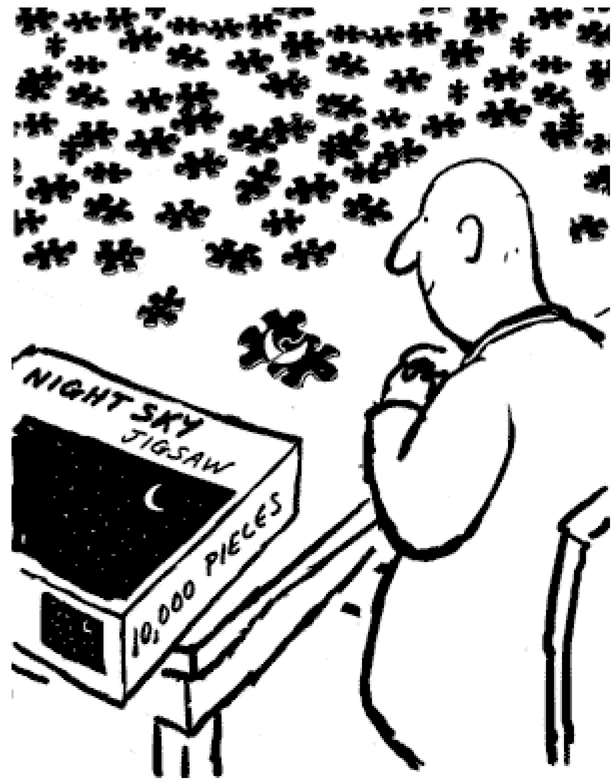
AS750 Observational Astronomy

Prof. Sebastian Lopez
Lecture 10

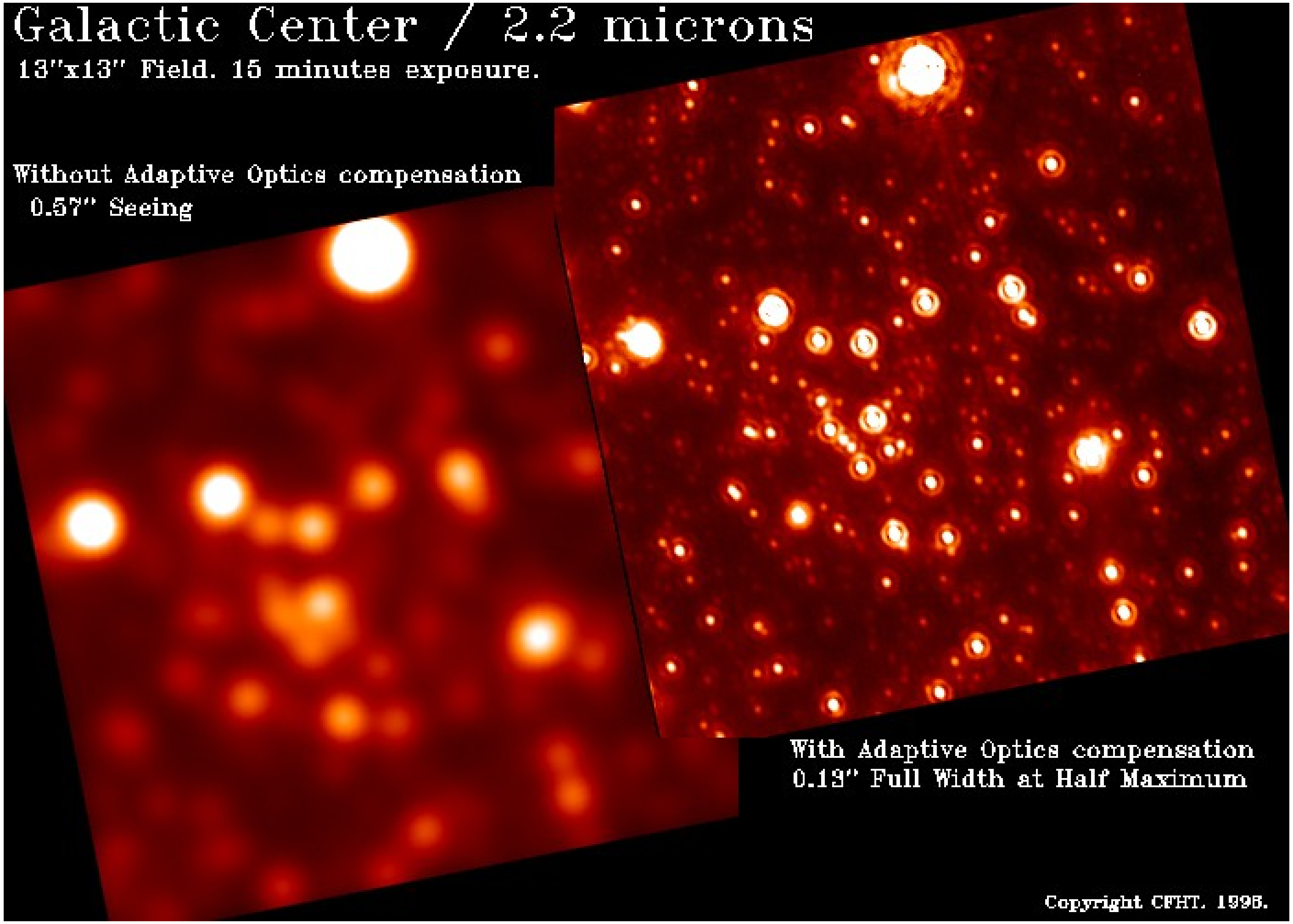
Observational limits



AS750 Observational Astronomy
Prof. Sebastian Lopez

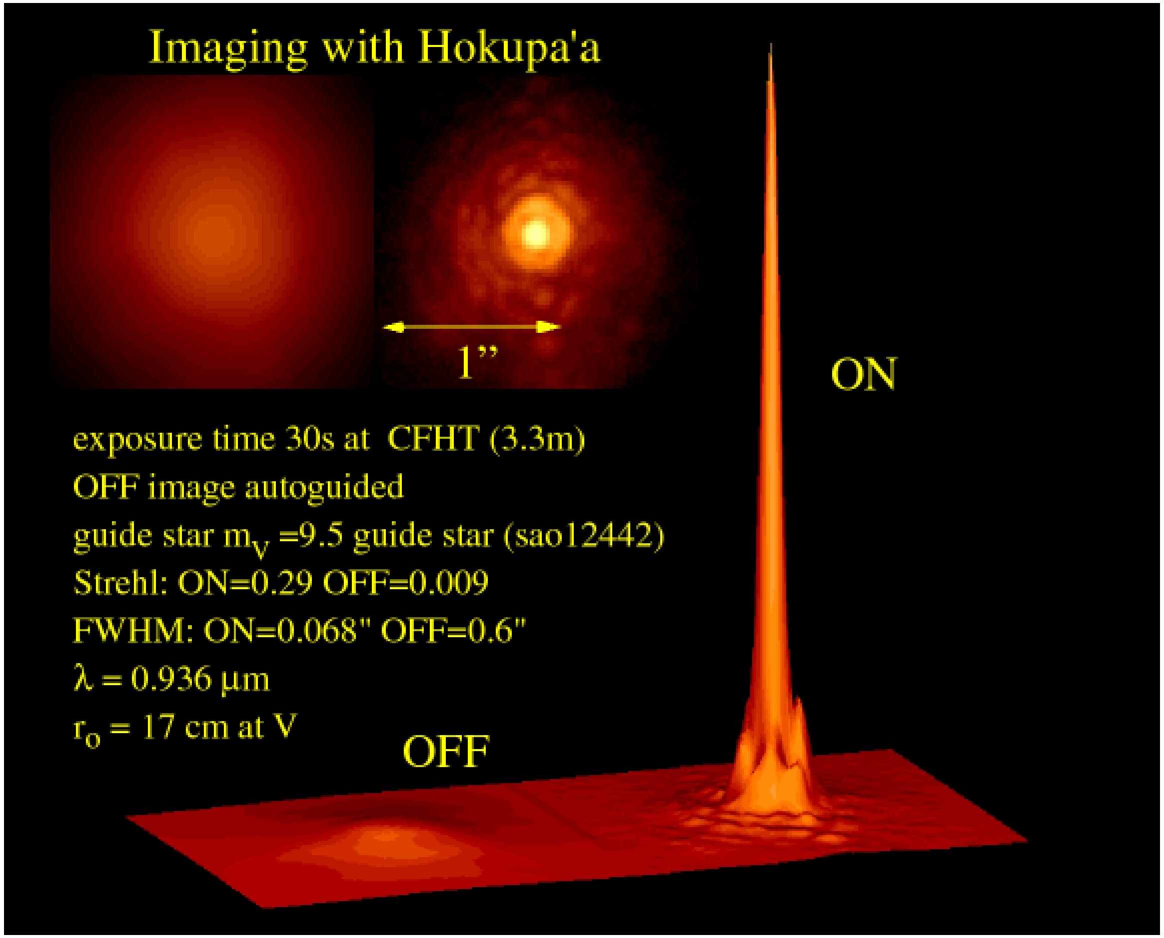
Observational limits

A note on Adaptive Optics



Observational limits

A note on Adaptive Optics



Deformable Mirror

Rear View

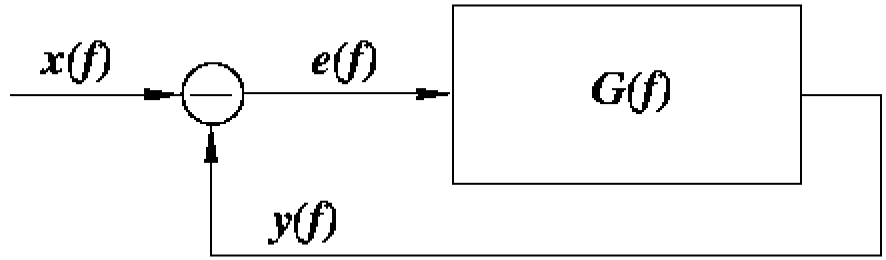
349 Actuators
on 7 mm spacing

Front View

