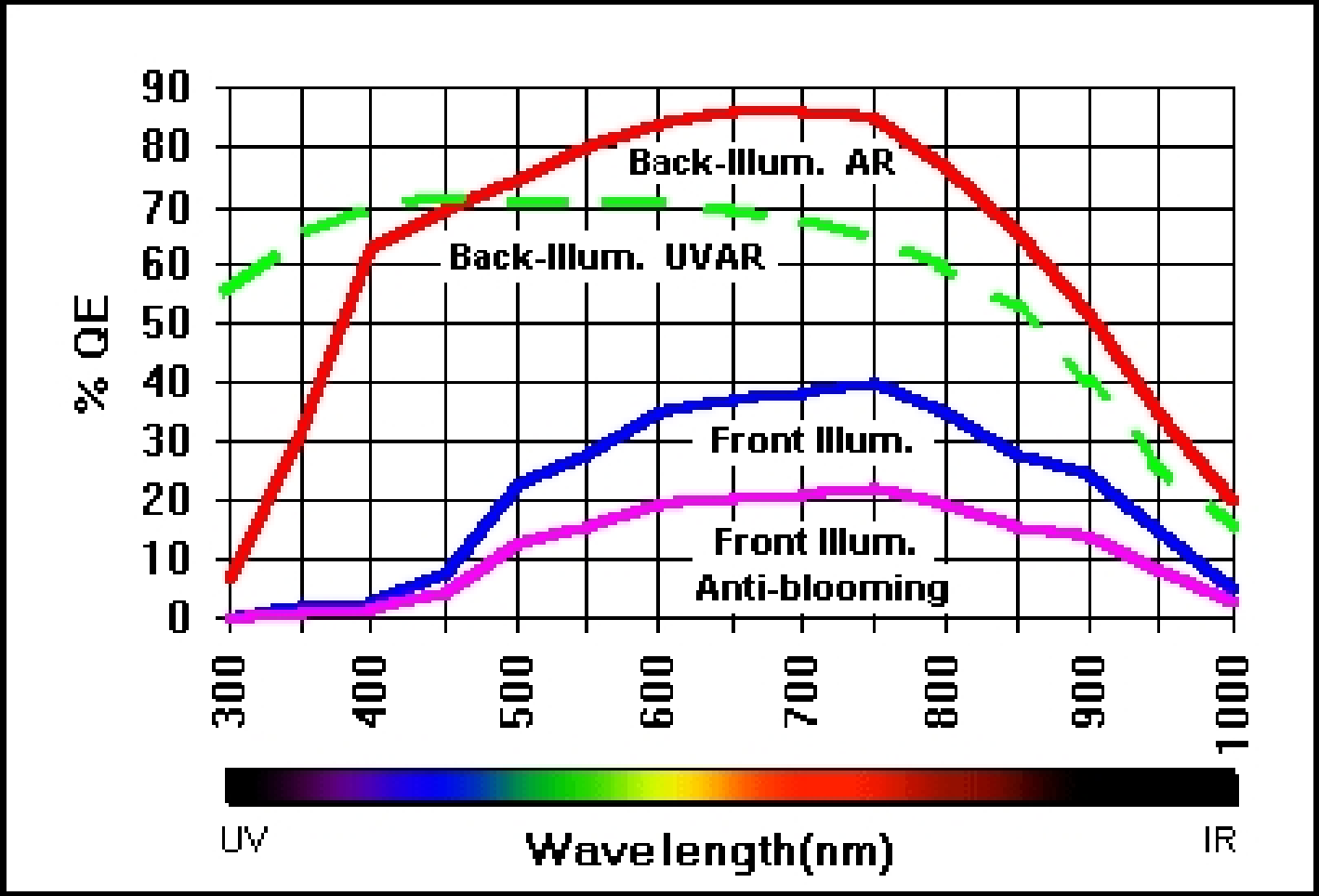

Transfer
Rows
Horizontal Register
Output
Node
Digitize
And
Display
Transfer Pixels


IØ3
IØ2
IØ1
(1)
Charge collection
IØ2 high, IØ1 and IØ3 low
IØ3
IØ2
IØ1
(2)
Charge transfer (charge coupling)
IØ2 and IØ3 high, IØ1 low
IØ3
IØ2
IØ1
(3)

