The Use of CCDs in Astronomy

A.Ederoclite

Nobel Prize!

The Nobel Prize in Physics 2009

Photo: U. Montan
Charles Kuen Kao
Prize share: 1/2

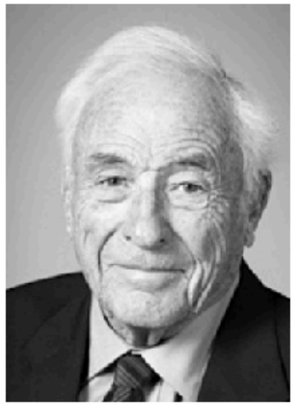
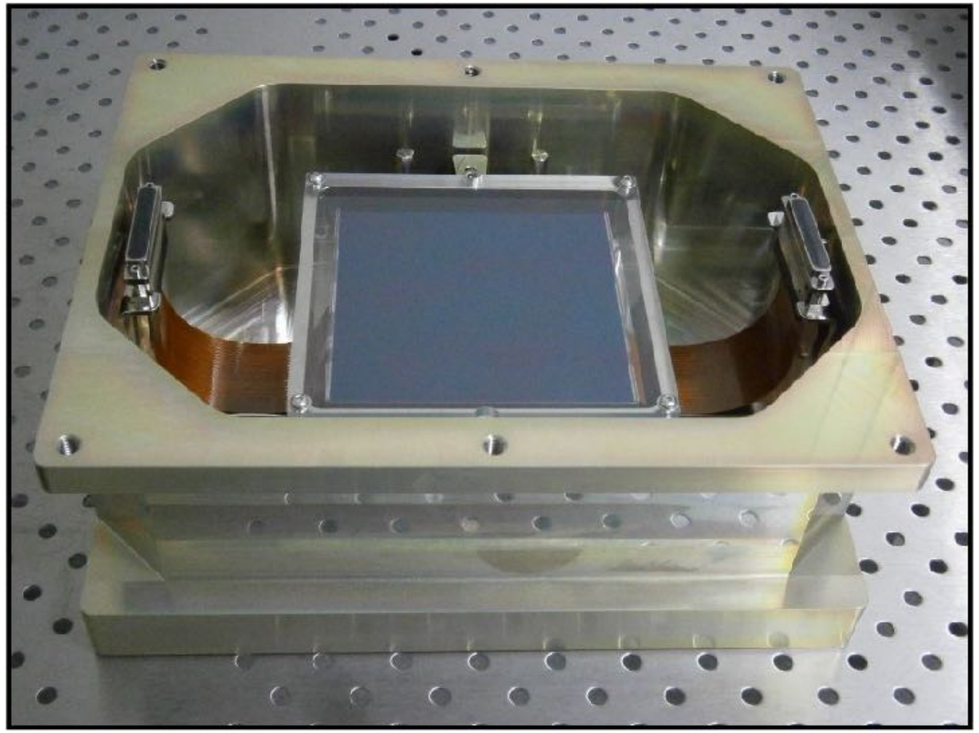


Photo: U. Montan
Willard S. Boyle
Prize share: 1/4

Photo: U. Montan
George E. Smith
Prize share: 1/4

The Nobel Prize in Physics 2009 was divided, one half awarded to Charles Kuen Kao *"for groundbreaking achievements concerning the transmission of light in fibers for optical communication"*, the other half jointly to Willard S. Boyle and George E. Smith *"for the invention of an imaging semiconductor circuit - the CCD sensor"*.

What is a CCD?

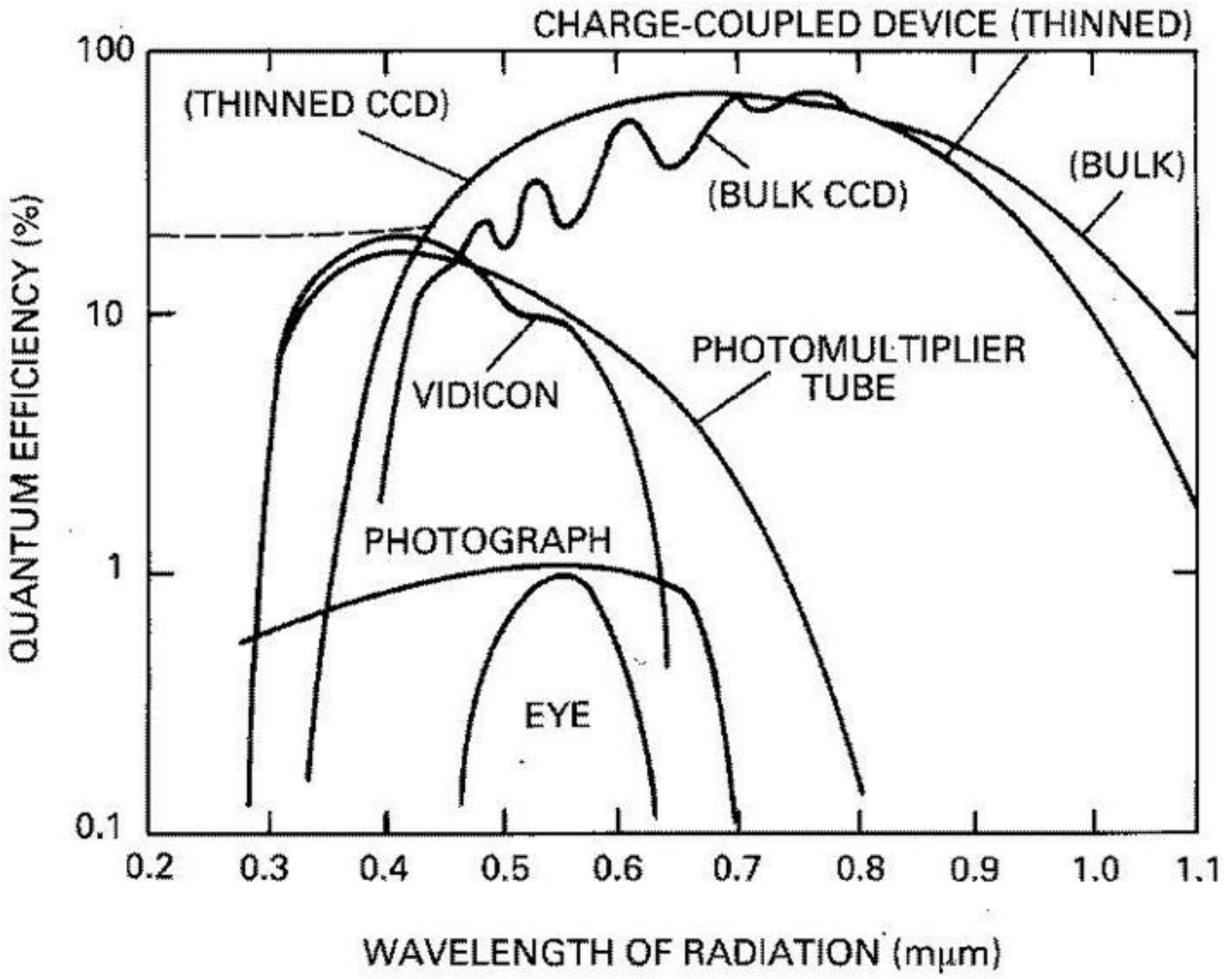


http://oajweb.cefca.es/telescopes/t80cam

Charged-Coupled Device

Main detector for optical astronomy

CCDs in Astronomy



Photographic plates
and photomultipliers
until 1980s

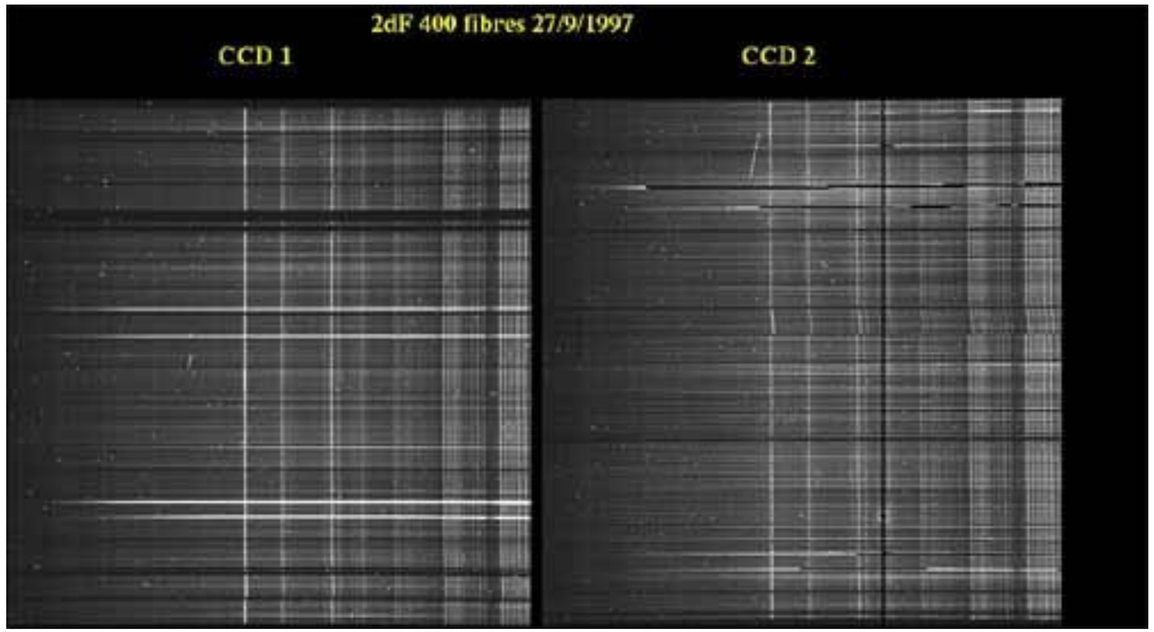
First CCDs were 256x256 pixels^2.
Now we have 10k x 10k

CCDs in Astronomy

Advantages of using CCDs:

- good response over optical range
- linearity
- low-noise
- immediate usable data

http://www.lna.br/gallery2/index.php/



http://www.atnf.csiro.au/outreach/education/senior/astrophysics/spectrographs.html

What is my best choice?

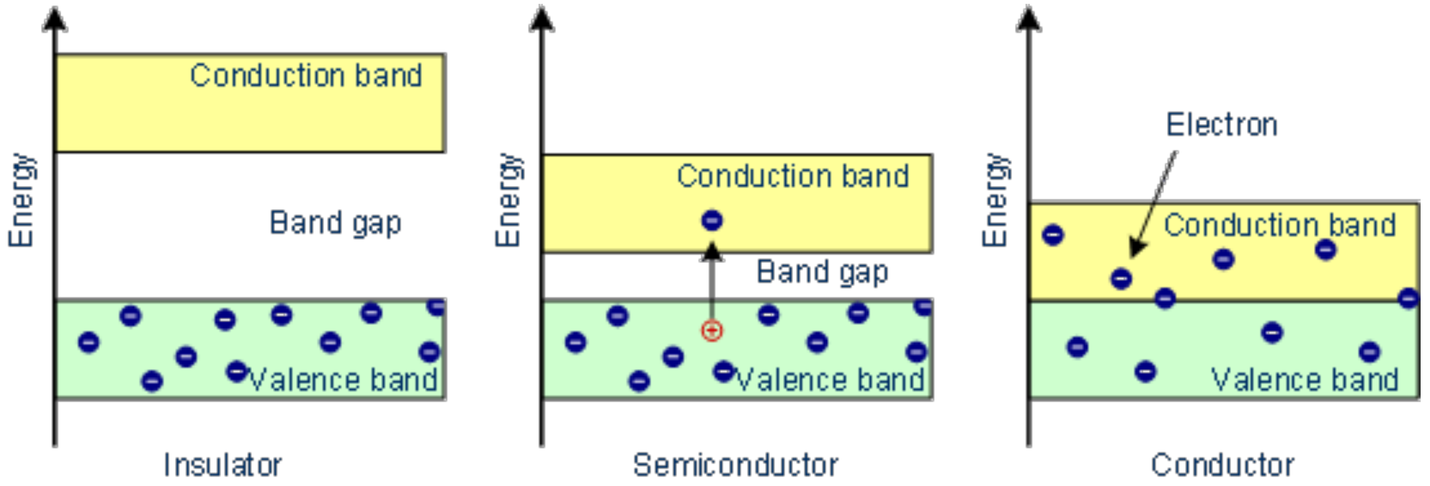
- Characteristics:

- dimension
- pixel size
- quantum efficiency
- readout noise
- readout speed

<u>cost!</u>

How a CCD works

https://www.halbleiter.org/en/fundamentals/conductors-insulators-semiconductors/



For Silicon, the gap is ~1.14eV

Silicon works well between 1.1 and 4 eV
(11000 and 3000 Å)