146 mm diameter
clear aperture

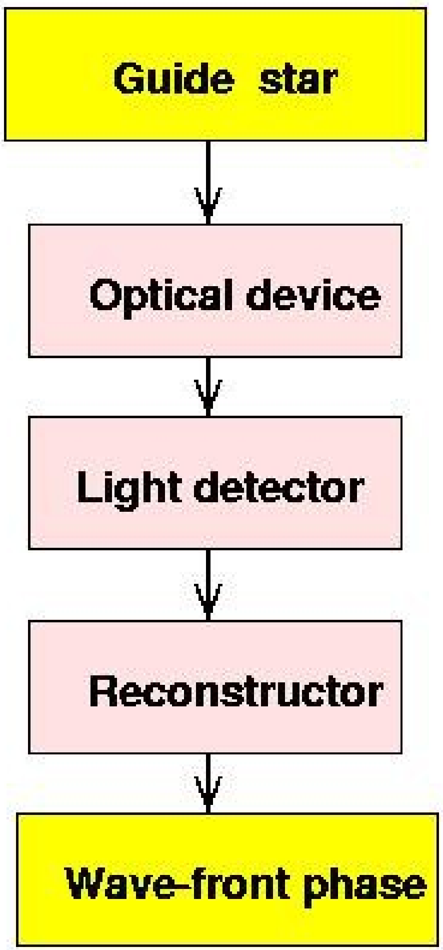
Observational limits

AO loop

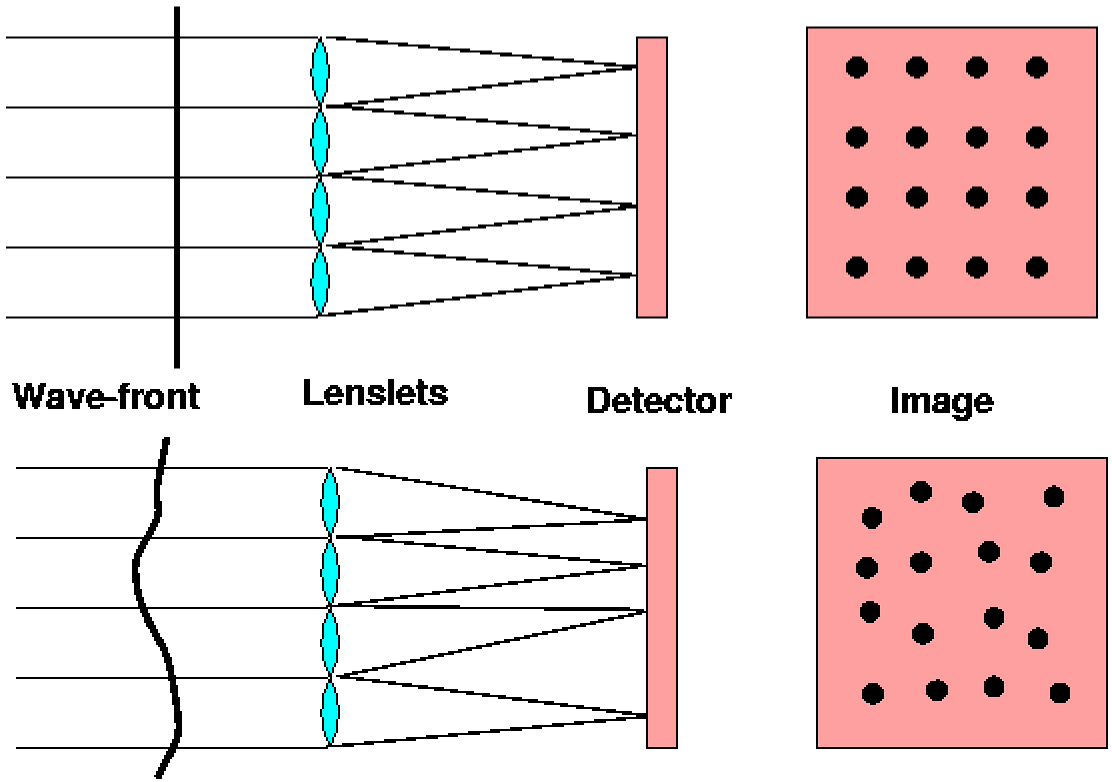


Let be the input signal (e.g. a coefficient of some Zernike mode), - the signal applied to the DM, and - the error signal as measured by the wave-front sensor (WFS). The error signal must be filtered before applying it to DM, otherwise the servo system would be unstable. In the frequency domain this filter is called open-loop transfer function.