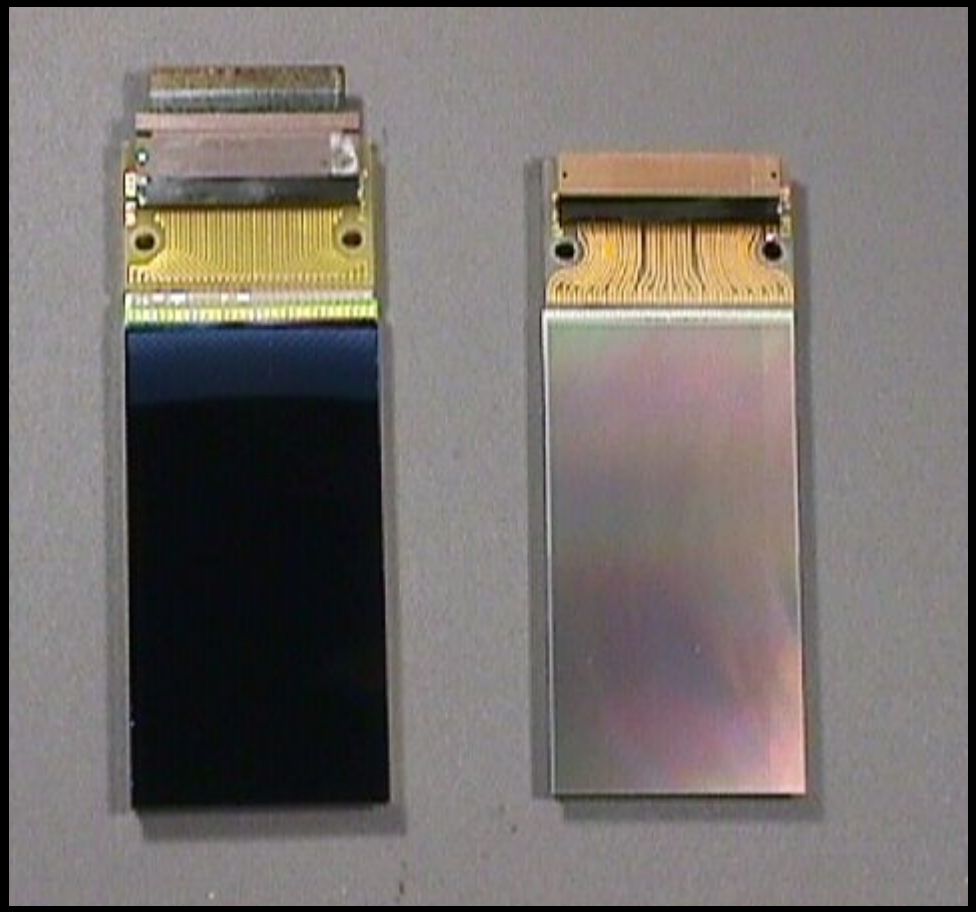
Quantum Efficiency

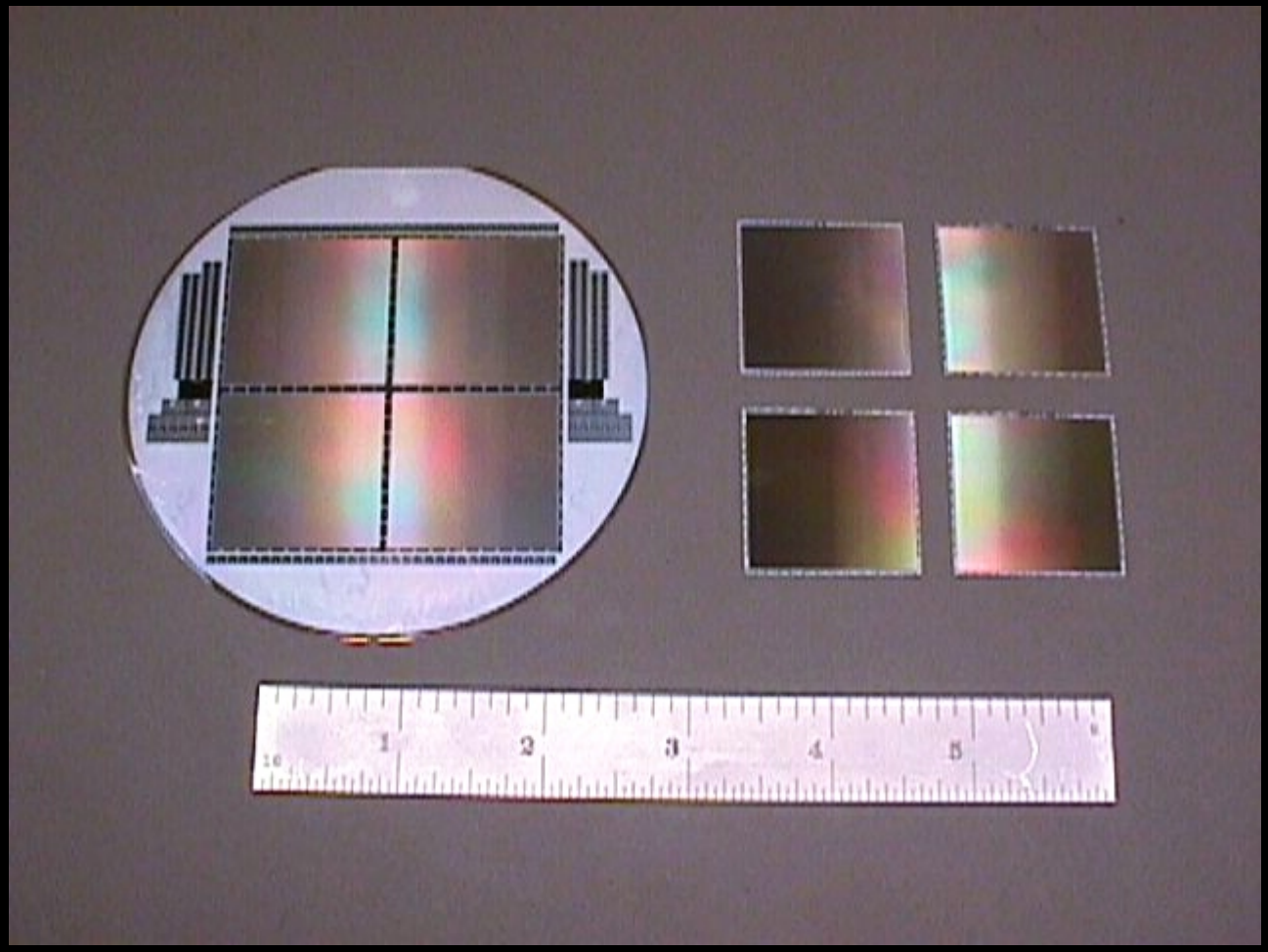
- blue cut-off results from short penetration depth of photons through gate structure
- red cut-off results from band-gap of silicon (1.14 eV = 1085 nm, at 173 K)