Readout

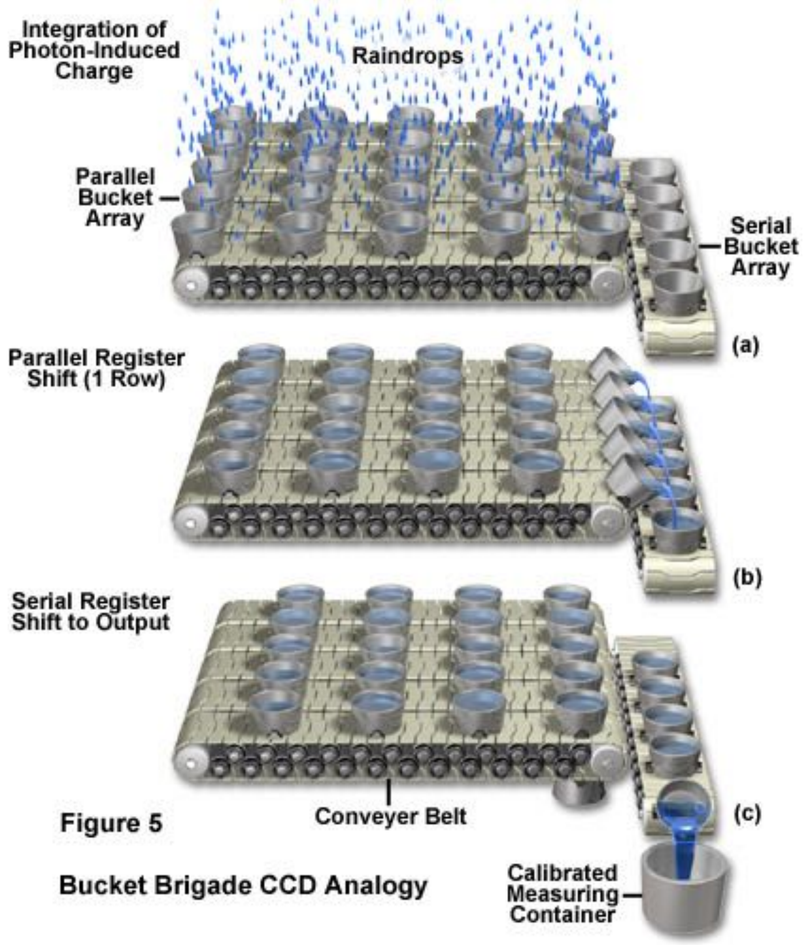
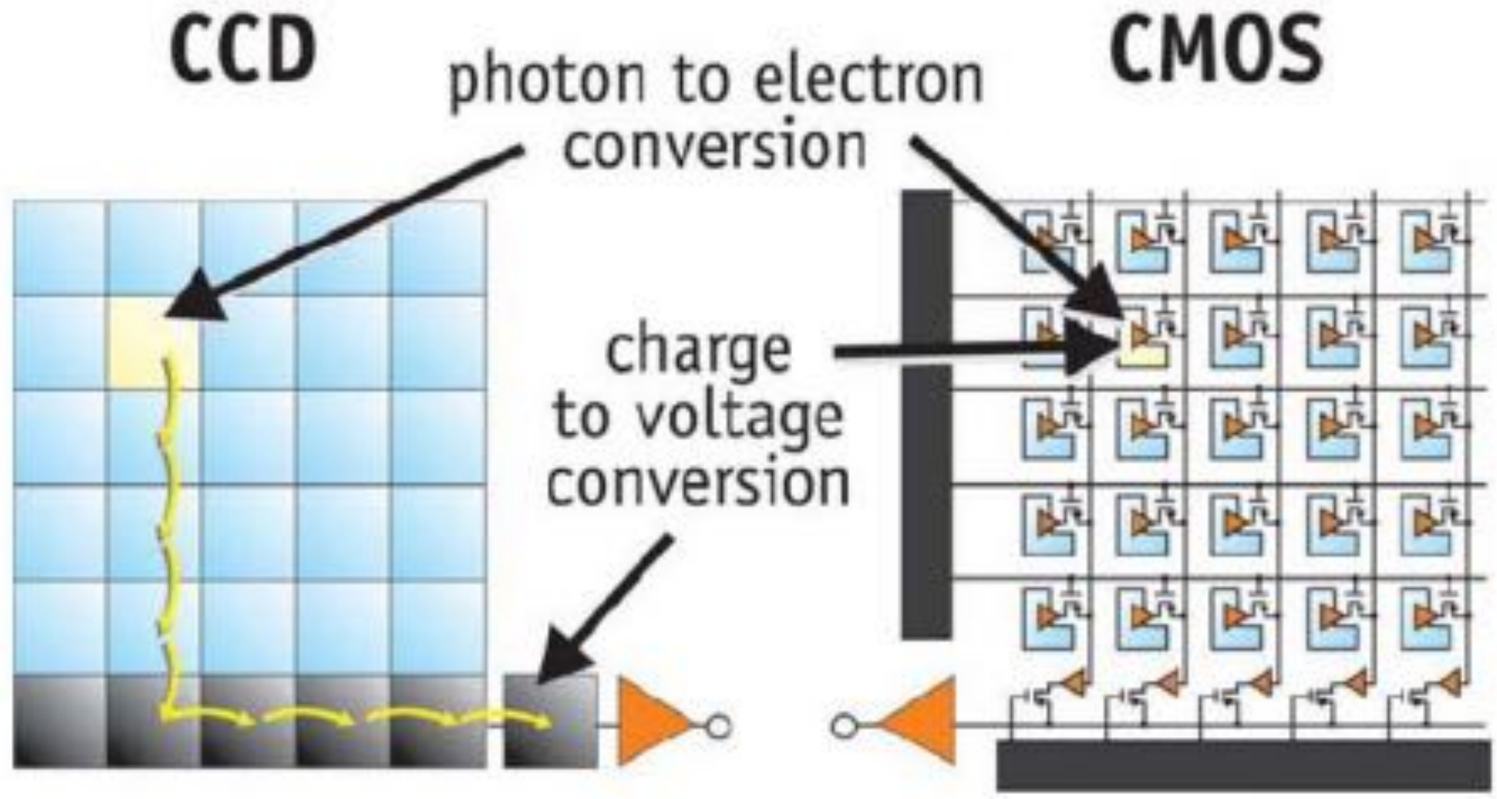


Figure 5

Bucket Brigade CCD Analogy

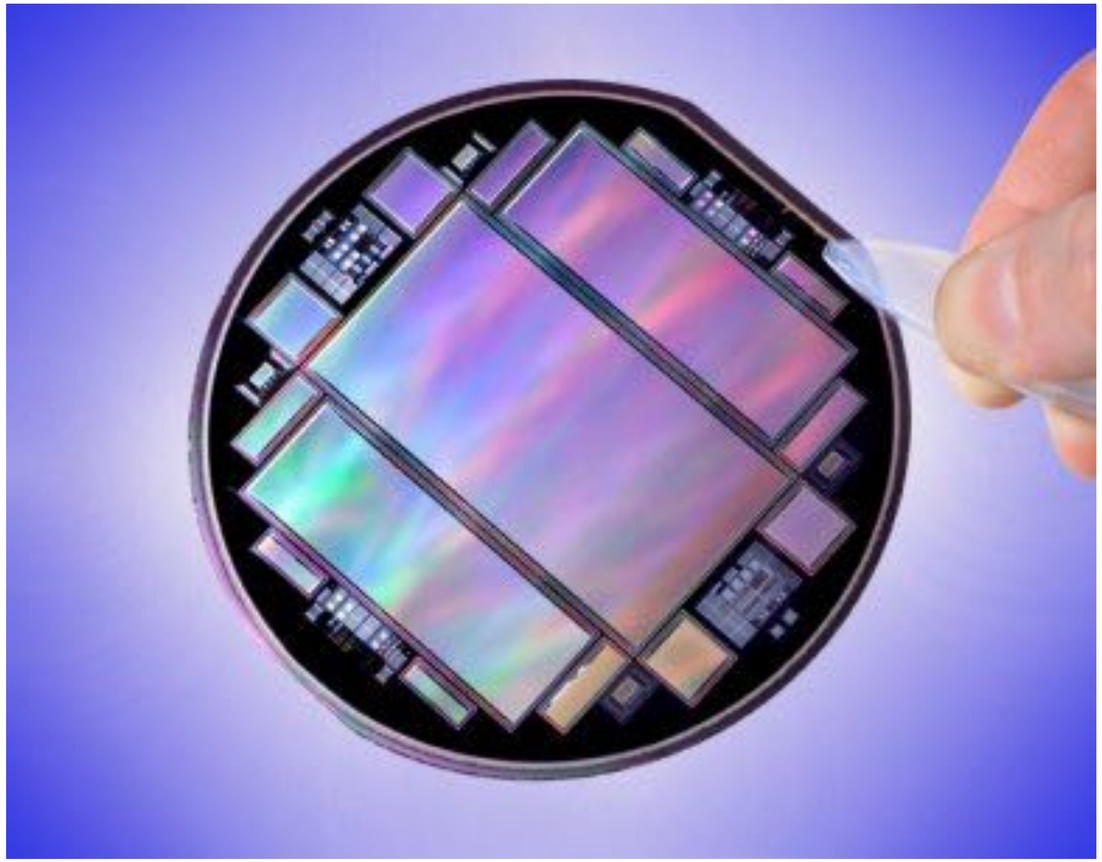
http://www.ysctech.com/digital-microscope-CCD-camera-info.html

CCDs vs CMOS



Complementary Metal Oxide Semiconductor arrays

Fabrication



"Grades": 0,1, 2, or 3

0 - science grade

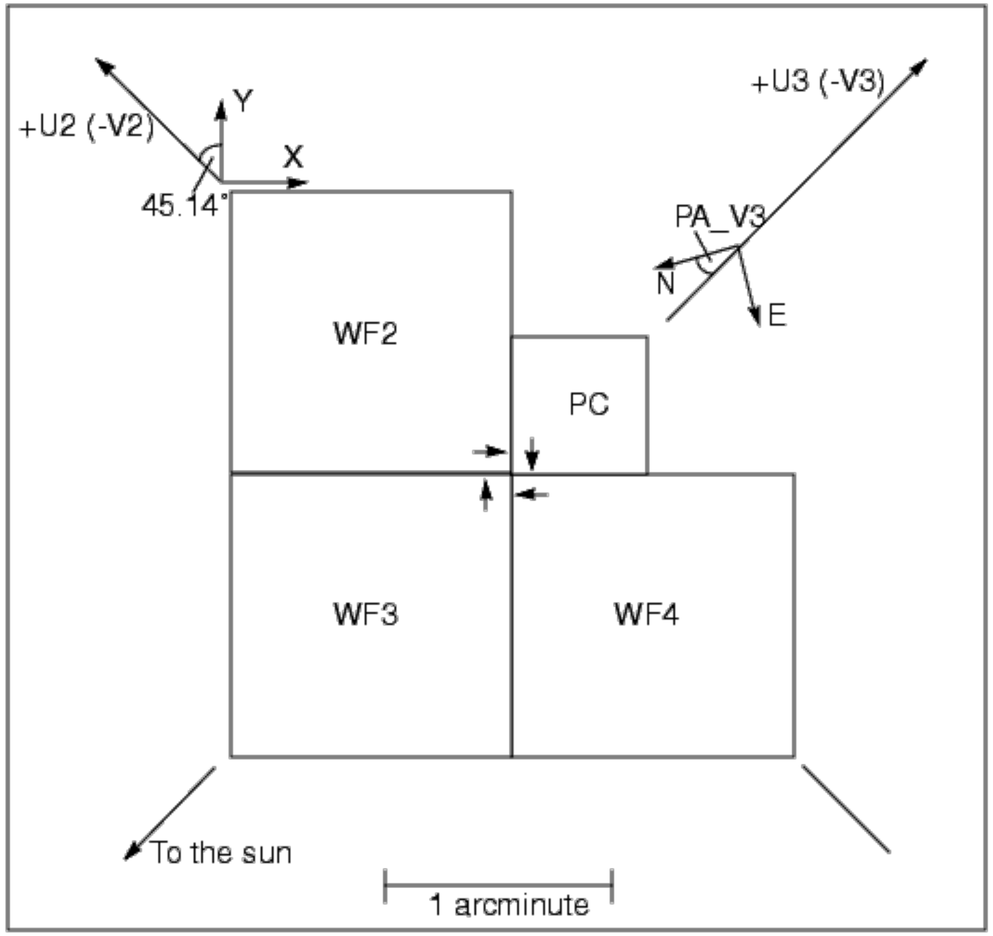
3 - mobile phones

http://www.faculty.virginia.edu/rwoclass/astr511/lec11-f03.html

Sizes

- Pixel (10-24microns)
  - need to match half of the psf of your instrument
- CCD (n_{pixels} * $size_{pixel}$), from 512 to 10k
  - need to match the field of view of your instrument

Wide Field /Planetary Camera 2



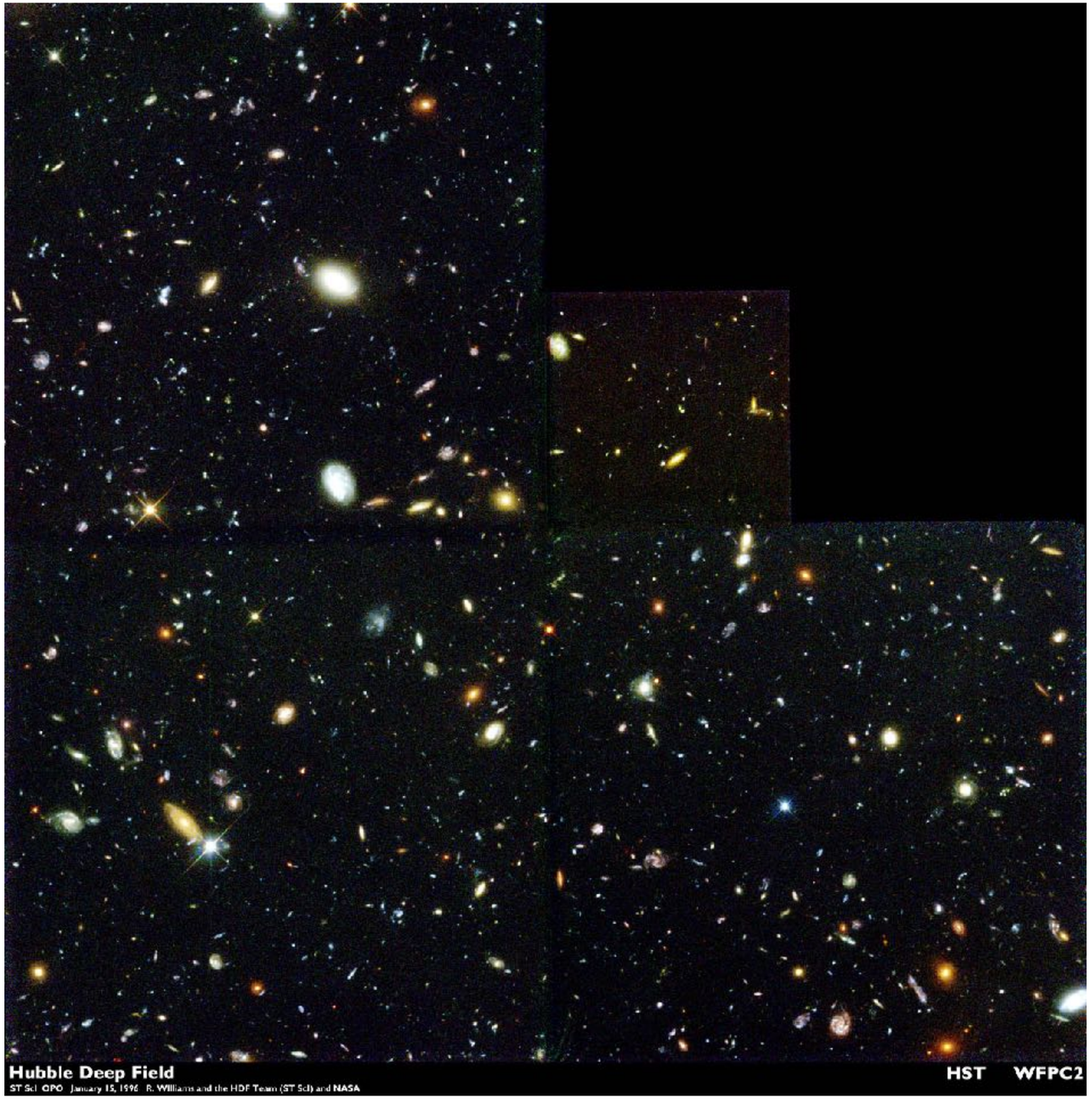
Instrument on the Hubble Space Telescope between 1993 and 2009