Observational limits

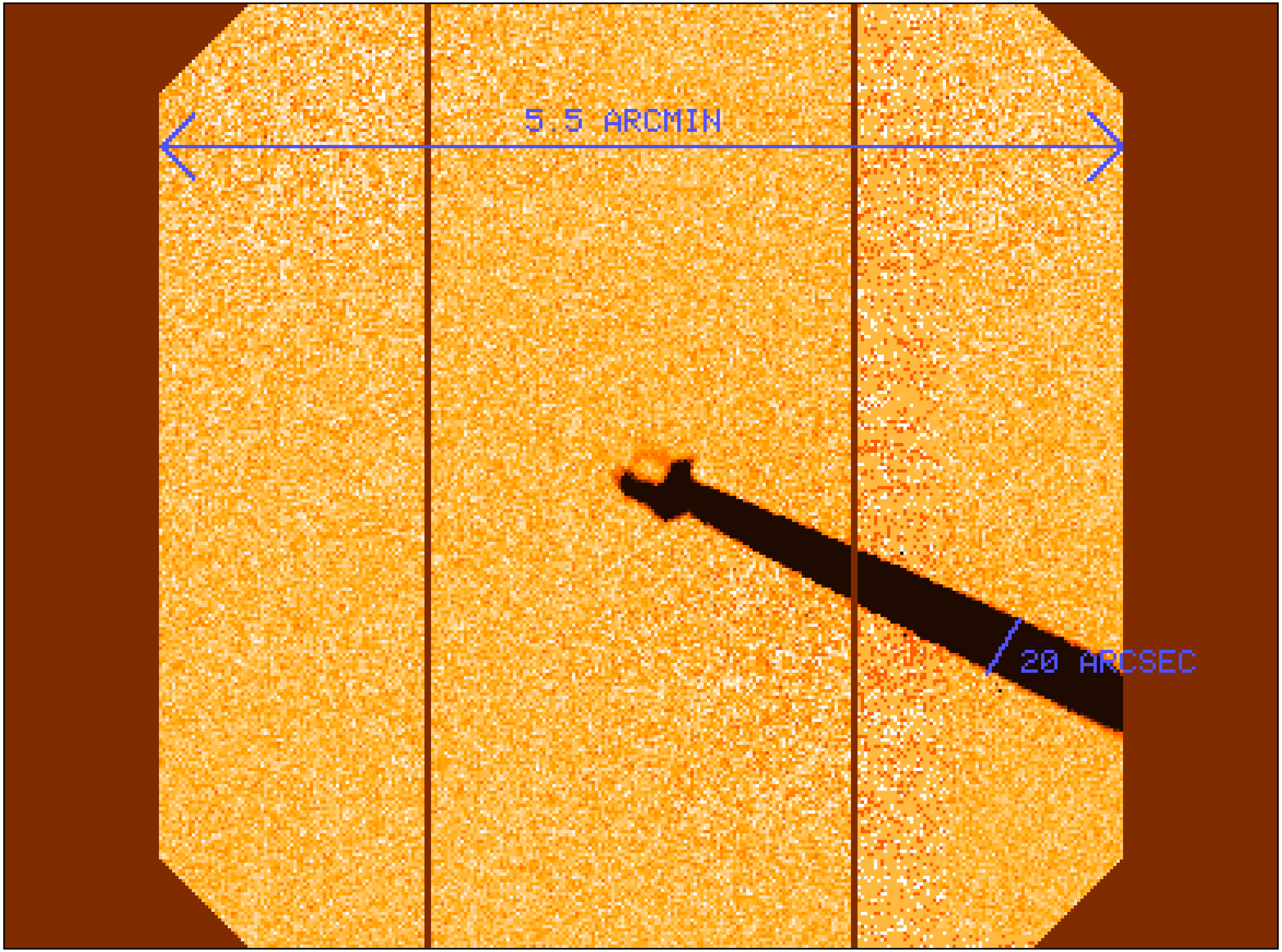


Shack-Hartmann WFS



Observational limits

Natural guide stars

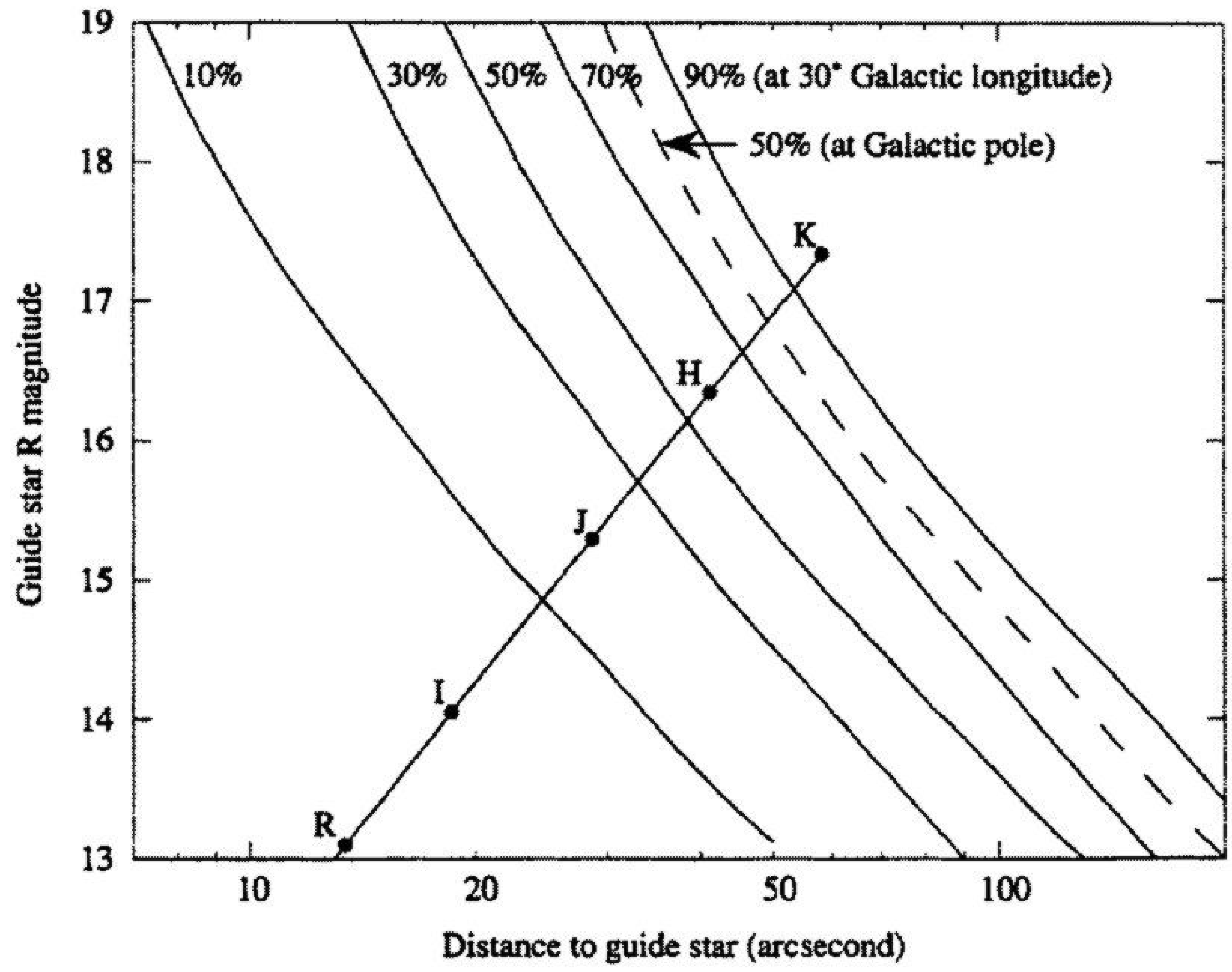


Gemini/
GMOS

Observational limits

Why artificial?
Sky coverage too low using just NGSs.

Image spectral band	R	I	J	H	K
Wavelength (for imaging)	0.65	0.85	1.22	1.65	2.2
Maximum guide star mag (at 0.63 μm)	13.1	14.0	15.2	16.3	17.3
Maximum angular distance (arcsec)	13.4	18.6	28.6	41.1	58.1



Observational limits

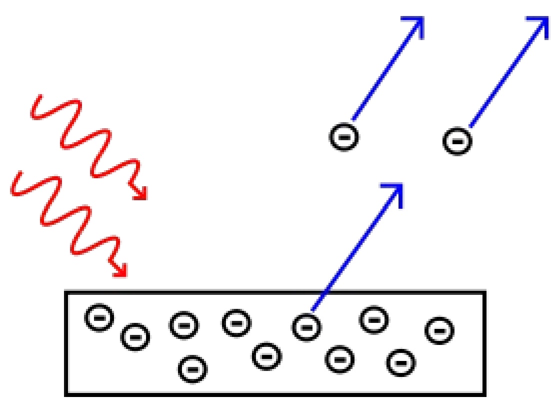
Artificial guide stars

Why artificial?
Sky coverage too
low using just NGSs.