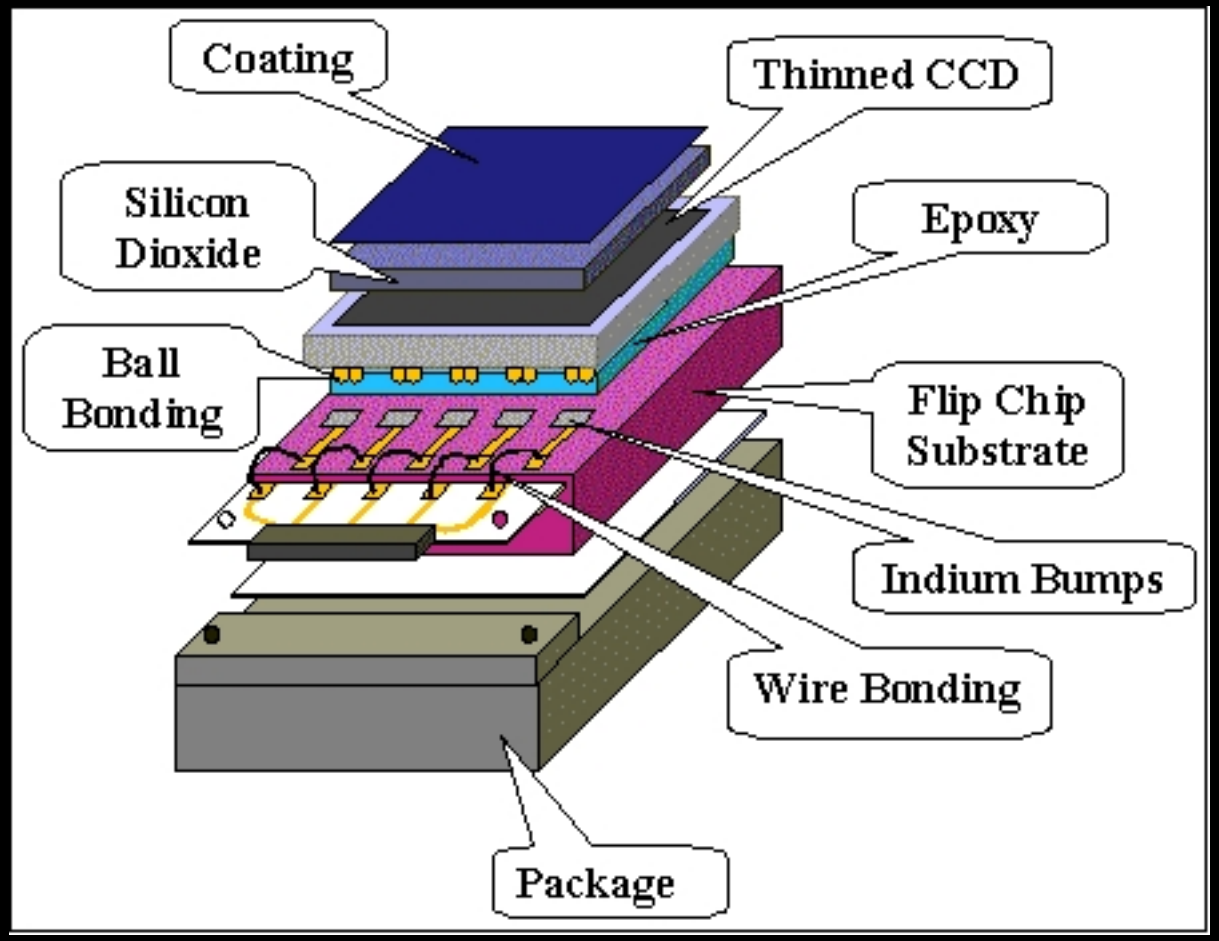
CCD quantum efficiency

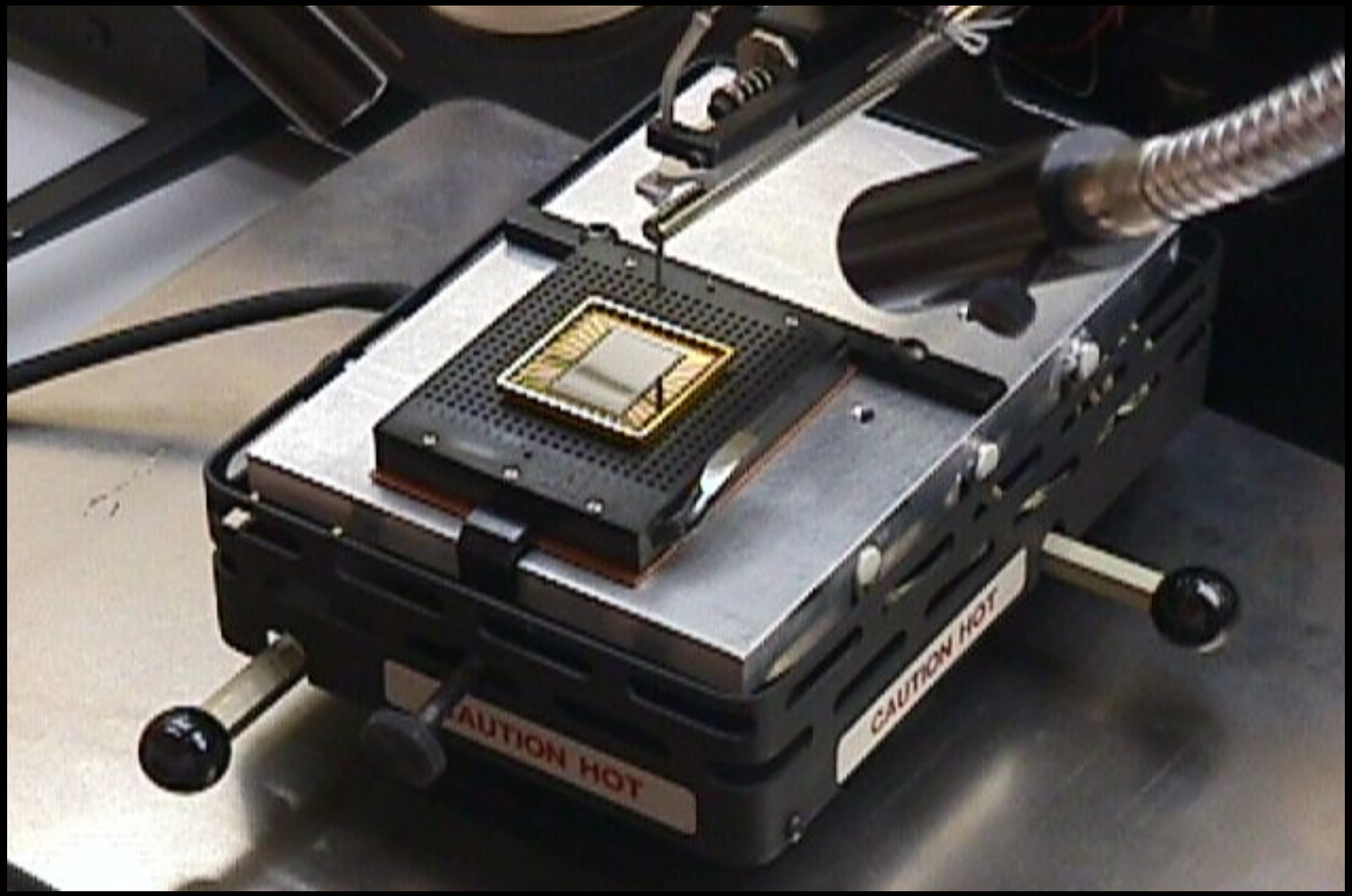


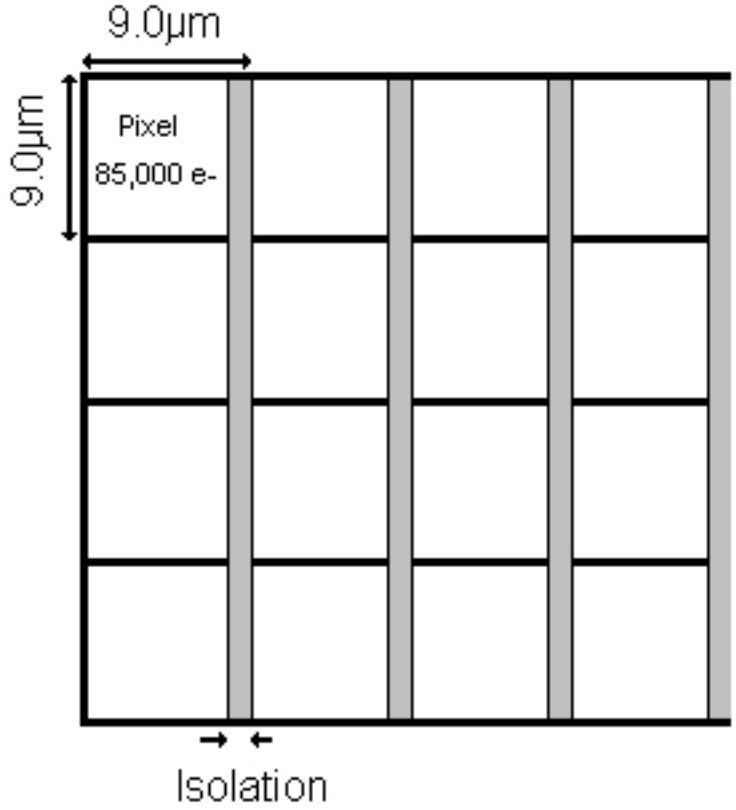
Front-side vs. back-side illumination




1
2
3
4
5

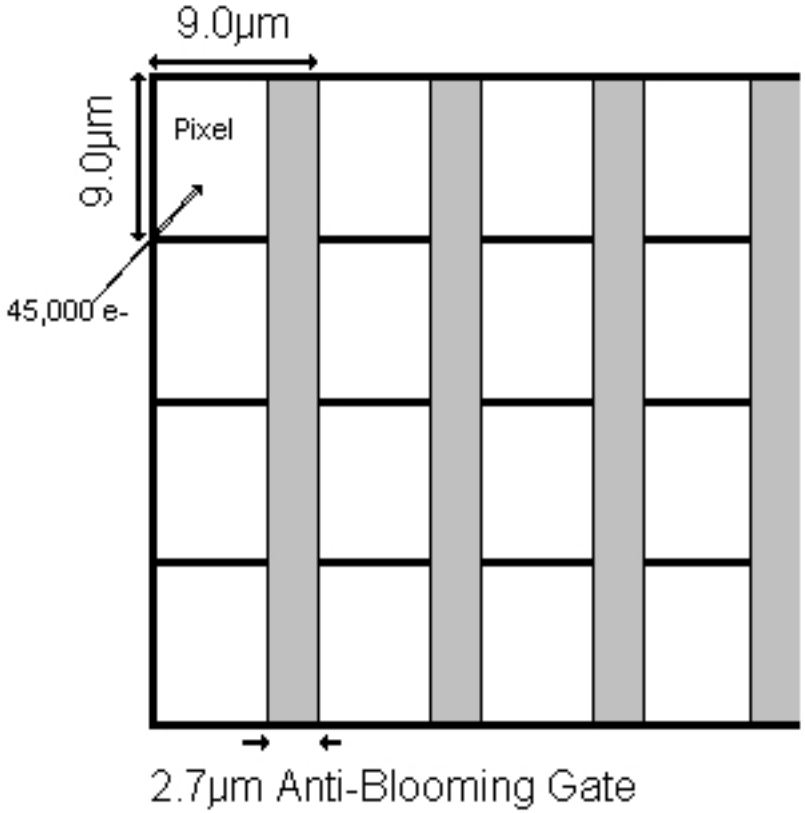

Coating
Thinned CCD
Silicon Dioxide
Epoxy
Ball Bonding
Flip Chip Substrate
Indium Bumps
Wire Bonding
Package