800x800 pixel Loral CCD

WF -> 0.1 arcsec/pixel

PC -> 0.046 arcsec/pixel

Diffraction limit of HST: 0.05”

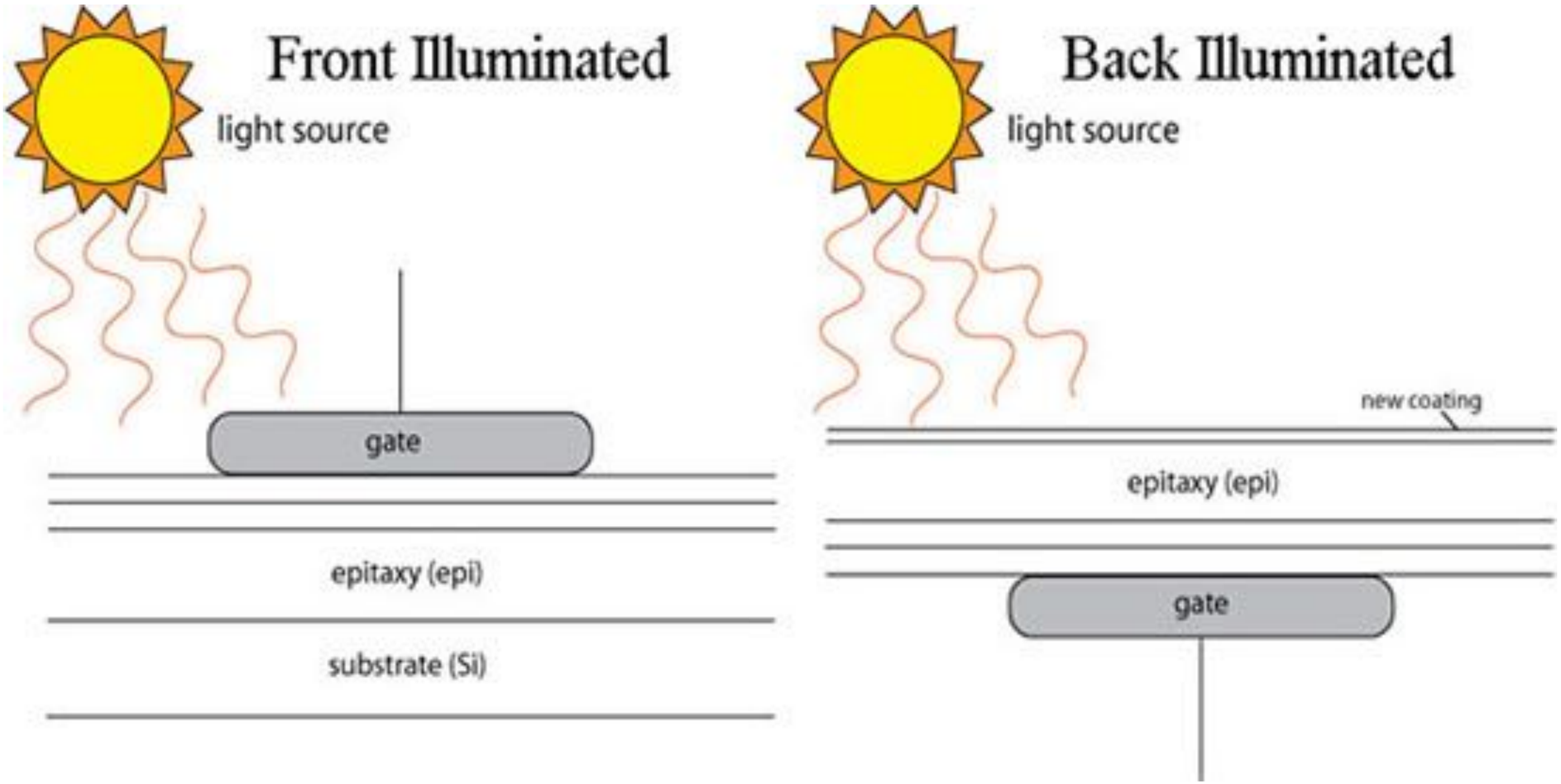


Hubble Deep Field

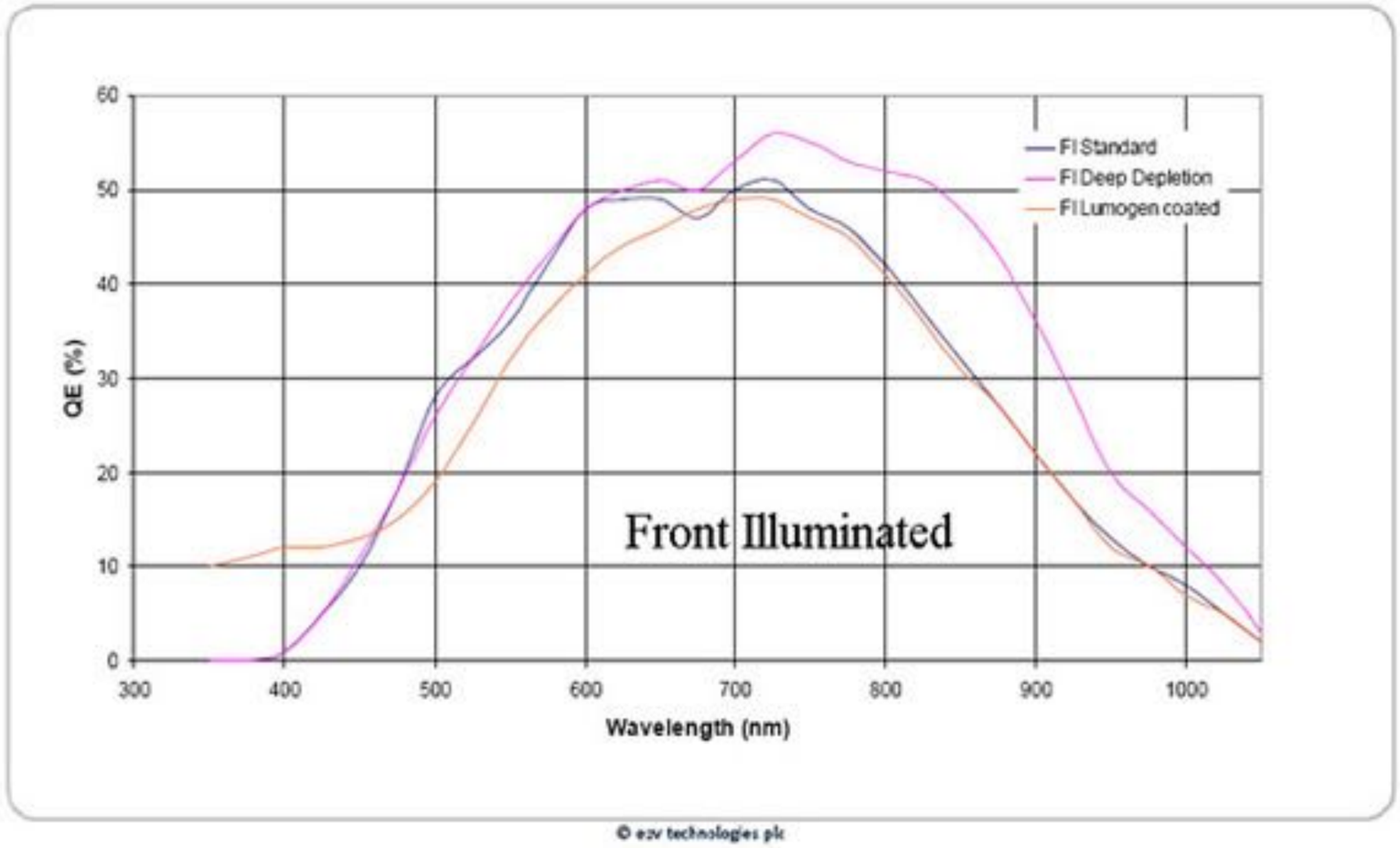
100 hours on target during Christmas 1995

Williams et al. (1996)

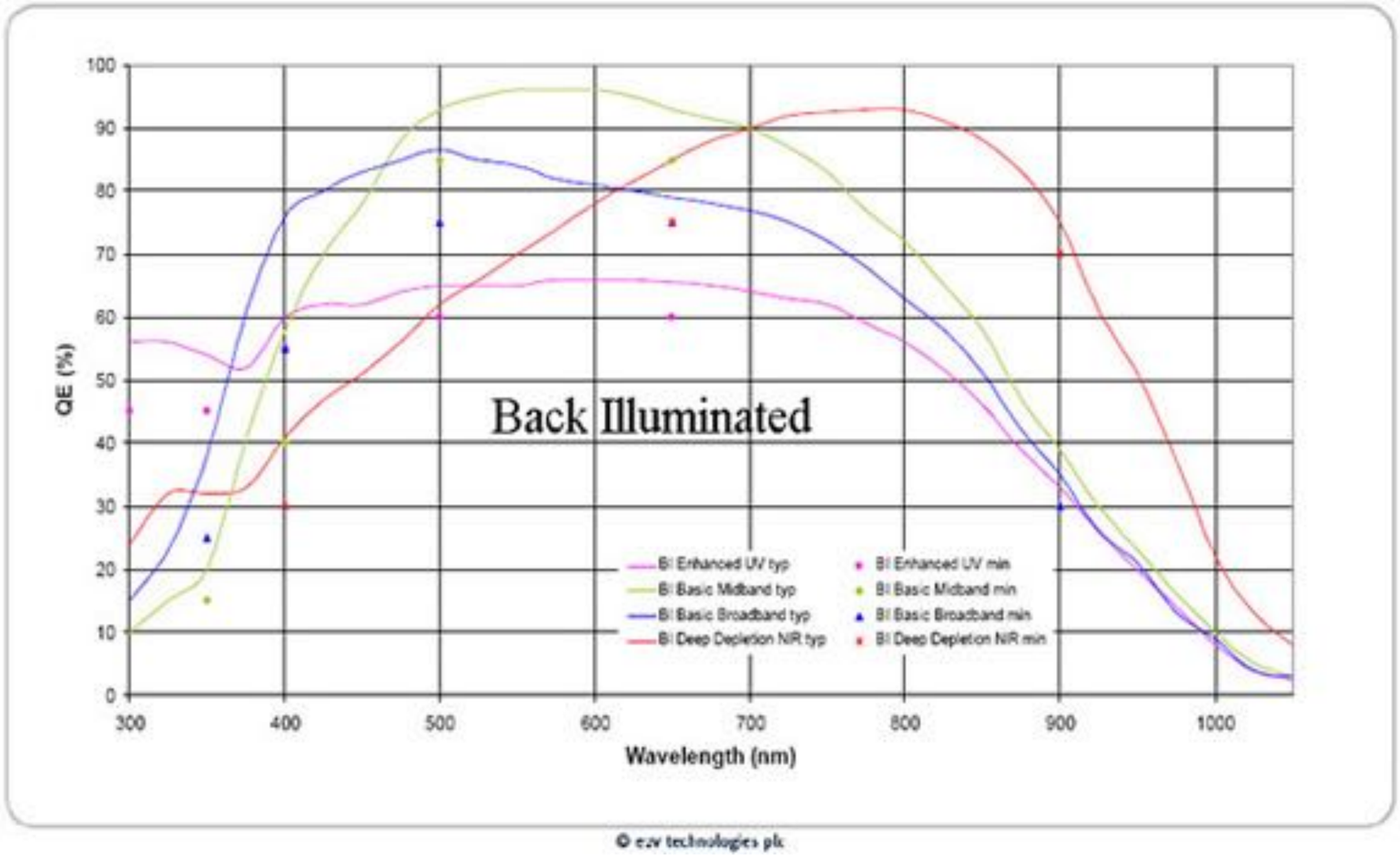
Quantum Efficiency



Quantum Efficiency



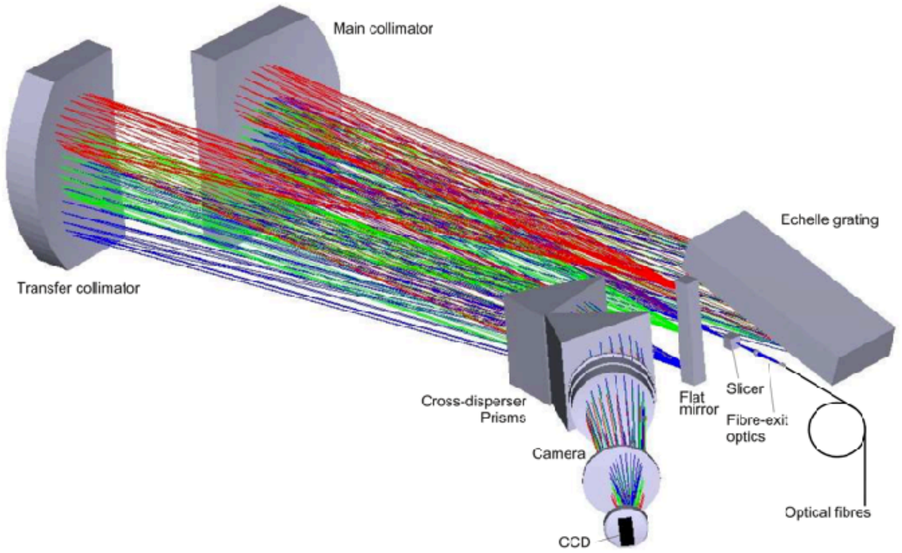
Quantum Efficiency



Coatings

HERMES: a high-resolution fibre-fed spectrograph for the Mercator telescope ⋆

Gert Raskin[1], Hans Van Winckel[1], Herman Hensberge[2], Alain Jorissen[3], Holger Lehmann[4], Christoffel Waelkens[1], Gerardo Avila[5], Jean-Pierre De Cuyper[2], Pieter Degroote[1], René Dubosson[6], Louis Dumortier[2], Yves Frémat[2], Uwe Laux[4], Bernard Michaud[6], Johan Morren[7], Jesus Perez Padilla[1], Wim Pessemier[1], Saskia Prins[1], Kristof Smolders[1], Sophie Van Eck[3], and Johannes Winkler[4]



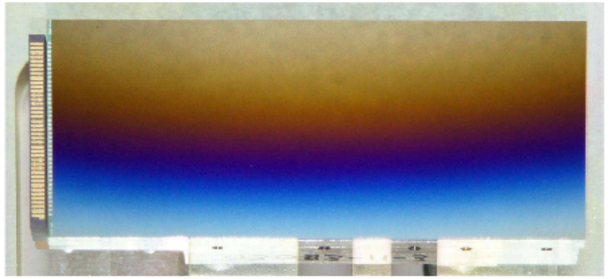


Fig. 14. Picture of the graded-AR coated CCD. The red-sensitive part at the top of the chip looks blue because red light is absorbed while blue light is reflected.