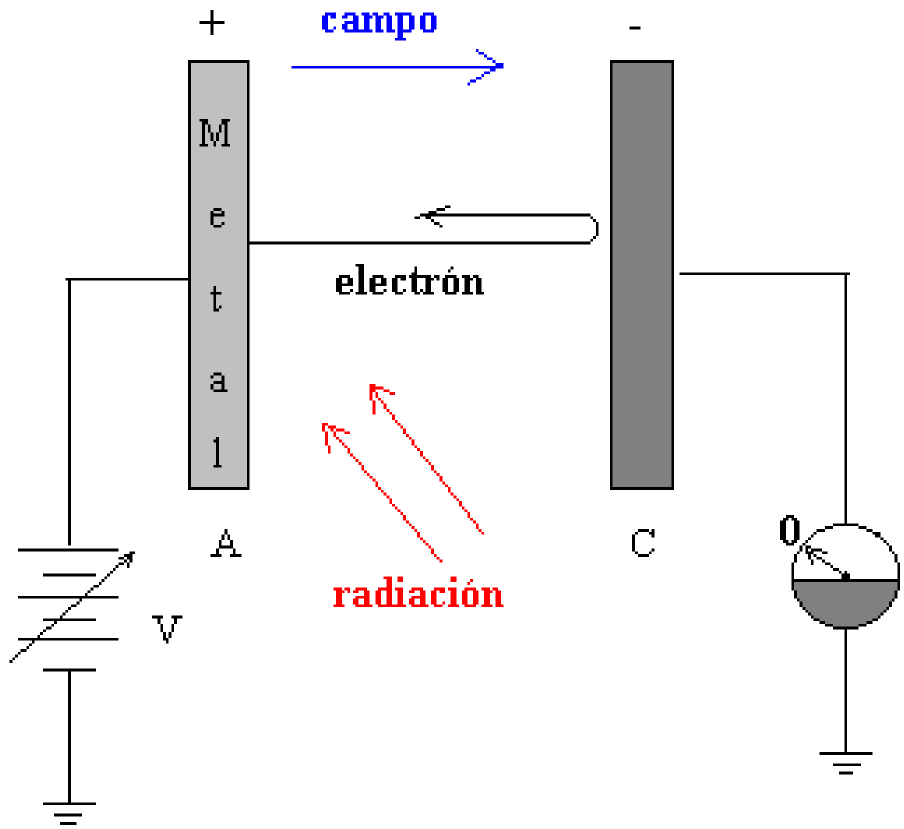
A

Charge Coupled Devices (CCDs)

Photoelectric effect (Einstein, Nobel prize in 1905)

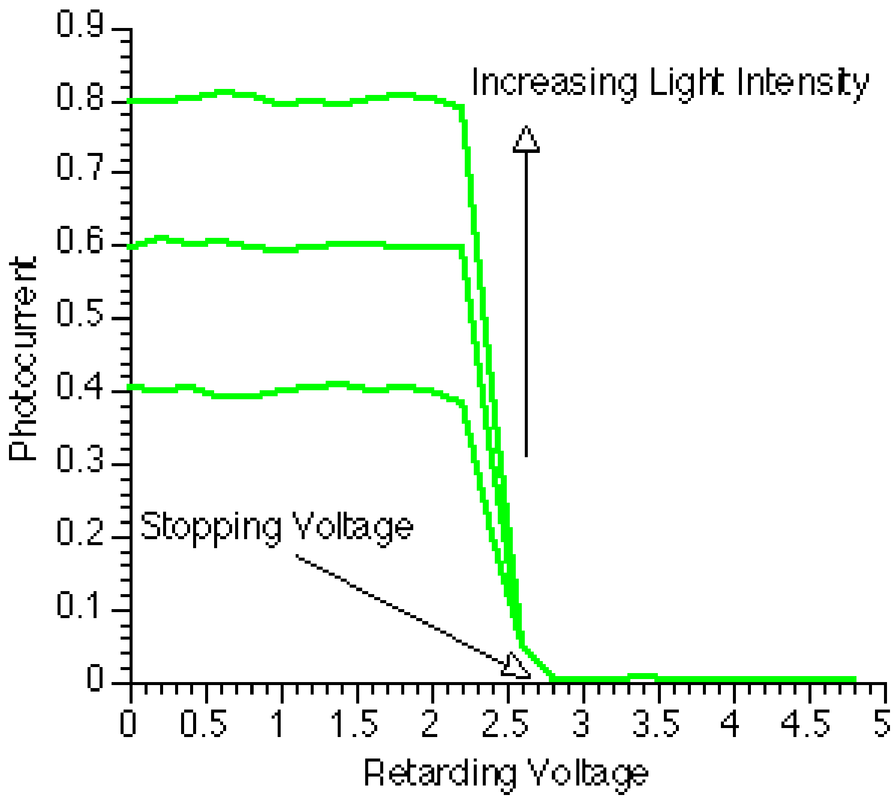


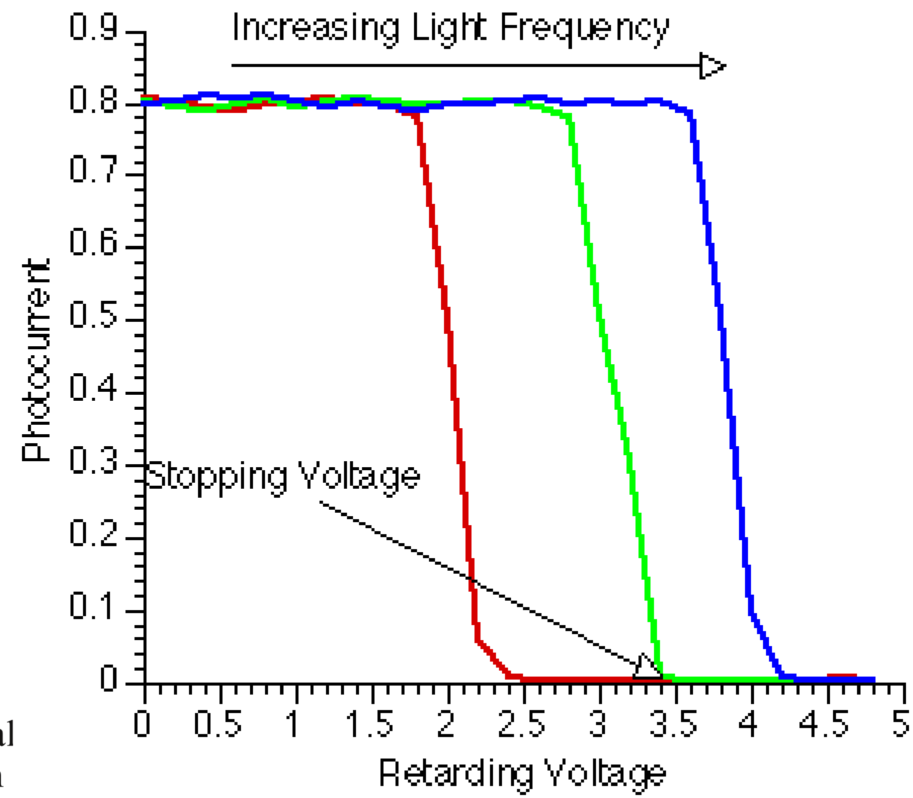
Charge Coupled Devices (CCDs)



Charge Coupled Devices (CCDs)

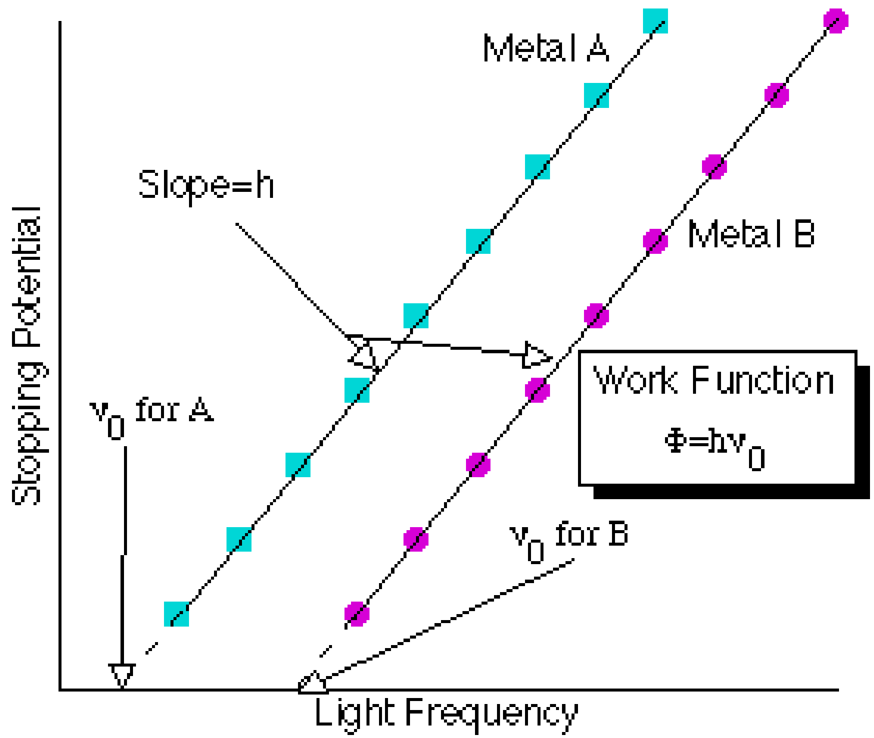
Cannot be explained using waves





Charge Coupled Devices (CCDs)