AUTION HOT
CAUTION HOT



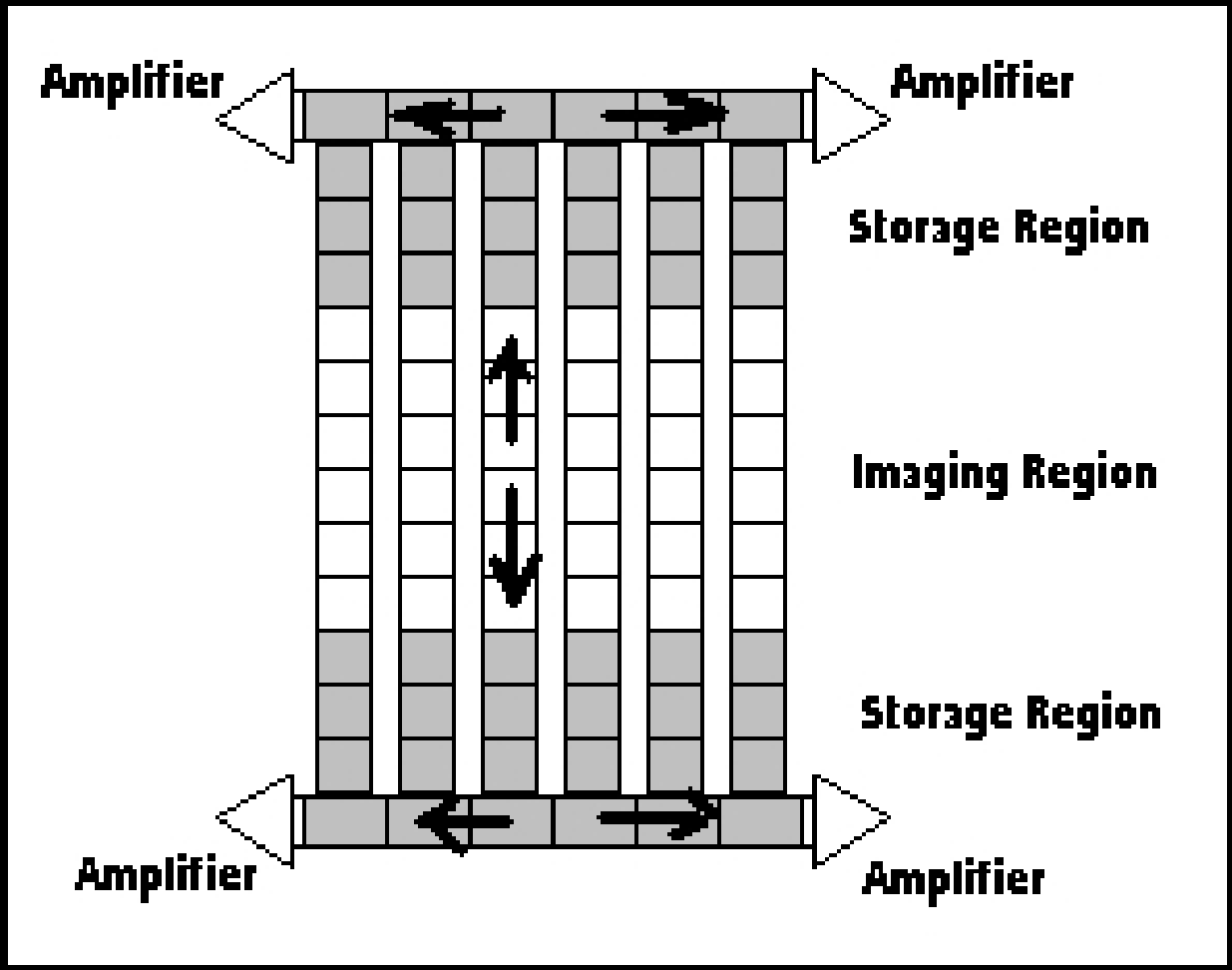
No Anti-Blooming Gate

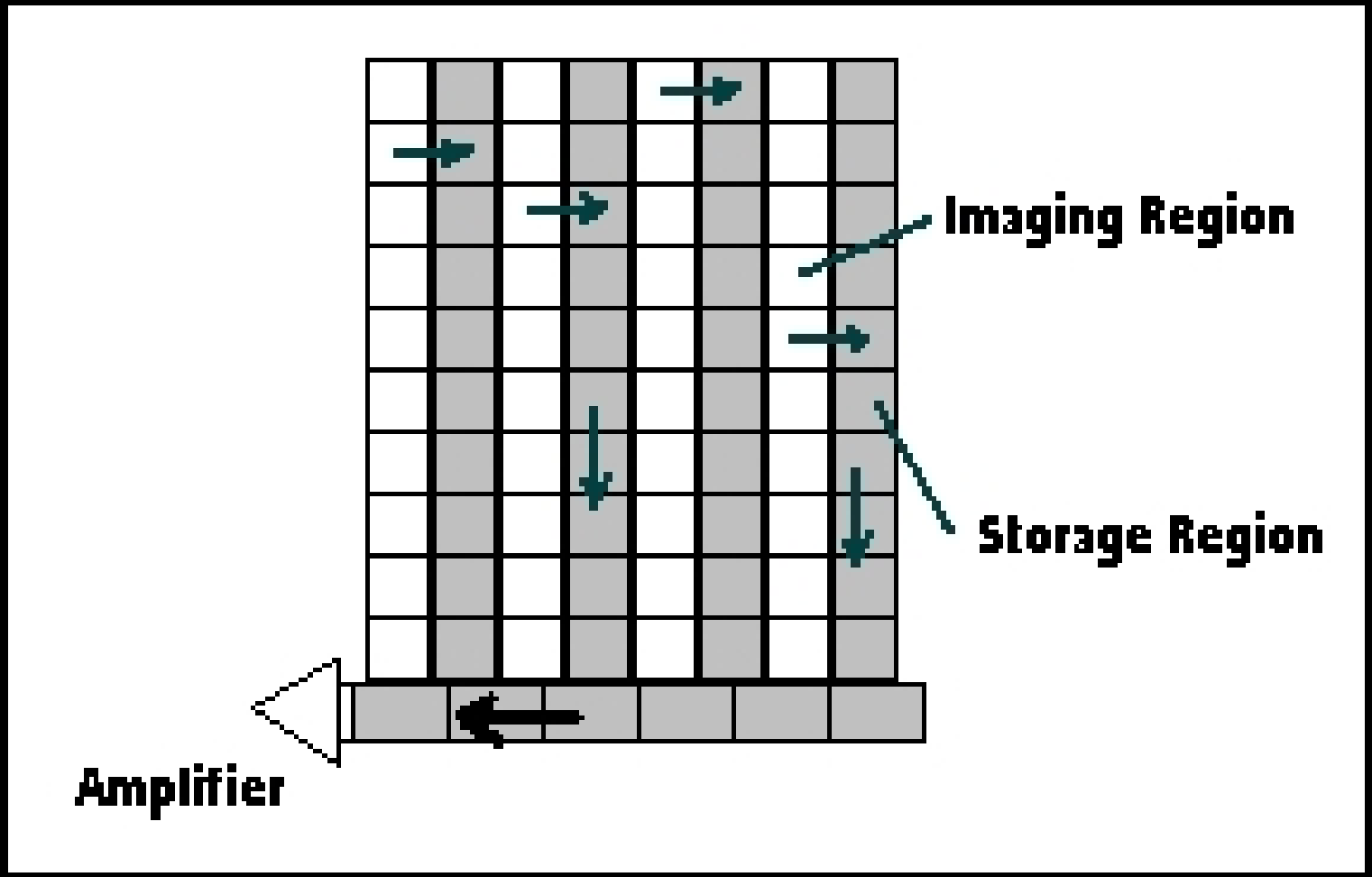
100% Fill Factor
85,000 electron well depth
Higher Quantum Efficiency
Blooming (Streaking) possible