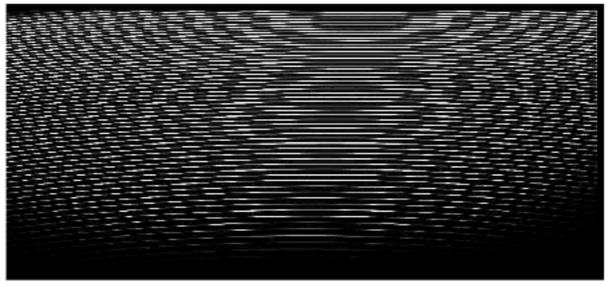
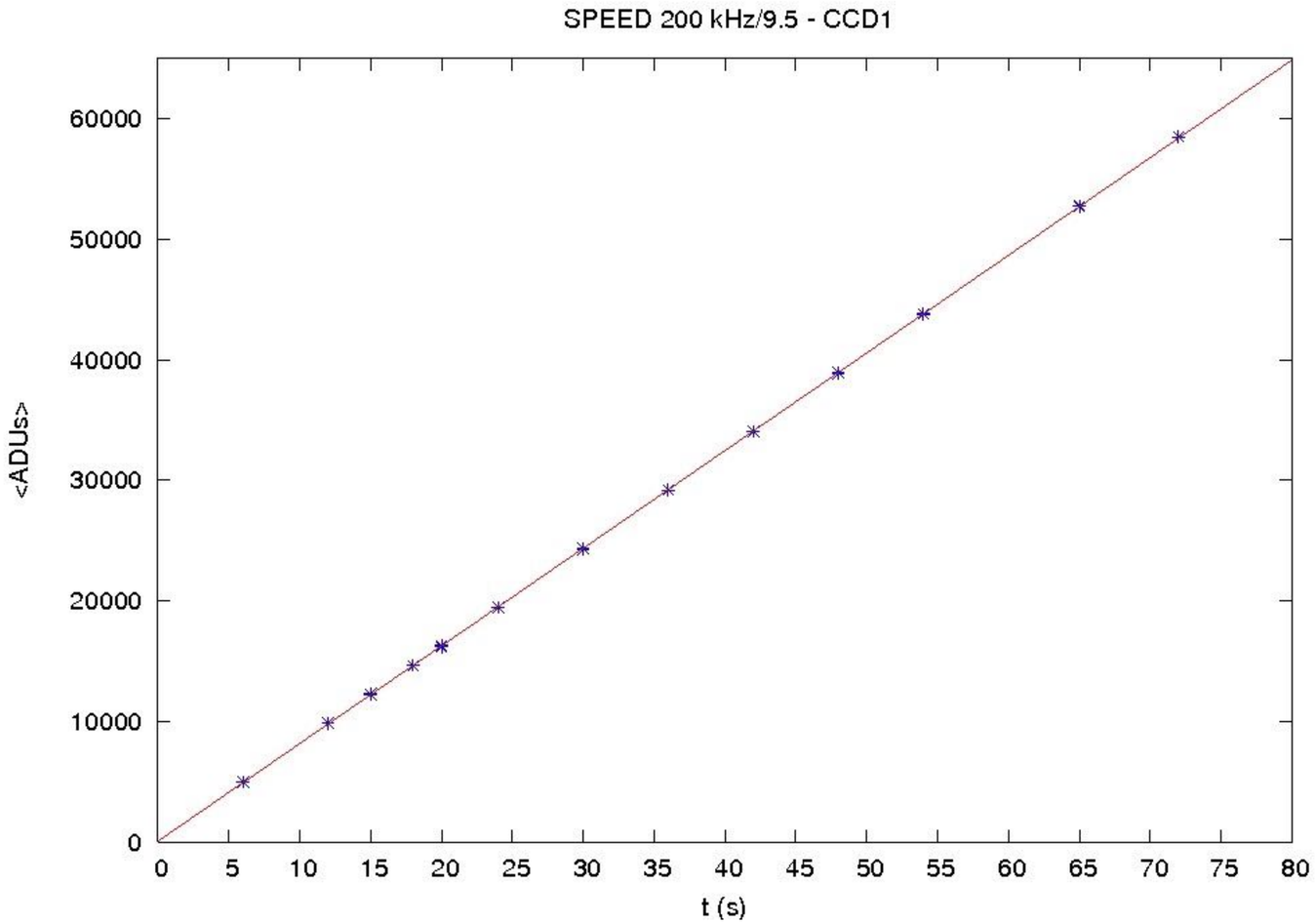


Fig. 15. Full-frame raw image of a flat-field spectrum in the low-resolution fibre.

Linearity

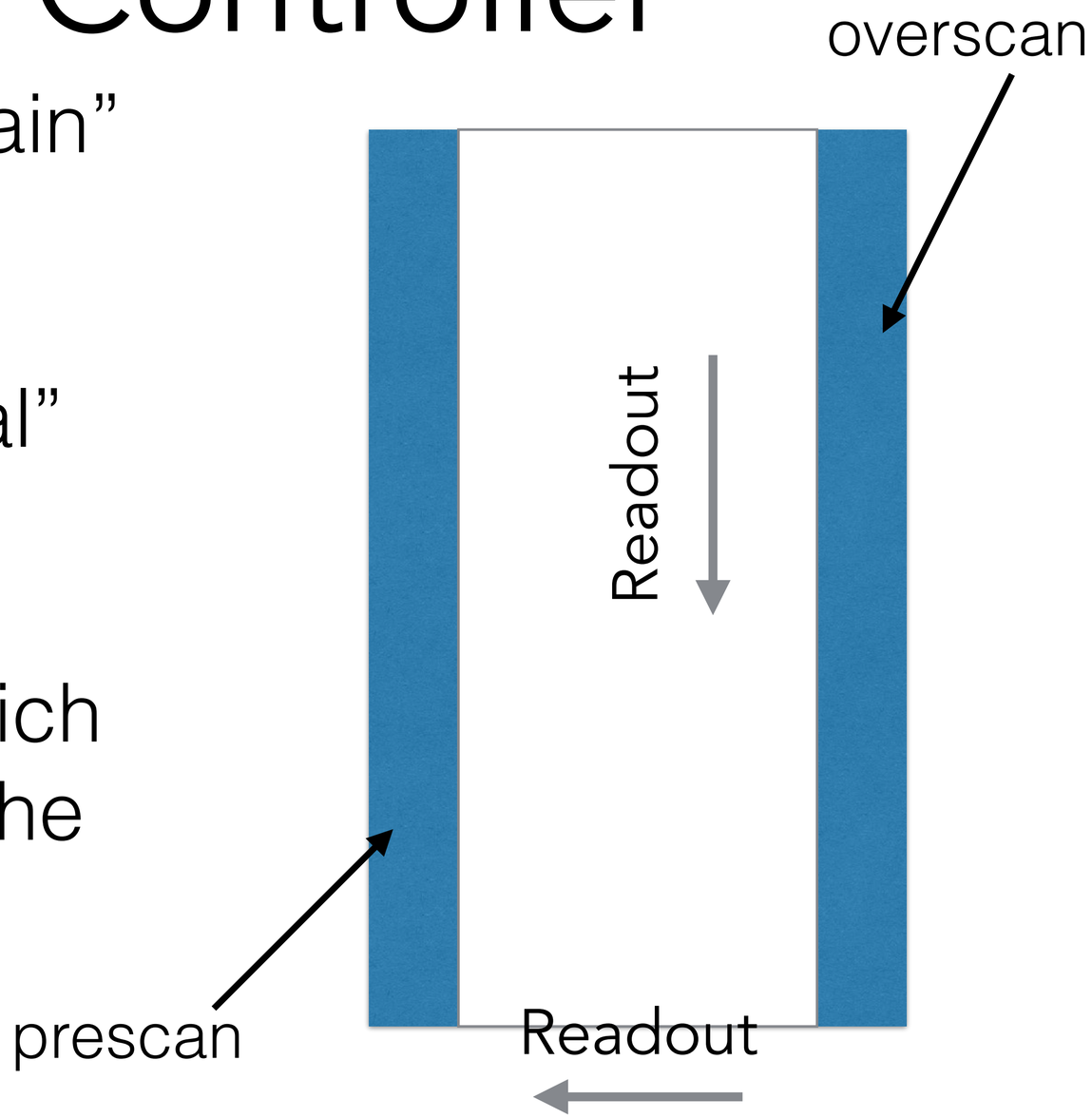

SPEED 200 kHz/9.5 - CCD1
<ADUs>
t (s)
0
10000
20000
30000
40000
50000
60000
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80

The Controller

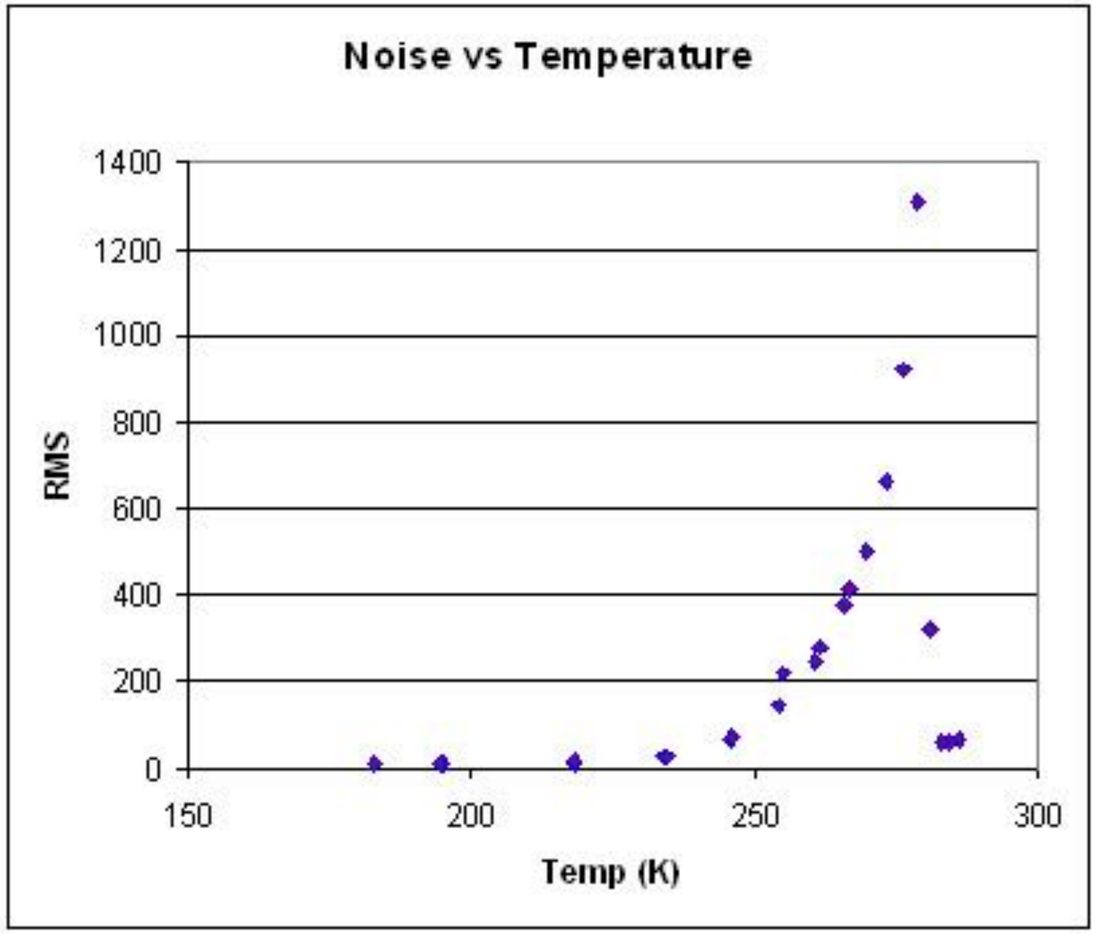
The Controller is the “brain” of the detector.

Not only allows “normal” readout.

Allows observations which involve movements of the telescope and/or the instrument!