$$K = h\nu - W$$

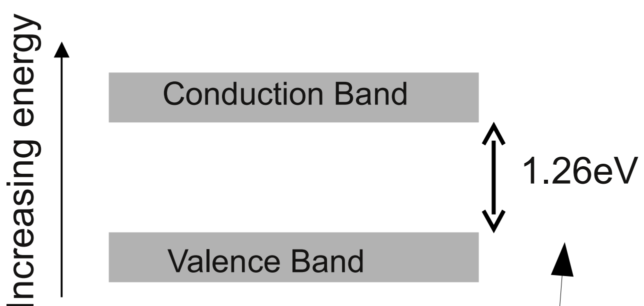


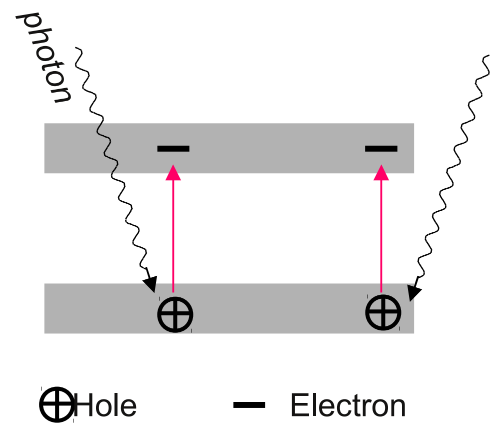
Charge Coupled Devices (CCDs)

$$K = h\nu - W$$

Element	Work Function(eV)
Aluminum	4.08
Beryllium	5.0
Cadmium	4.07
Calcium	2.9
Carbon	4.81
Cesium	2.1
Cobalt	5.0
Copper	4.7
Gold	5.1
Iron	4.5
Lead	4.14
Magnesium	3.68
Mercury	4.5
Nickel	5.01

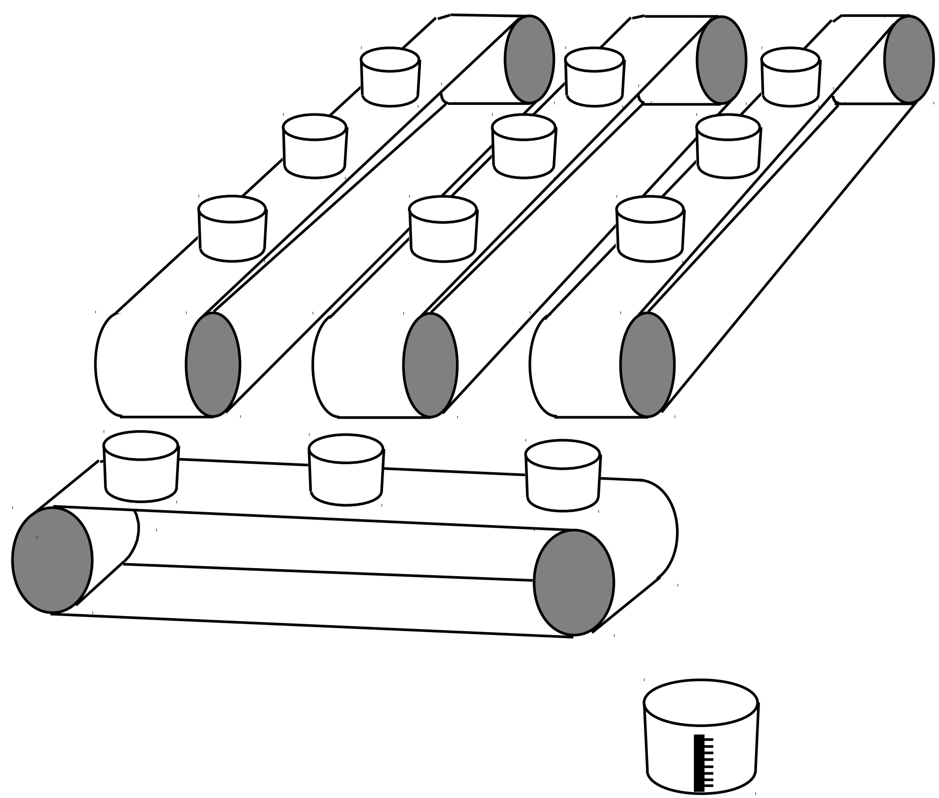
Charge Coupled Devices (CCDs)