Anti-Blooming Gate

70% Fill Factor
45,000 electron well depth
Lower Quantum Efficiency


Amplifier
Amplifier
Storage Region
Imaging Region
Storage Region
Amplifier
Amplifier


Imaging Region
Storage Region
Amplifier

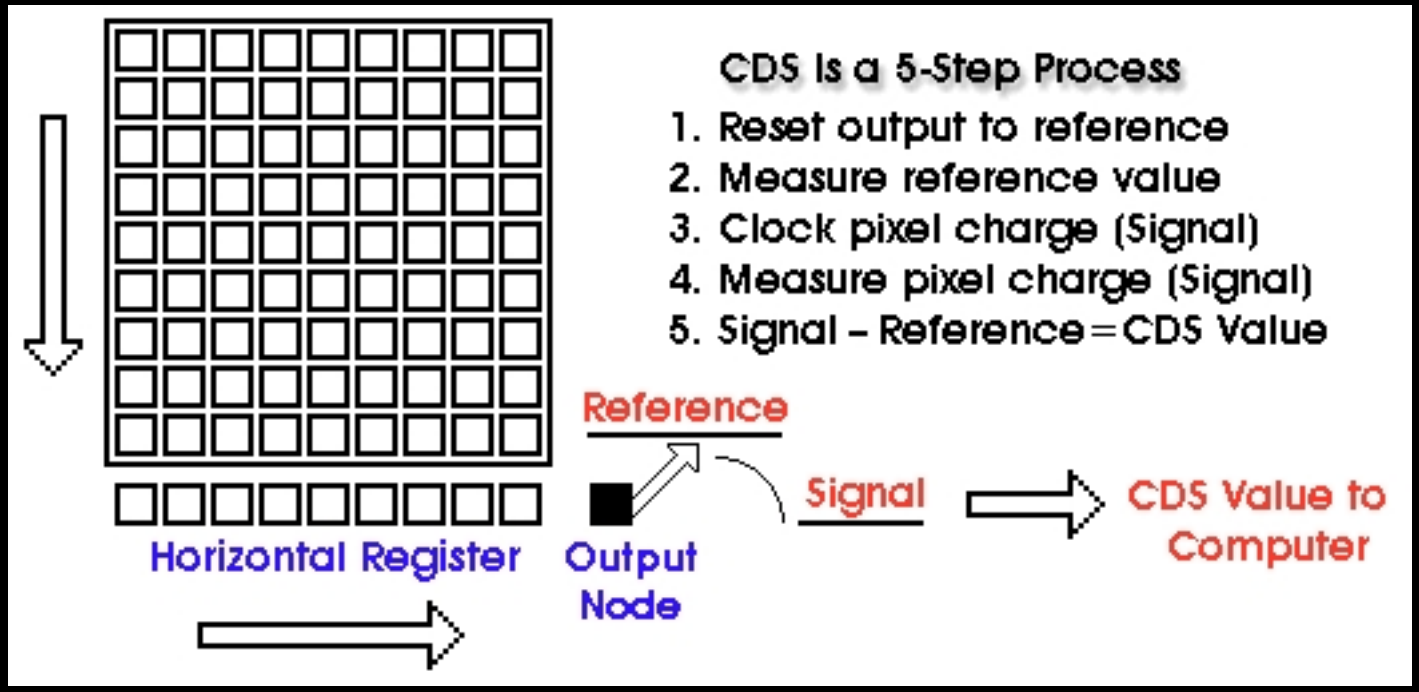
Dynamic Range

- determined by the "full well depth" of the device
- scales approximately with pixel volume
- $\sim 200,000\ e^-$ for SPIcam CCD $(\sim 60,000 ADU)$
- newer CCDs with read noise $\sim 1e^-$ ($>$ 16-bit dynamic range)

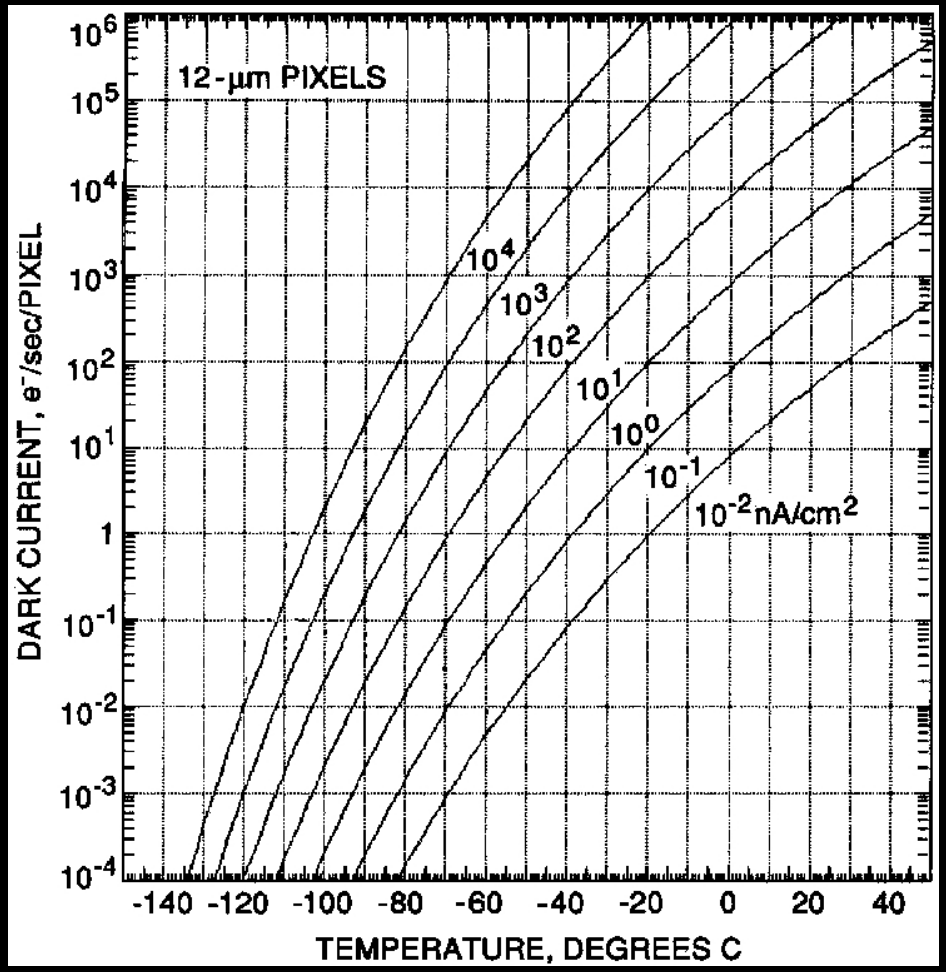
Read Noise

- usually dominated by the properties of the on-chip amplifier
- scales as $\sqrt{readout - rate}$
- typically 3-8 e^- for scientific CCDs
- newer devices are approaching sub-electron read noise