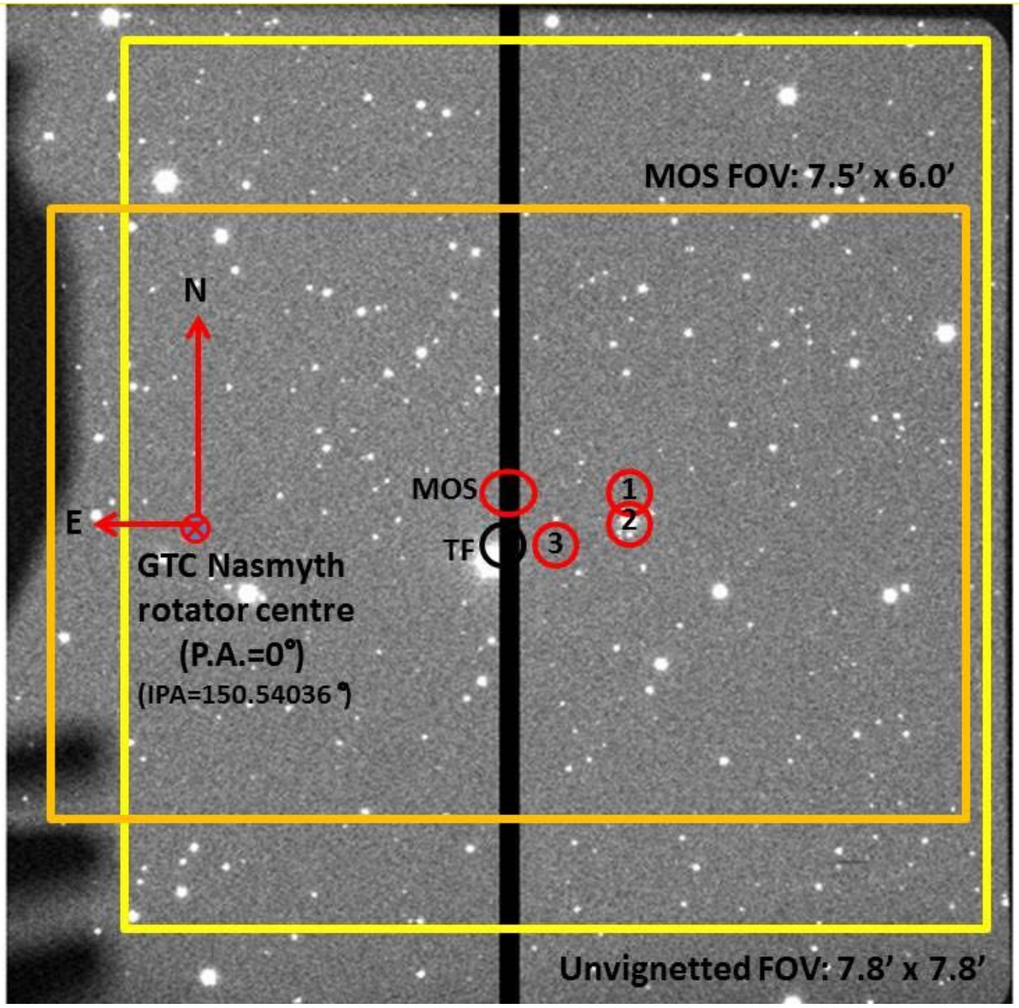
Noise



http://www.specinst.com/What_Is_A_CCD.html

Mosaics

OSIRIS



First instrument on the
Gran Telescopio Canarias
(10.4m)

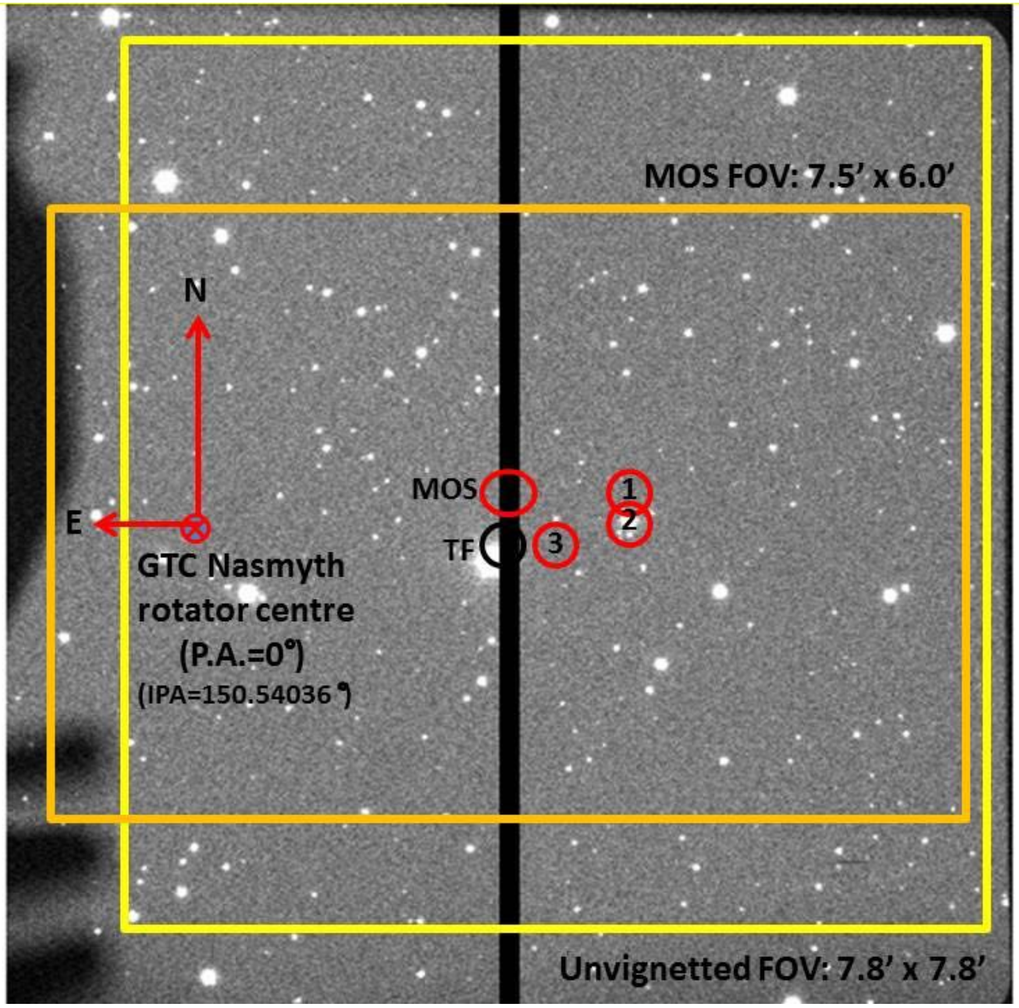
2 x 2kx4k CCDs
(Marconi CCD42-82)

pixel size = 15μm

scale = 0.125”/pixel

Typical seeing
0.6”

OSIRIS



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(Marconi CCD42-82)

pixel size = 15μm

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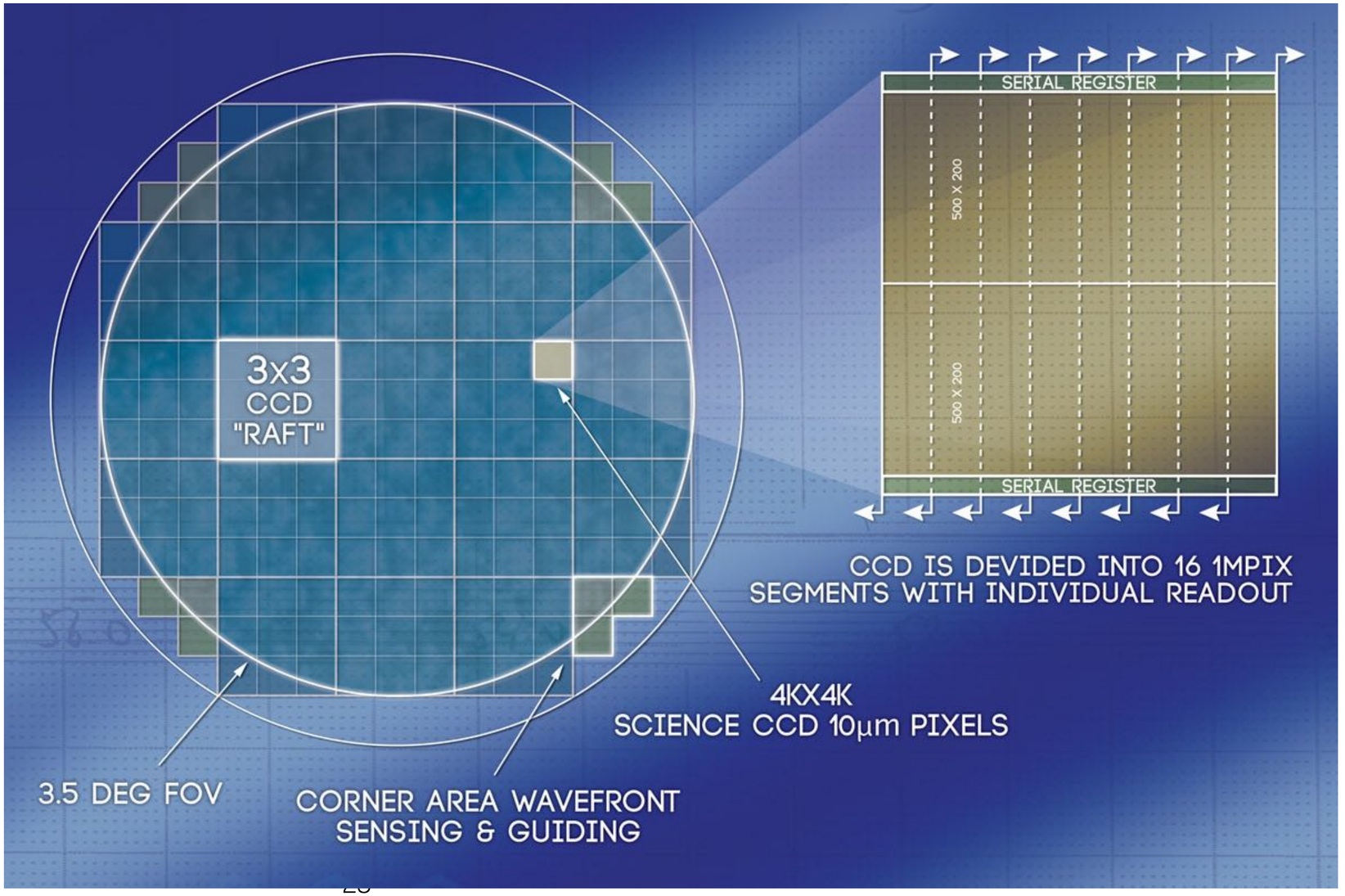
Typical seeing
0.6”

Oversampled psf

LSST

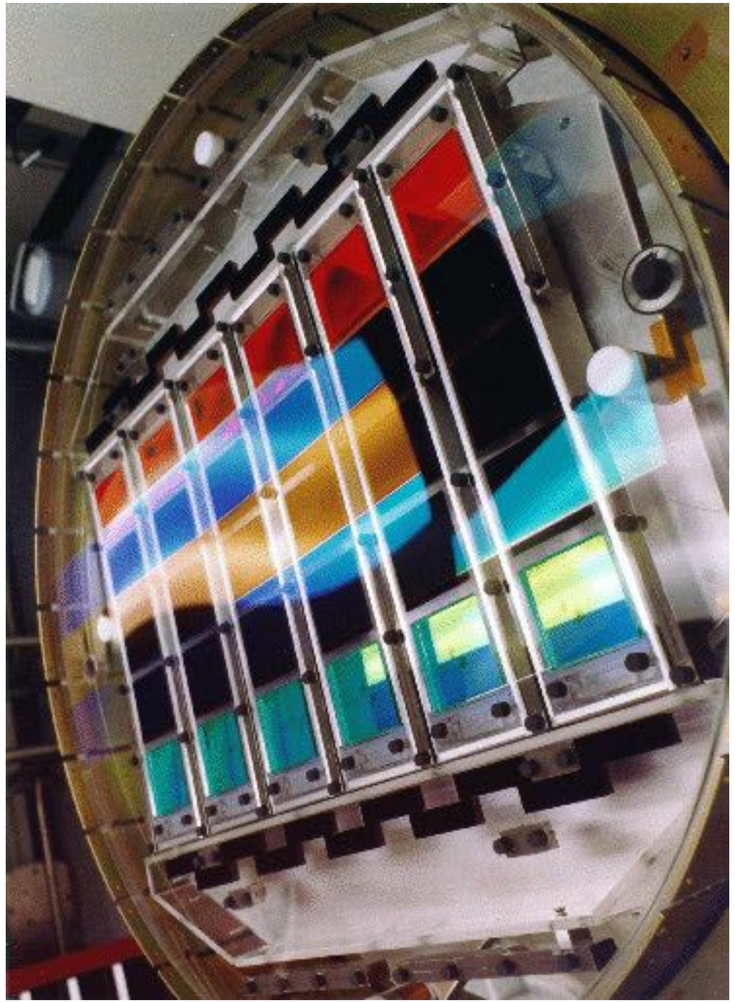


Large Synoptic Survey Telescope

8m telescope

Cerro Bachen (Chile)

SDSS



Sloan Digital Sky Survey

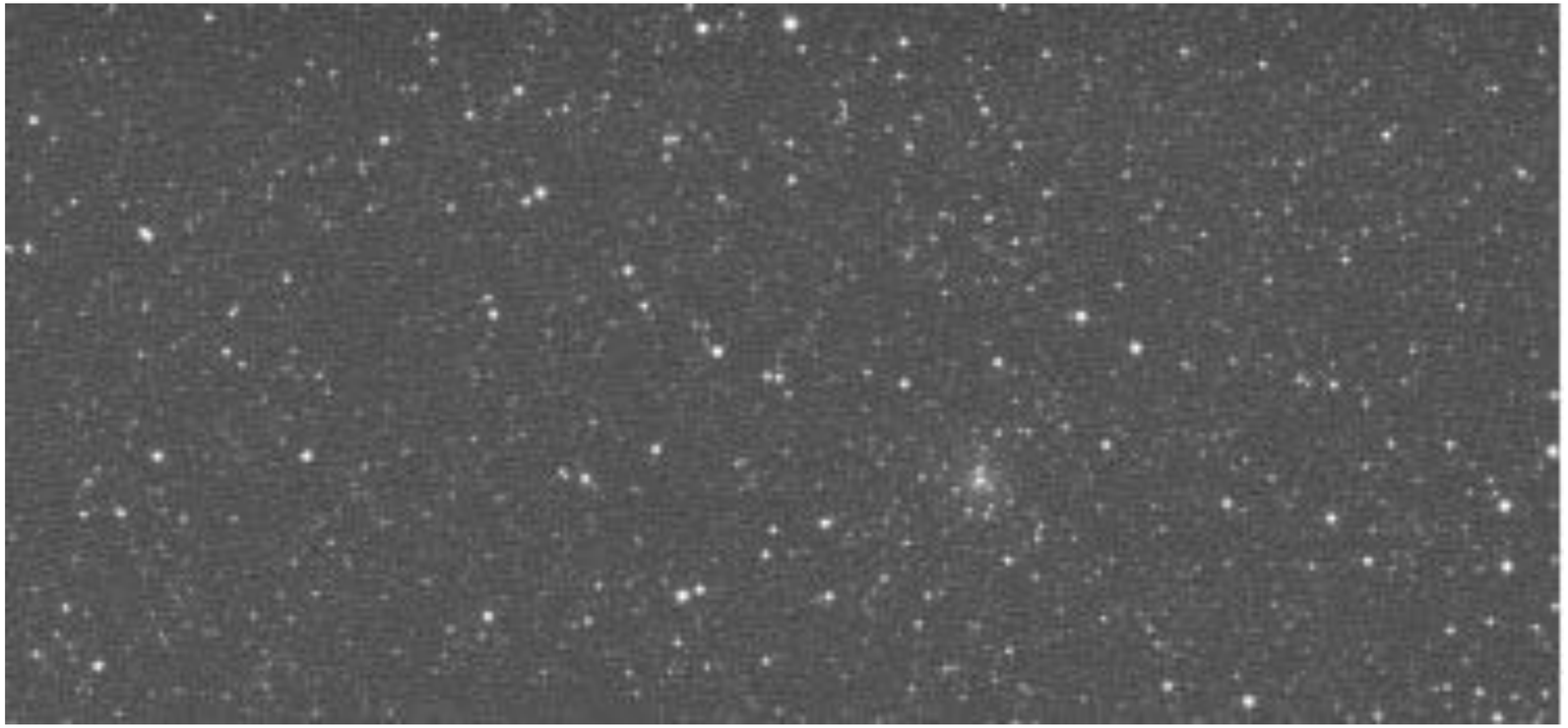
2.5m dedicated telescope
@Apache Point Observatory