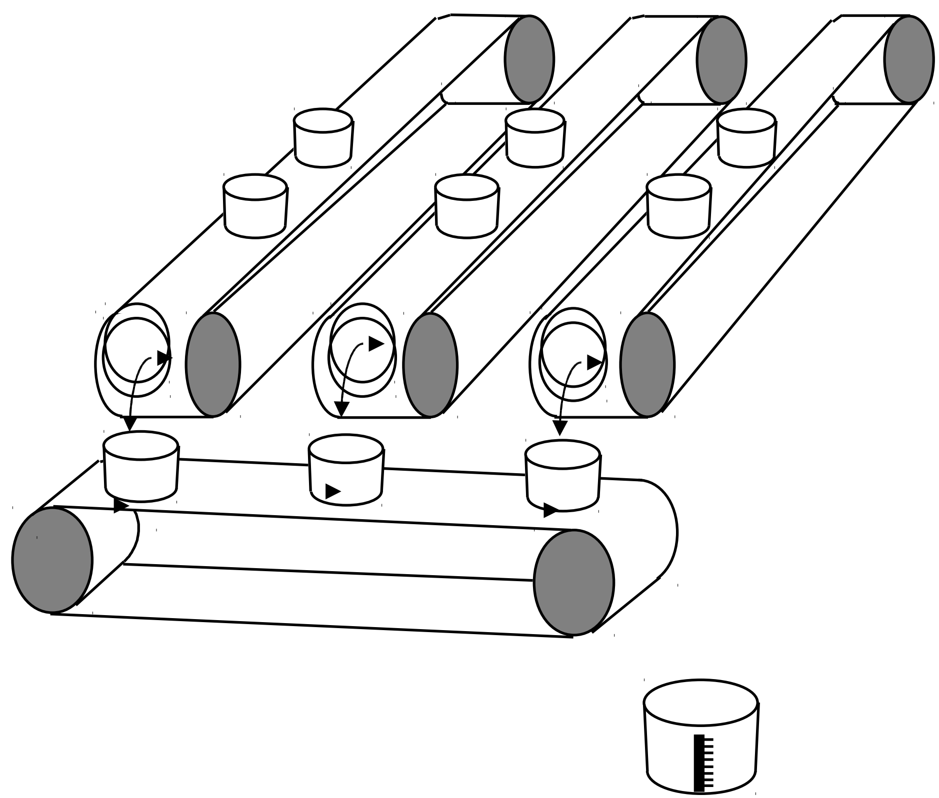


1 micron

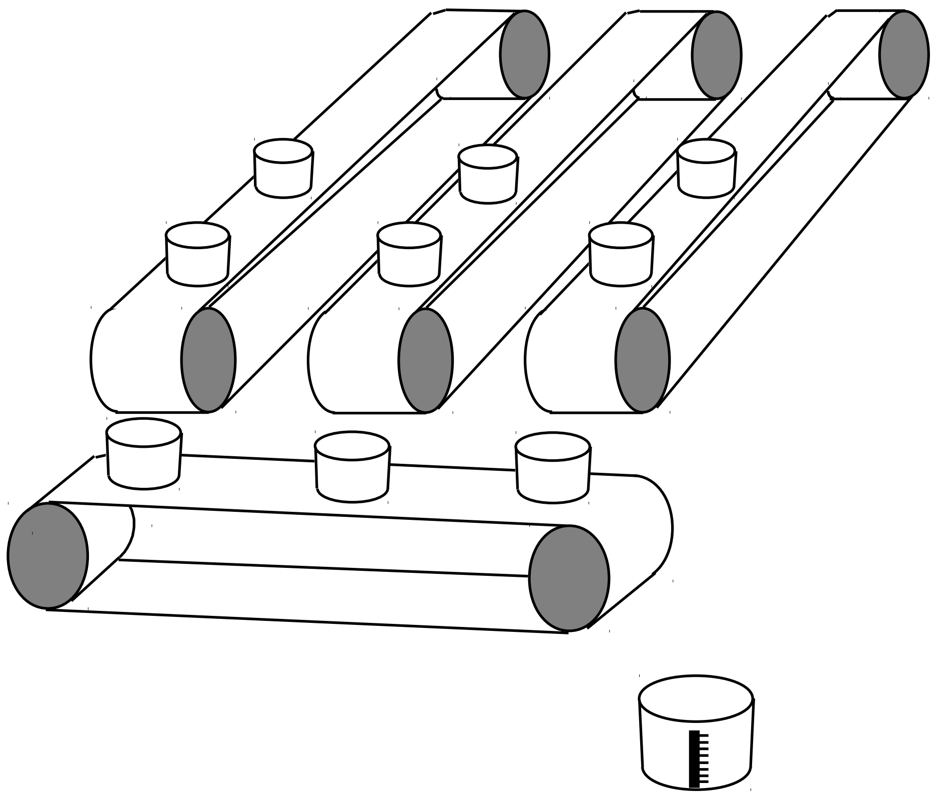
Exposure finished, buckets now contain samples of rain.



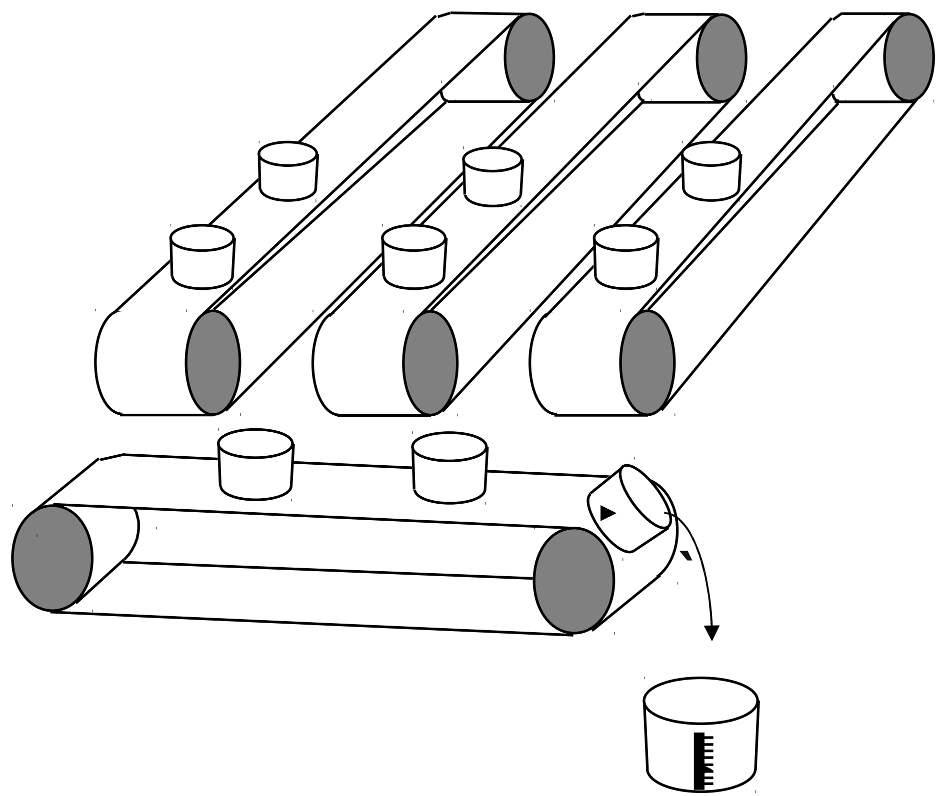
Conveyor belt starts turning and transfers buckets. Rain collected on the vertical conveyor is tipped into buckets on the horizontal conveyor.

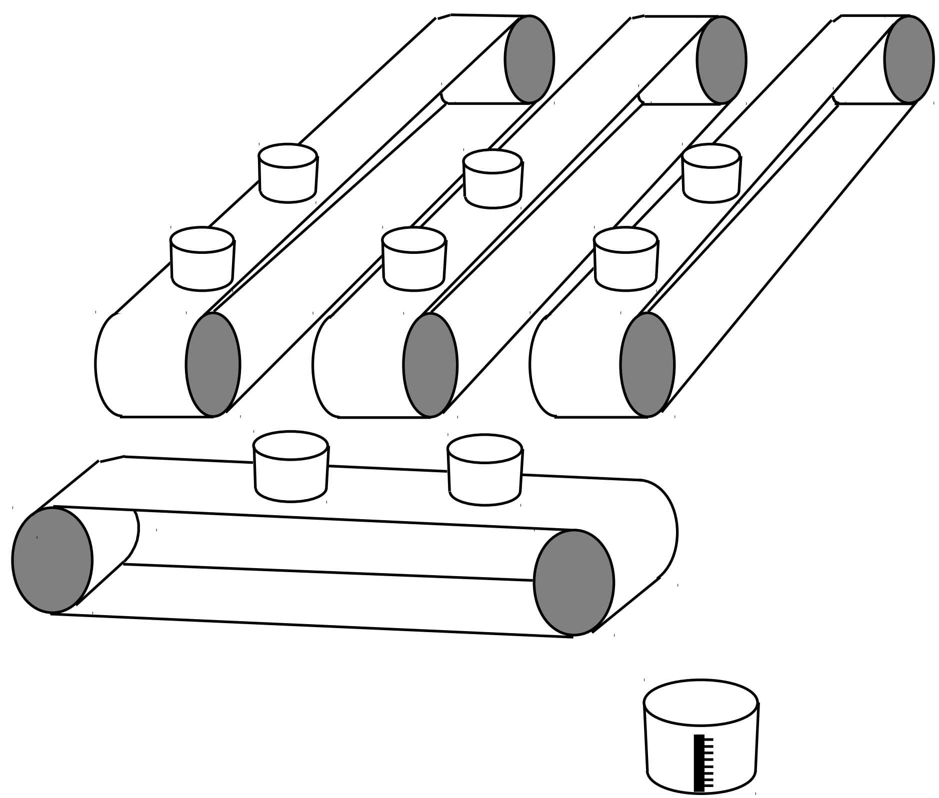


Vertical conveyor stops. Horizontal conveyor starts up and tips each bucket in turn into the measuring cylinder .

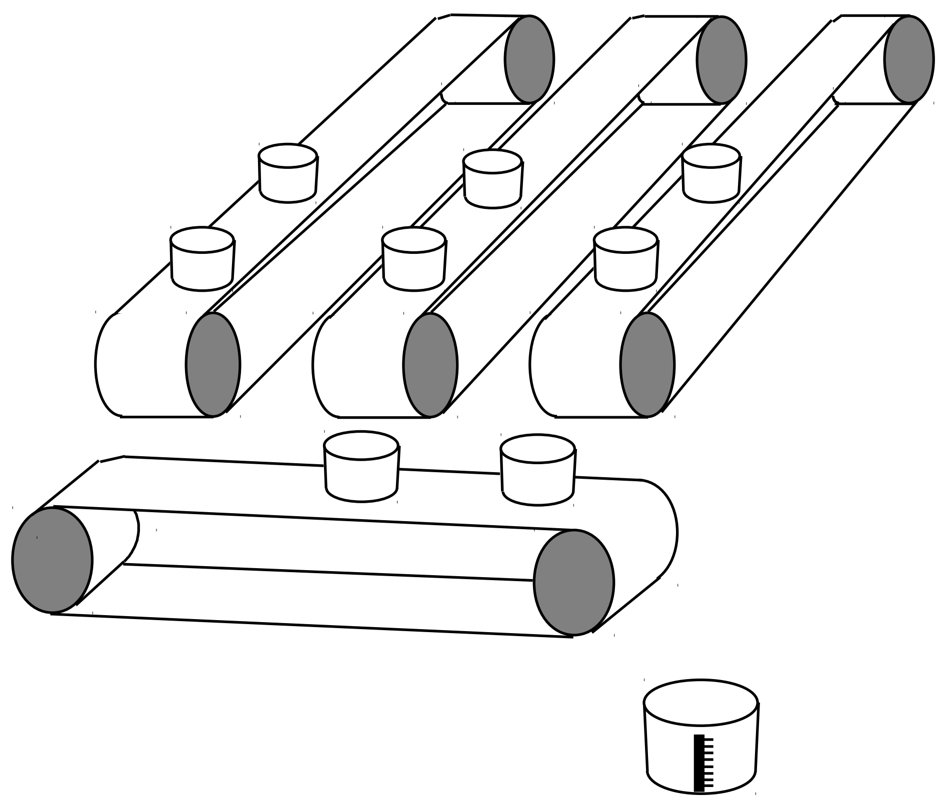


After each bucket has been measured, the measuring cylinder is emptied , ready for the next bucket load.