CCD readout

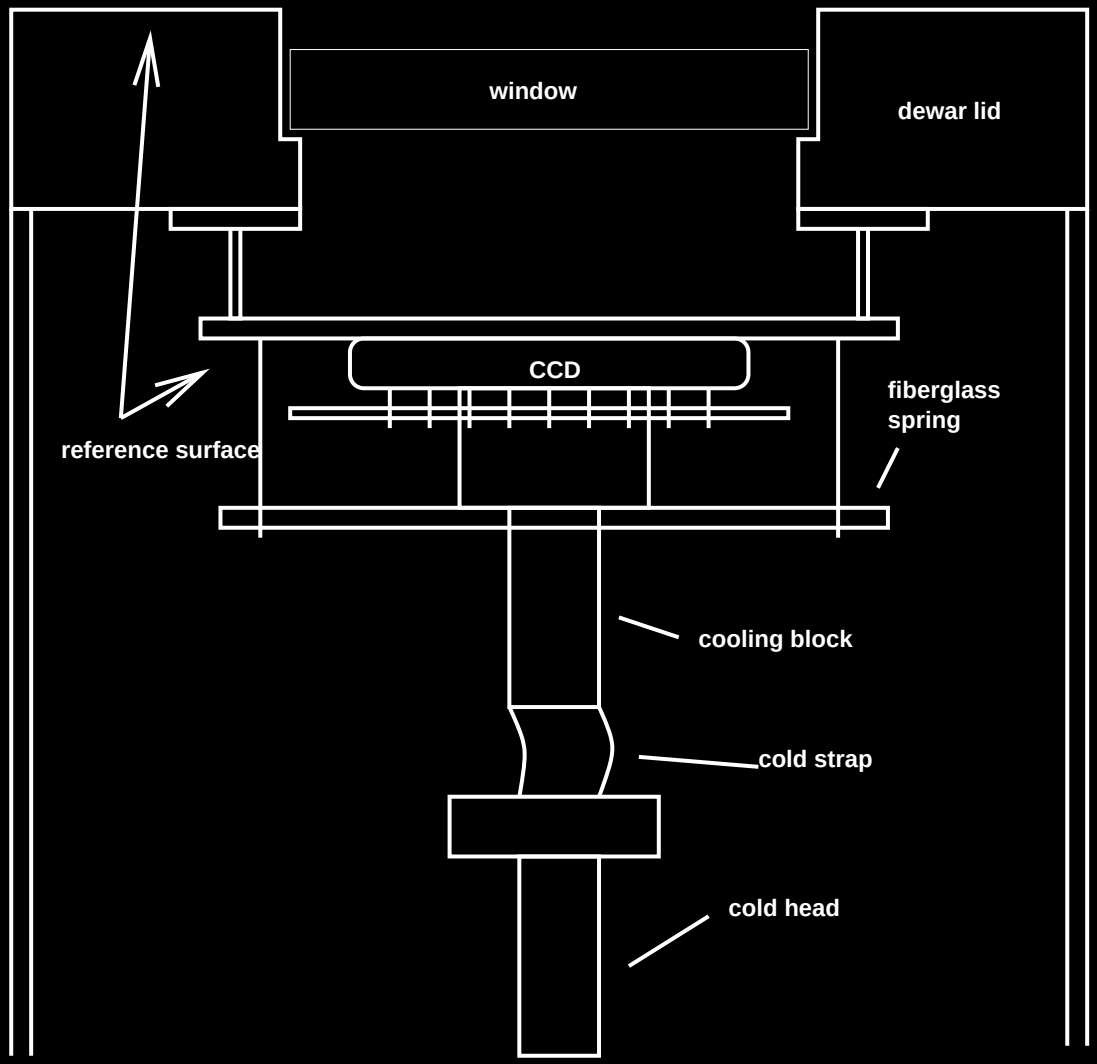

CDS Is a 5-Step Process
1. Reset output to reference
2. Measure reference value
3. Clock pixel charge (Signal)
4. Measure pixel charge (Signal)
5. Signal – Reference = CDS Value
Reference
Signal
CDS Value to Computer
Horizontal Register
Output Node

Dark Current



Mechanical Design: Internal

- position detector rigidly with respect to optical path
- transfer mechanical registration from inside to outside of dewar
- thermally isolate detector from environment
- keep vacuum environment as clean as possible
- bring first-stage output amplifier as close to the detector as possible


window
dewar lid
CCD
fiberglass
spring
reference surface
cooling block
cold strap
cold head

positioning detector

- f/10 beam of 3.5-meter has $\sim 700\mu\mathrm{m}$ depth-of-focus
- calibrated contact to cooling head
- allow for thermal contraction on cooling $\Longrightarrow$ fiberglass spring

Cryogenics

- cool to $\sim -100^{\circ}C$
- eliminate need for liquid nitrogen
- ion-pump is useful
- reduce workload on observatory staff