30 2048x2048 CCDs

pixel size 24μm
scale 0.396 arcsec/pixel

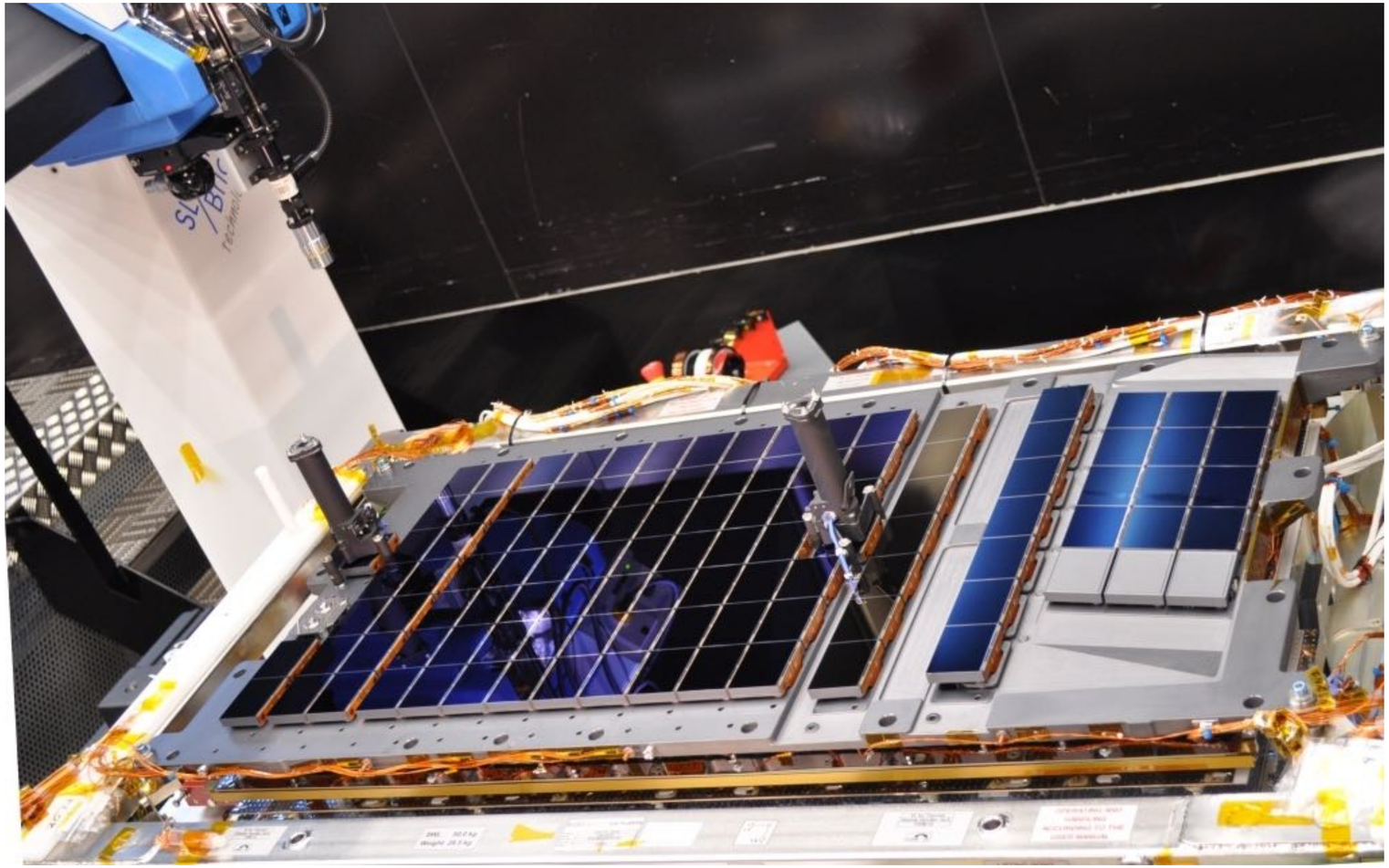
Drift scan

Circulo Meridiano @ Observatório Abrahão de Moraes



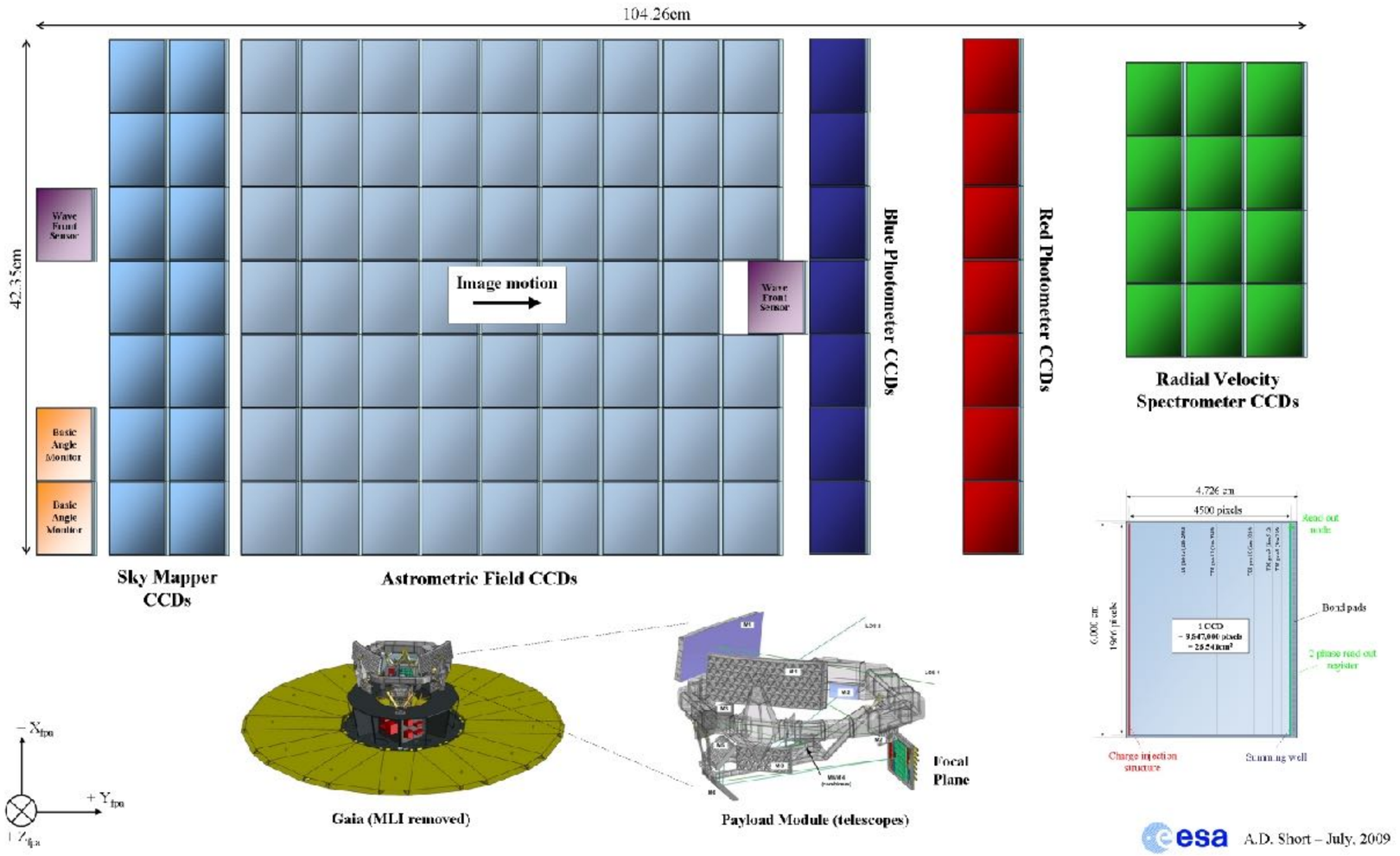
http://www.observatorio.iag.usp.br/index.php/mppesq/mpcirculo.html

Gaia



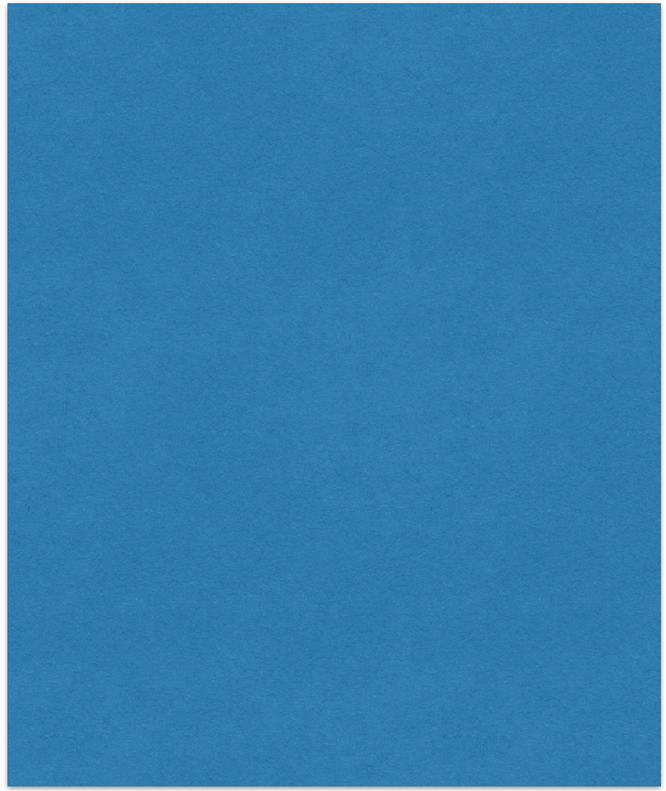
http://blogs.esa.int/gaia/2013/10/09/opening-activating-the-gates-of-gaia/

Gaia


104.26cm
42.35cm
Wave Front Sensor
Basic Angle Monitor
Basic Angle Monitor
Image motion
Wave Front Sensor
Blue Photometer CCDs
Red Photometer CCDs
Radial Velocity Spectrometer CCDs
Sky Mapper CCDs
Astrometric Field CCDs
4.726 cm
4500 pixels
Read out node
6.006 cm
1966 pixels
Bond pads
1 CCD
= 9,847,000 pixels
= 28.24 cm²
2 phase read out register
Charge injection structure
Scanning well
Gaia (MLI removed)
Payload Module (telescopes)
Focal Plane
A.D. Short – July, 2009

Fast Readout

Observing with Windows

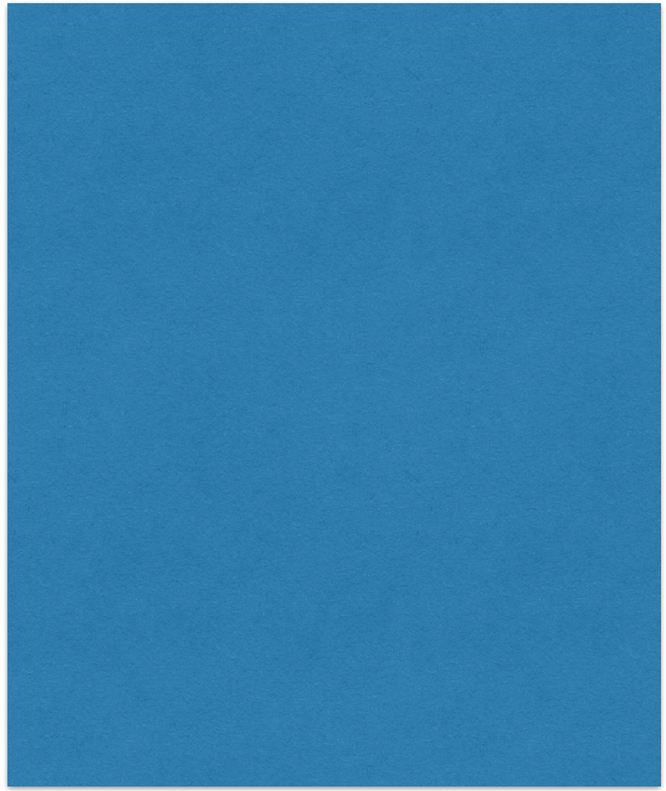


For sake of exercise:

- readout 100kHz
- 1000 pixels in x
- 4000 pixels in y

How long does it take to read the full CCD?

Observing with Windows



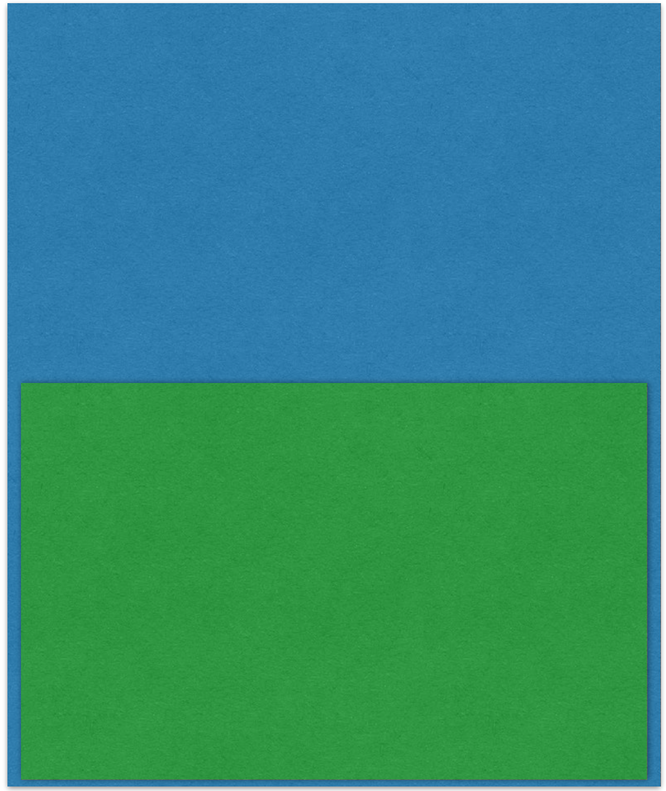
For sake of exercise:

- readout 100kHz
- 1000 pixels in x
- 4000 pixels in y

How long does it take to read the full CCD?