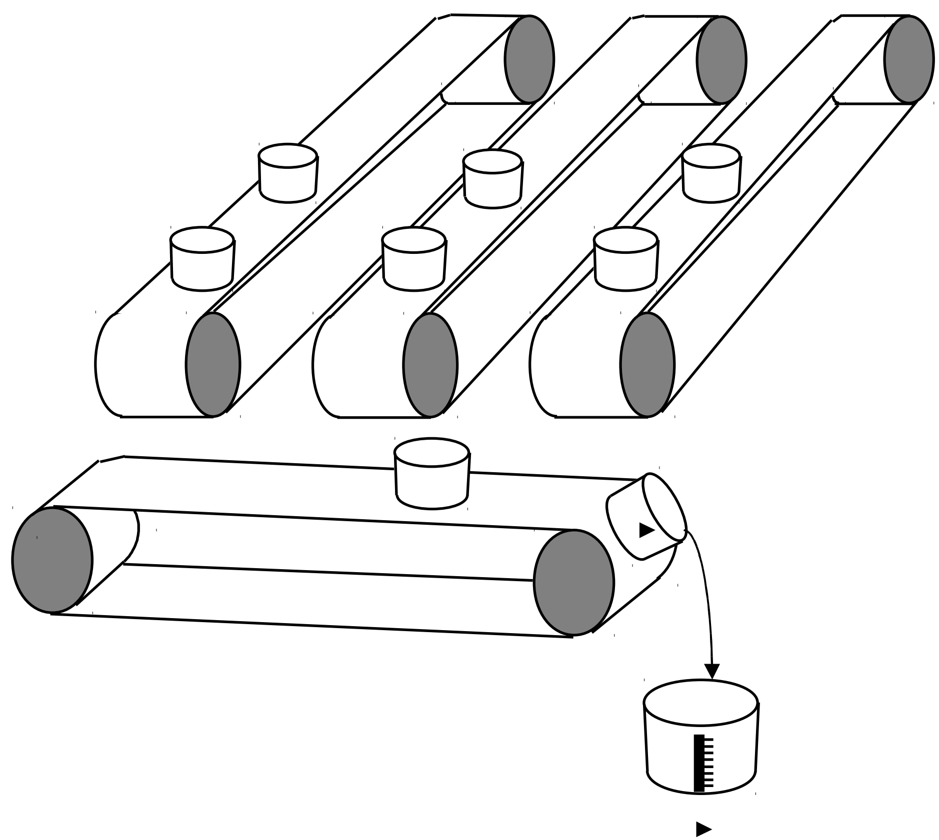




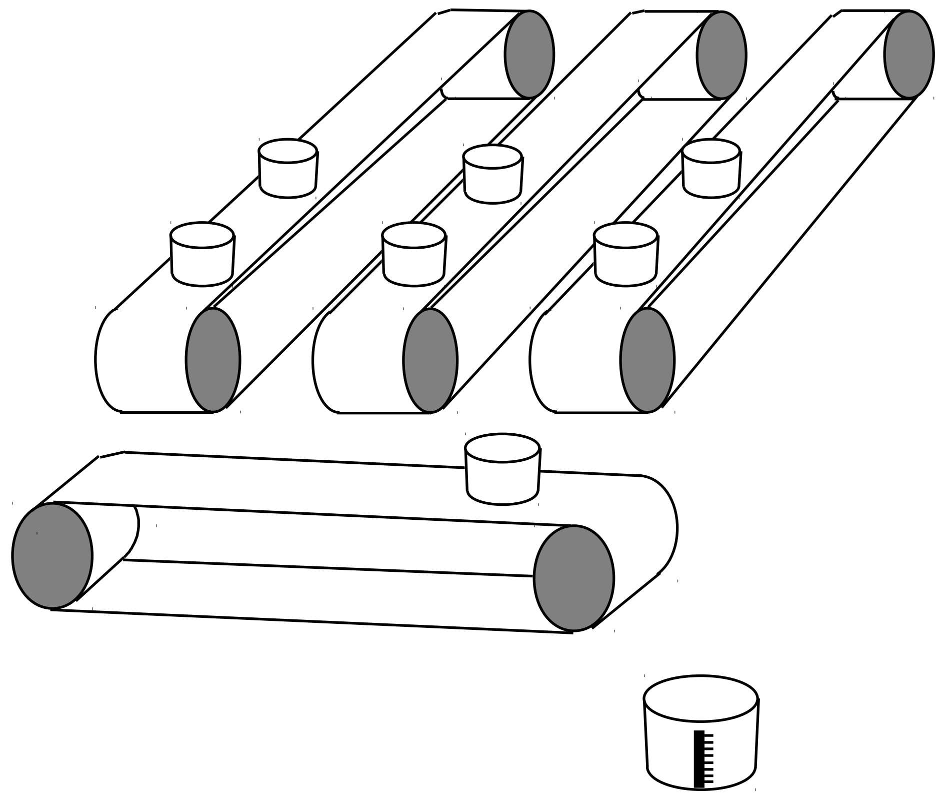
AS750 Observational Astronomy
Prof. Sebastian Lopez



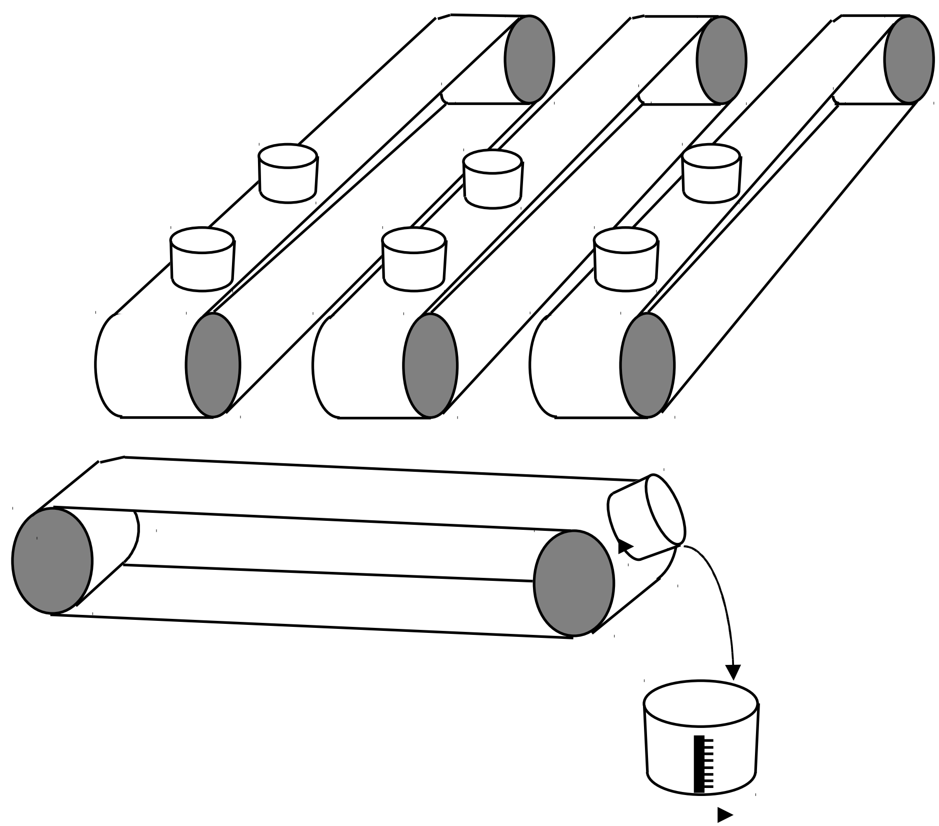
AS750 Observational Astronomy
Prof. Sebastian Lopez