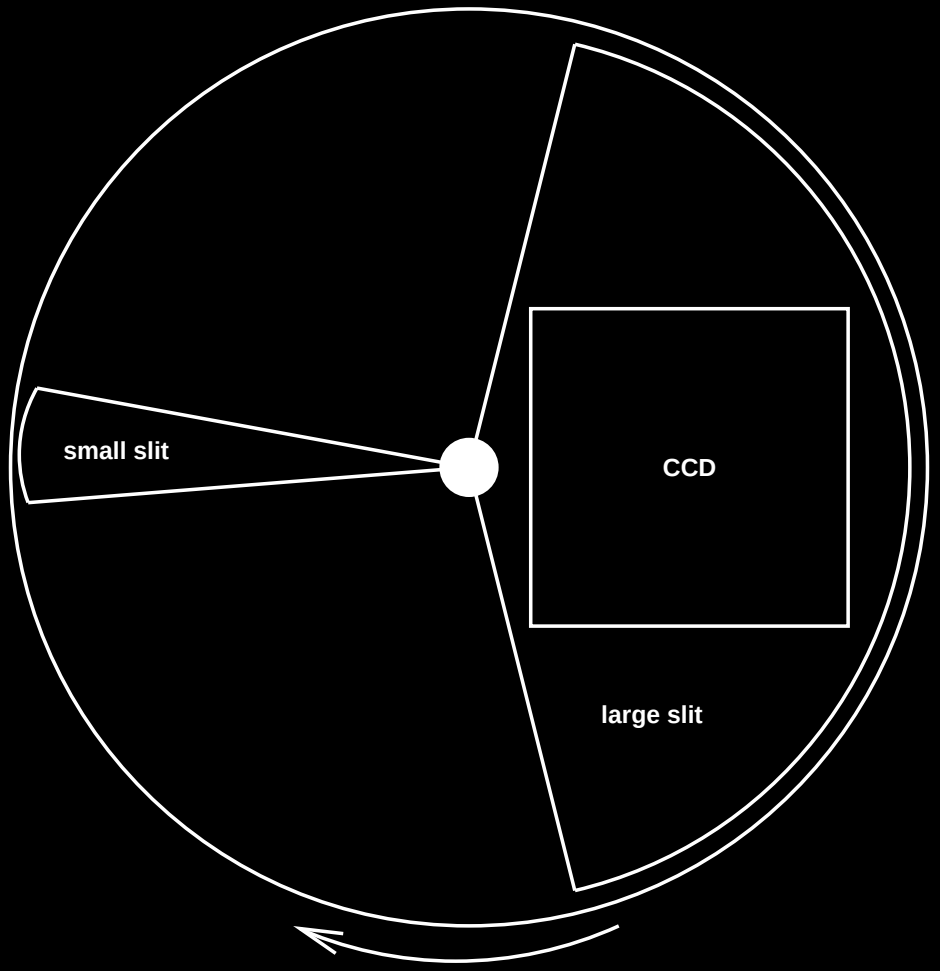
CryoTiger

CryoTiger

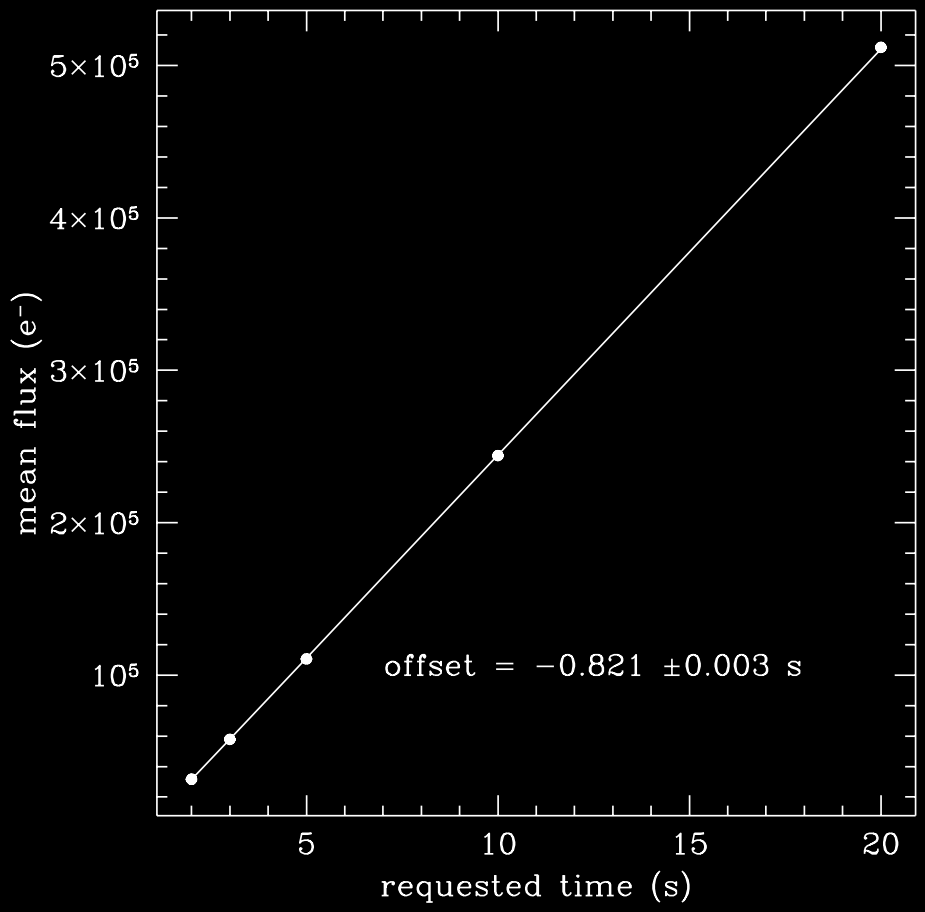
Mechanical Design: External

- shutter
- filter wheel
- electronics
- waste-heat control

Rotating-Wheel Shutter

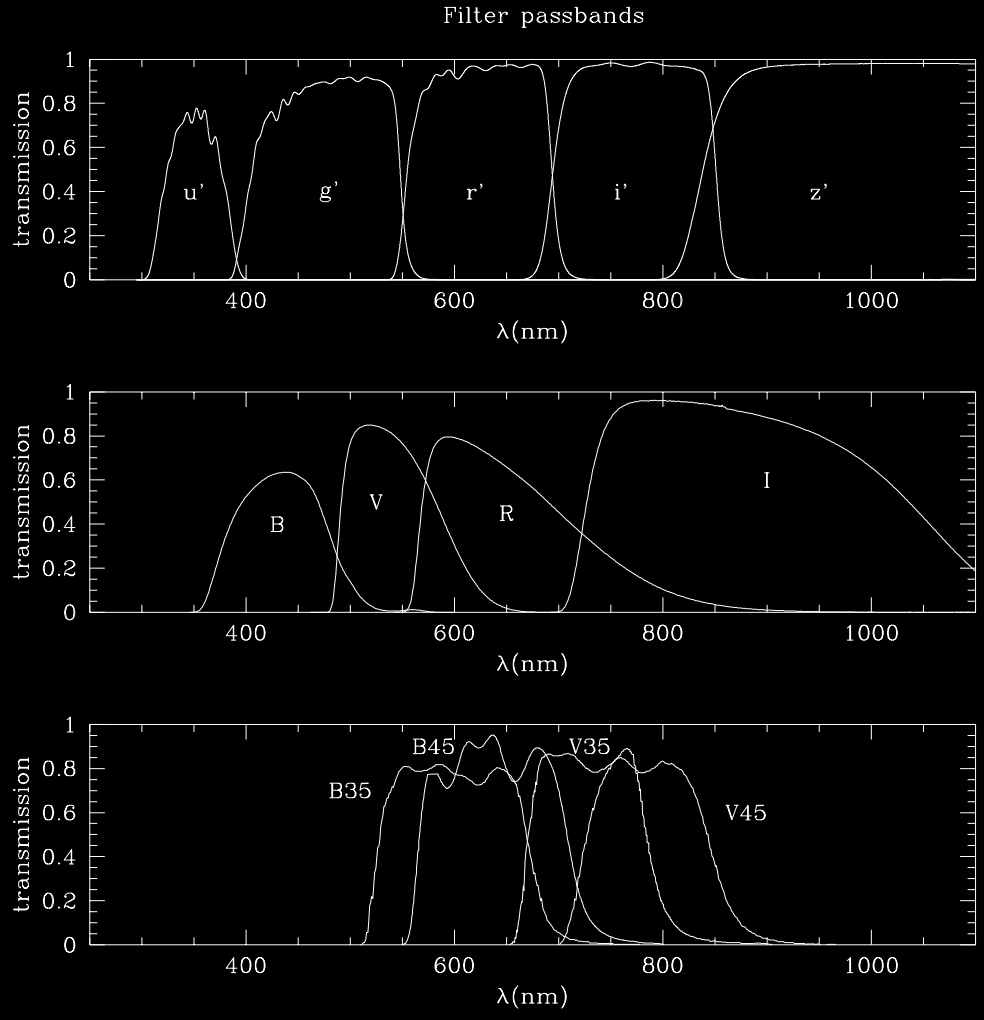


Shutter Timing



Filter Wheel

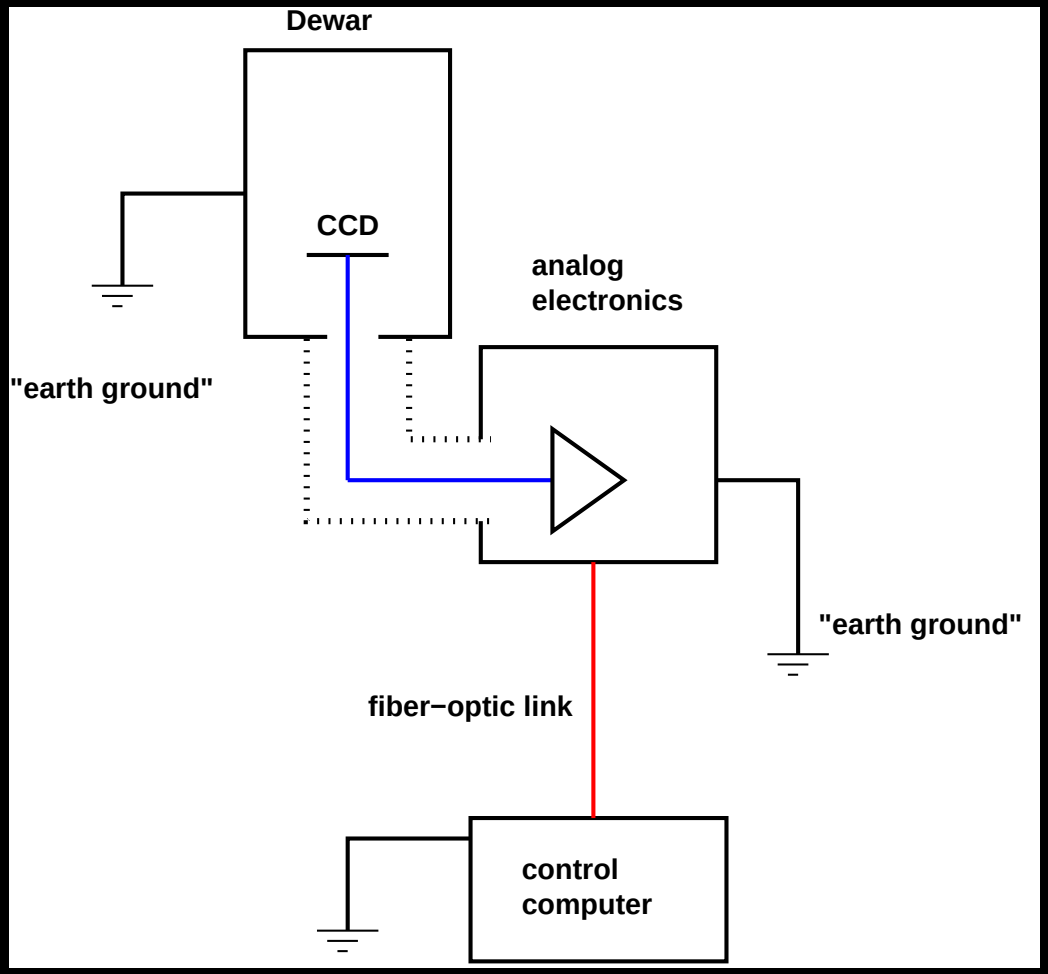
- must work
- read-back of wheel position
- holds 6 filters
- position filters to $\sim$ few microns
- minimize handling of filters


Filter passbands
transmission
λ(nm)
u'
g'
r'
i'
z'
B
V
R
I
B35
B45
V35
V45
0
0.2
0.4
0.6
0.8
1
400
600
800
1000

Electronics Packaging

- robust against electrical interference
- minimize cable lengths to dewar
- lightning protection

Simplified Grounding Scheme



Waste-Heat Removal

- forced-air heat removal from electronics packages
- dump heat to mid-level
- makes a good vacuum-cleaner

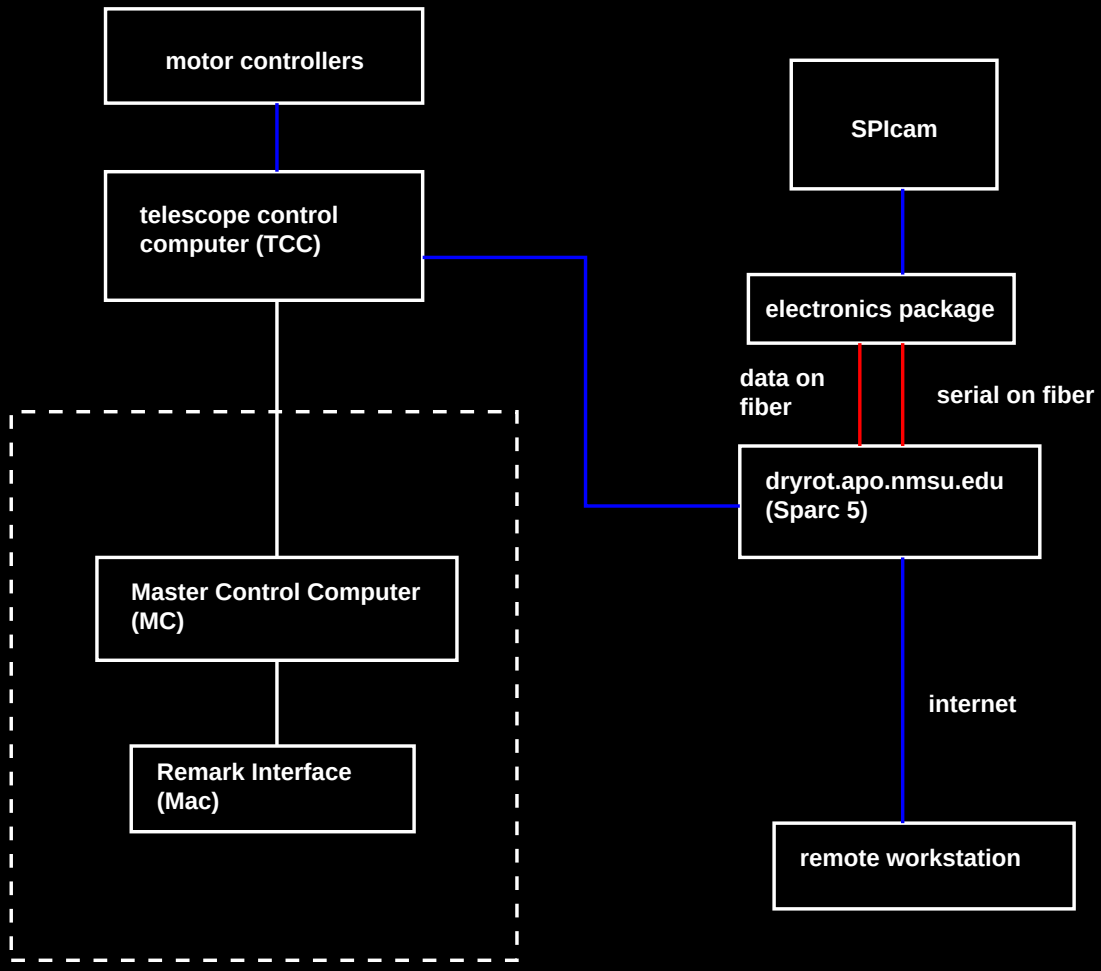
Electronics

- based on architecture developed by Peter Doherty at Photometrics
- 6811 $\Longrightarrow$ DSP $\Longrightarrow$ level-shifter $\Longrightarrow$ clock wave-forms
- 6811 also controls shutter and filter-wheel
- 40 kHz pixel rate