1000 * 4000 / 100 000 Hz = 40s

Observing with Windows

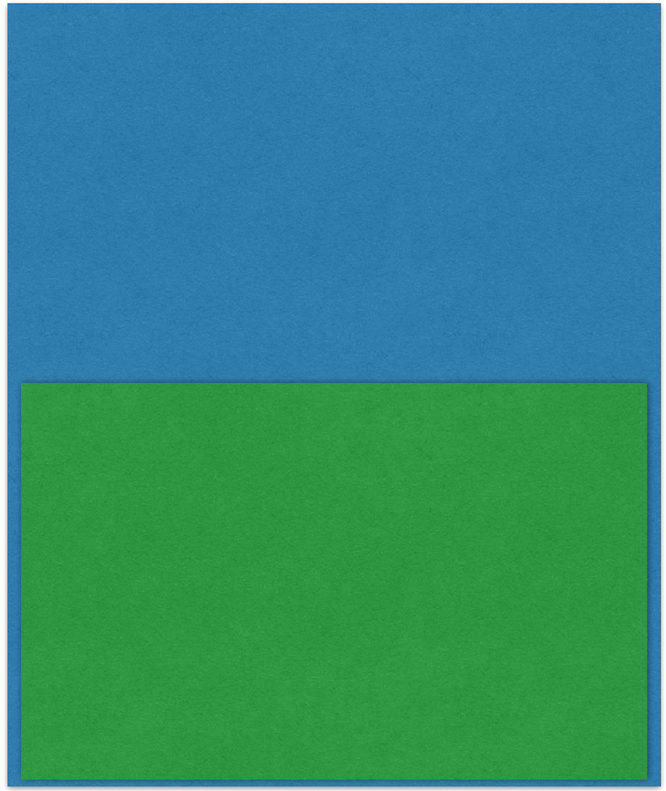


For sake of exercise:

- readout 100kHz
- 1000 pixels in x
- 4000 pixels in y

How long does it take to read half the CCD?

Observing with Windows



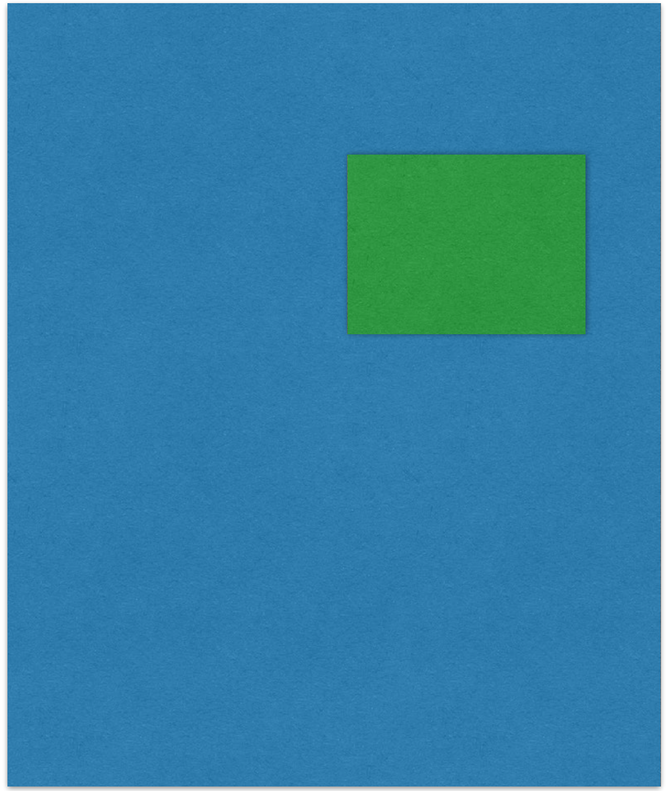
For sake of exercise:

- readout 100kHz
- 1000 pixels in x
- 4000 pixels in y

How long does it take to read half the CCD?

1000 * 2000 / 100 000 Hz = 20s

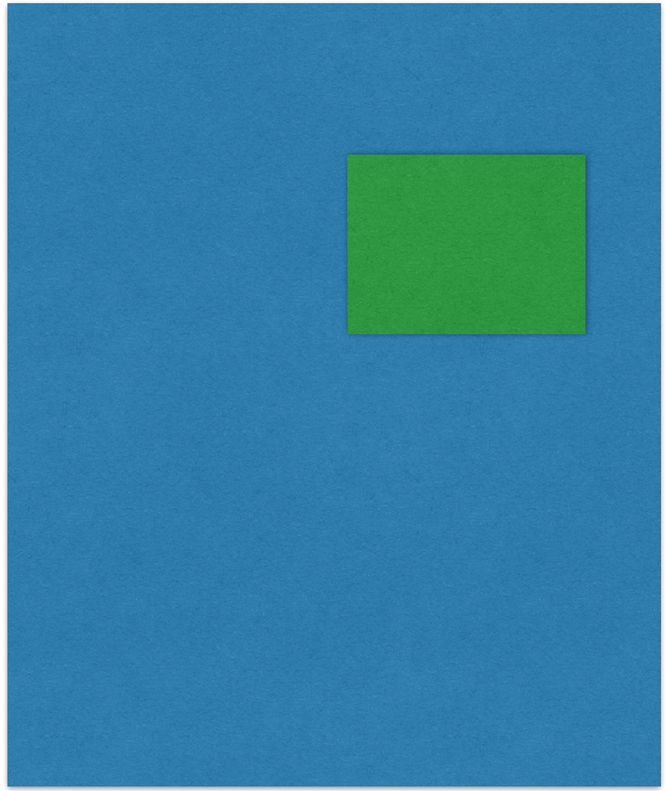
Observing with Windows



What happens if I place a small “region of interest”?
For example with:

- x = 500
- y = 2000
- dx = 10
- dy = 10

Observing with Windows

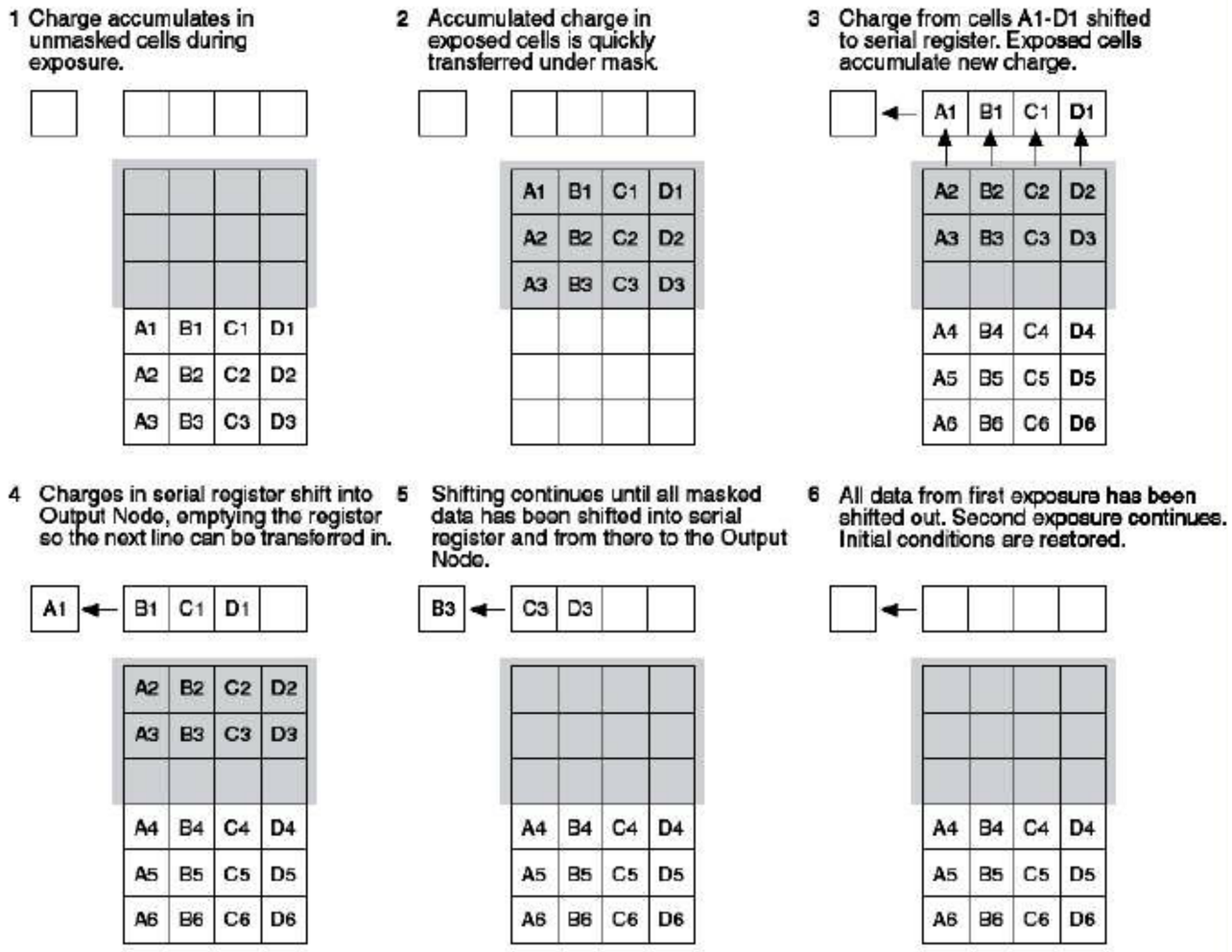


What happens if I place a small “region of interest”?
For example with:

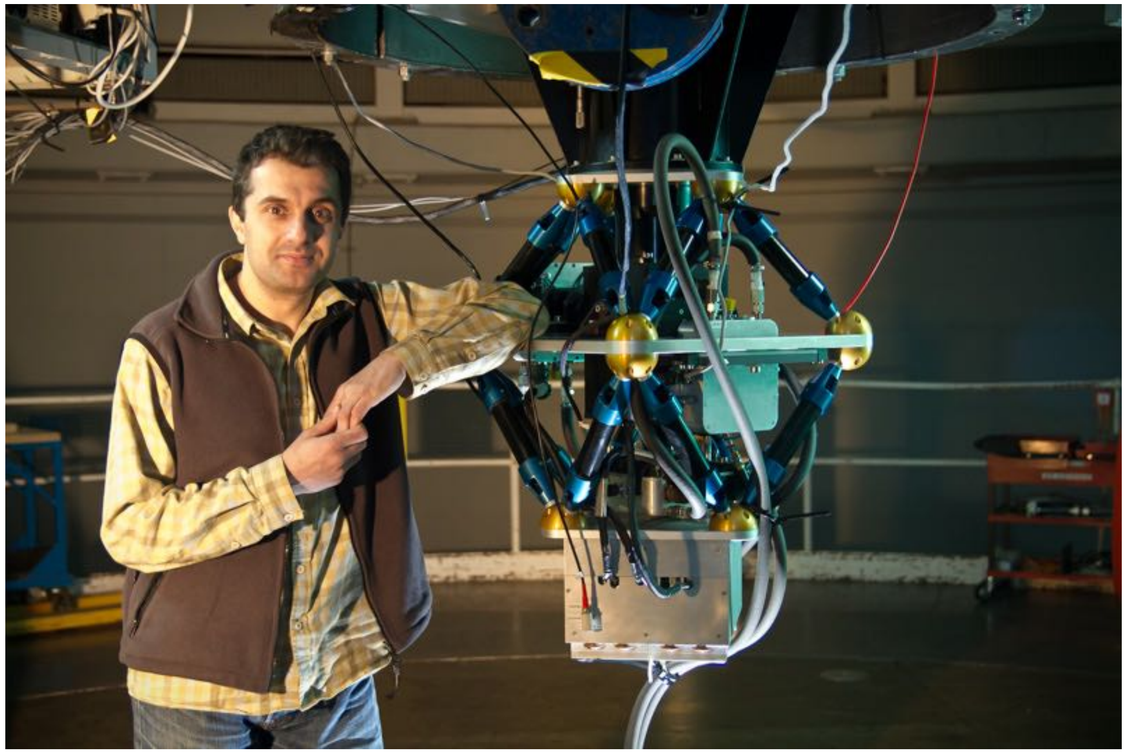
- x = 500
- y = 2000
- dx = 10
- dy = 10

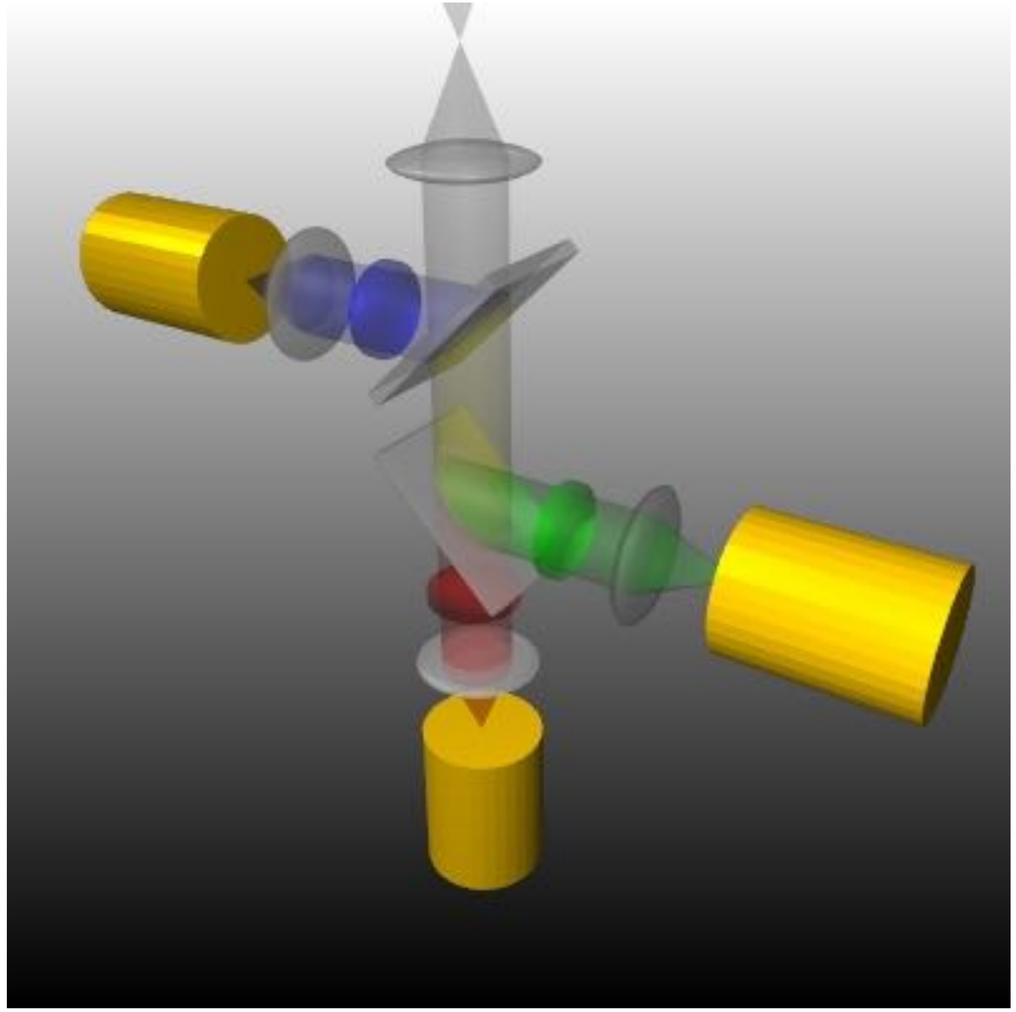
10 * 10 / 100 000 Hz = 0.001s

Frame Transfer CCDs



UltraCam





Dhillon et al. (2007)