- parallel data is serialized for transmission to control computer

Software control

- unix workstation for ease of networking
- command-line interface
- scripting in “mana” (Gene Magnier)
- instrument sends commands directly to TCC
- scripts for taking focus images, sky-flats
- automatic focus adjustment when changing filters

Software architecture



Performance

- 25 sec. full-frame read-time (binned 2×2)
- 4.78 arcminute F.O.V. at 0.14 arcsec per pixel
- 3.37 e^- / ADU sensitivity
- 5.7 e^- read-noise, 2.7 e^-/hr dark current
- 0.999999 CTE in both serial and parallel directions

http://www.apo.nmsu.edu/Instruments/SPIcam/

Sensitivity - Sloan

Filter	Star	Sky (per pixel)
u*	10.1	0.7
g*	303	12.8
r*	310	18.2
i*	259	25.6
z*	77.5	32.0

$m = 20$, 1 sec. integration, binned 2×2, area is $4\pi\sigma^2$ for Gaussian PSF

Sensitivity - Johnson-Cousins

Filter	Star (e^-/s)	Sky ($e^-/s/pixel$)
U	20.2	2.4
B	189	3.7
V	303	7.4
R	256	12.1
I	216	22.9

$m = 20$, 1 sec. integration, binned 2×2, area is $4\pi\sigma^2$ for Gaussian PSF

Anecdotes from SPIcam construction

- know when to "wing it"
- monitor everything
- efficiency of operation is critical
- always carry tools
- roads in New Mexico are rough