EMCCDs

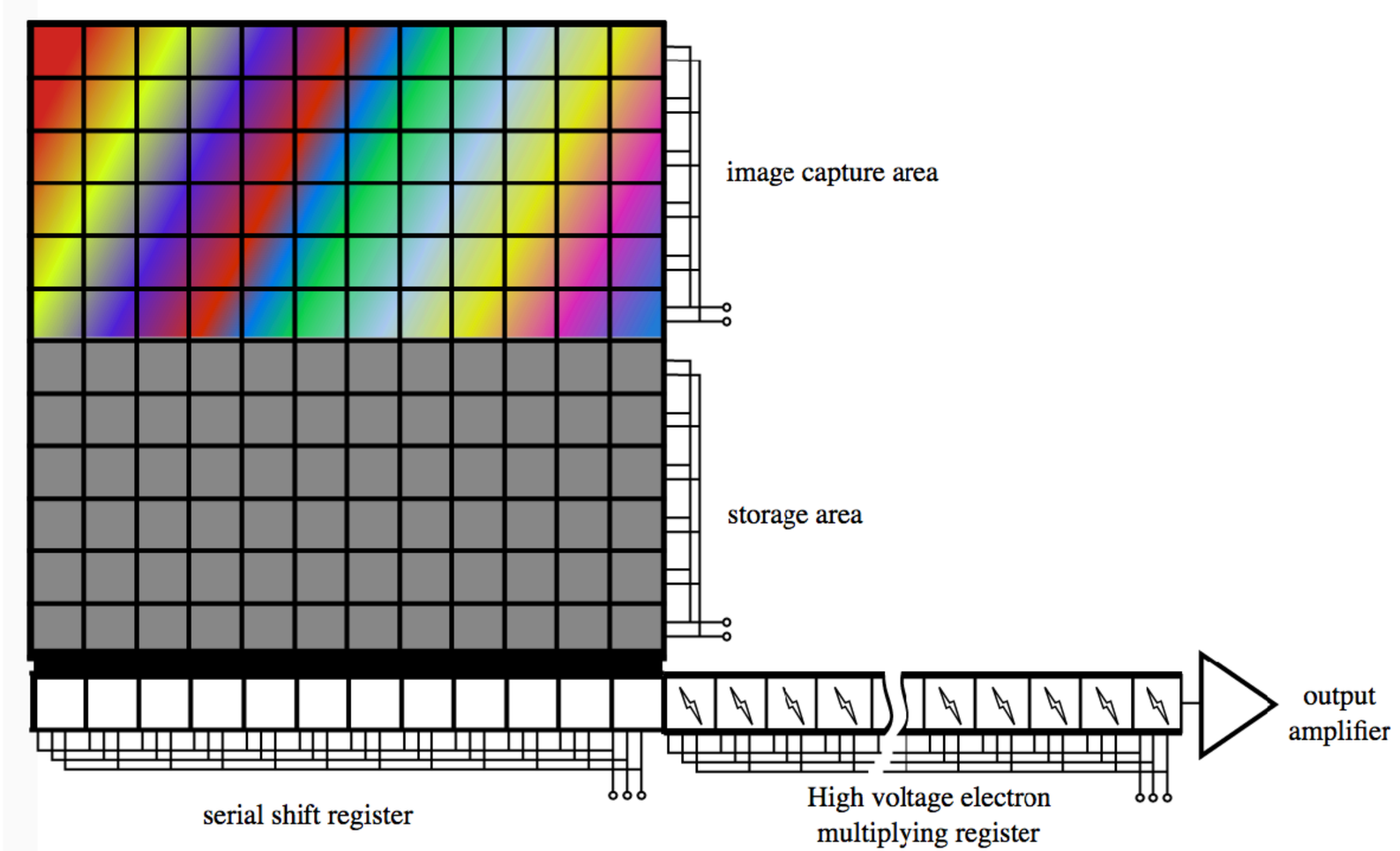
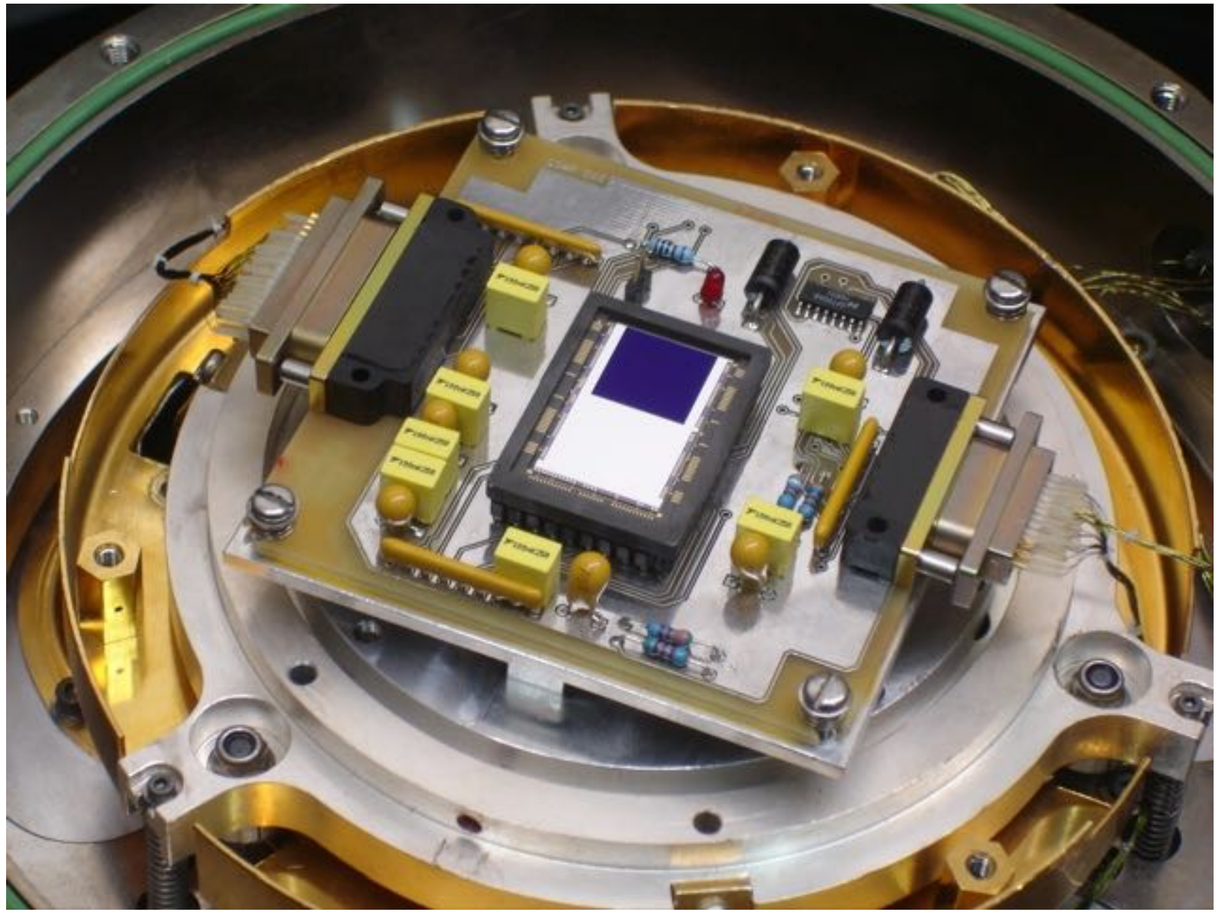


image capture area
storage area
output amplifier
serial shift register
High voltage electron multiplying register

Ultraspec

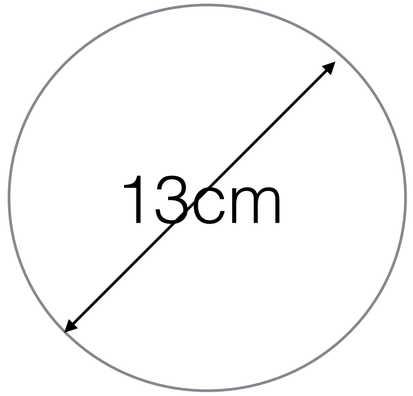


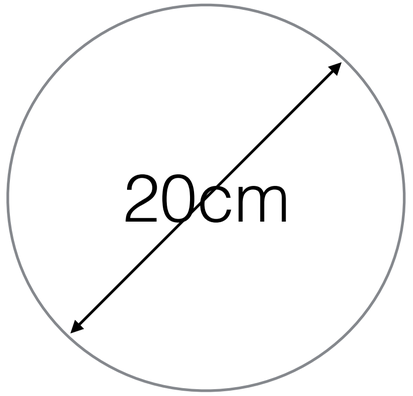
Ives et al. (2008)

Homeworks

Homeworks 1

typical psf ~0.6”



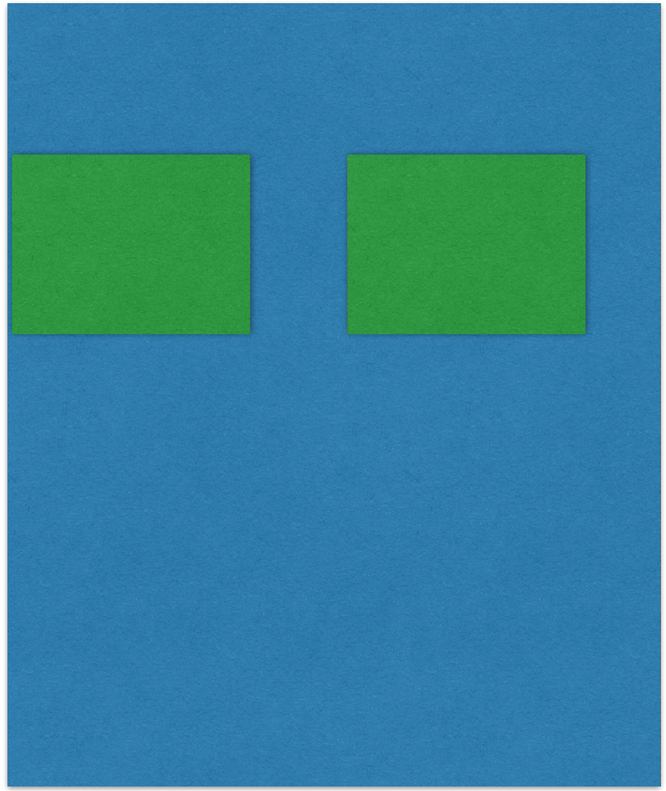


scale = 55.56”/mm

scale =5.41”/mm

n_{pixels} x	n_{pixels} y	pixel size (μm)
2k	4k	13.5
2k	4k	10
9k	9k	10
4k	4k	13.5

Observing with 2 Windows

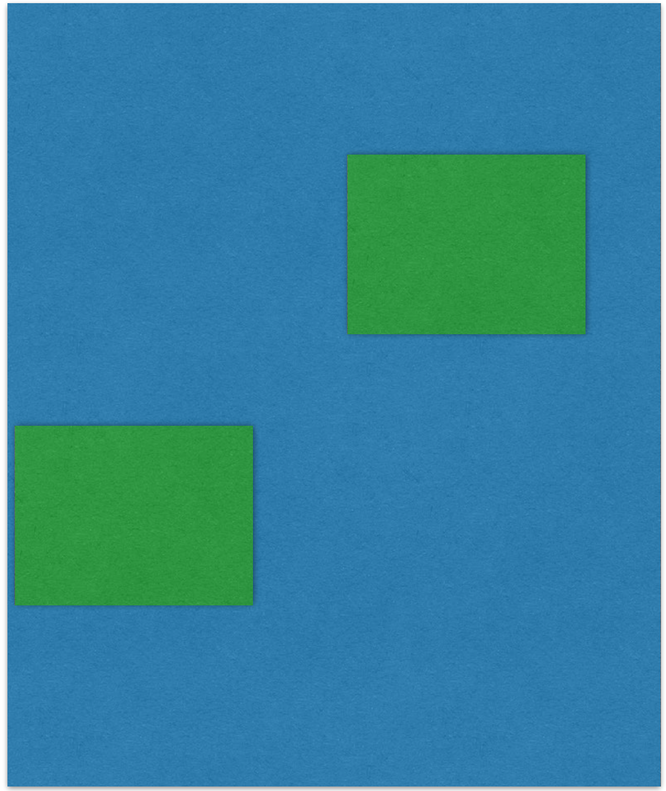


For example with:

- x1 = 500
- y1 = 2000
- dx1 = 10
- dy1 = 10

- x1 = 100
- y1 = 2000
- dx1 = 10
- dy1 = 10

Observing with 2 Windows



For example with:

- x1 = 500
- y1 = 2000
- dx1 = 10
- dy1 = 10

- x1 = 100
- y1 = 1000
- dx1 = 10
- dy1 = 10