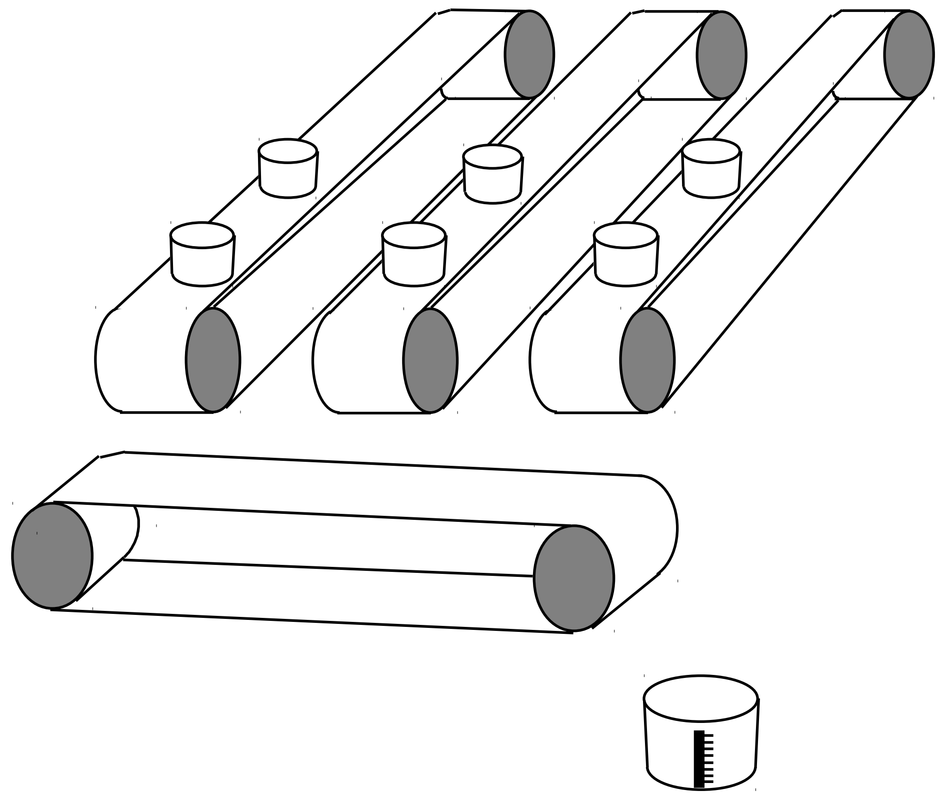
AS750 Observational Astronomy
Prof. Sebastian Lopez



AS750 Observational Astronomy
Prof. Sebastian Lopez

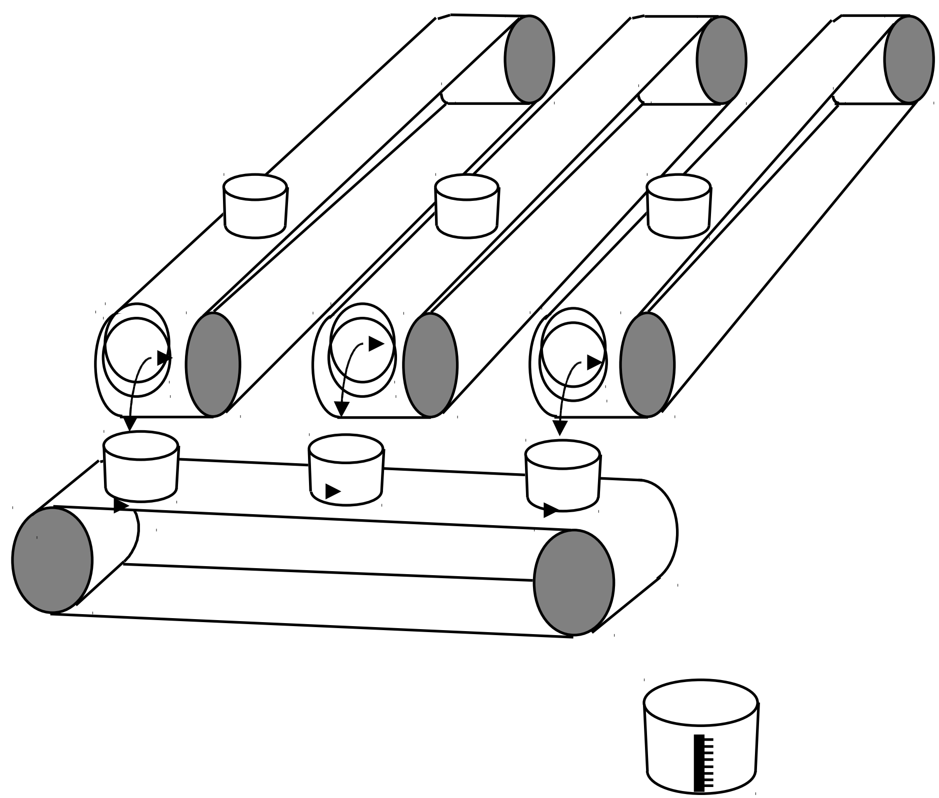


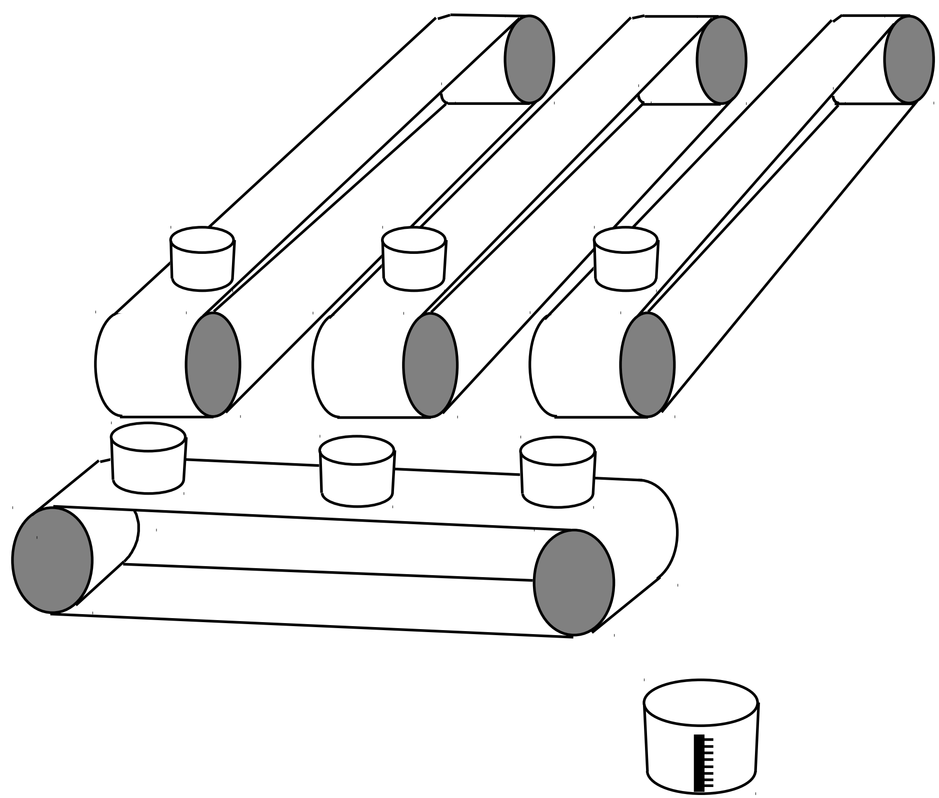
AS750 Observational Astronomy
Prof. Sebastian Lopez



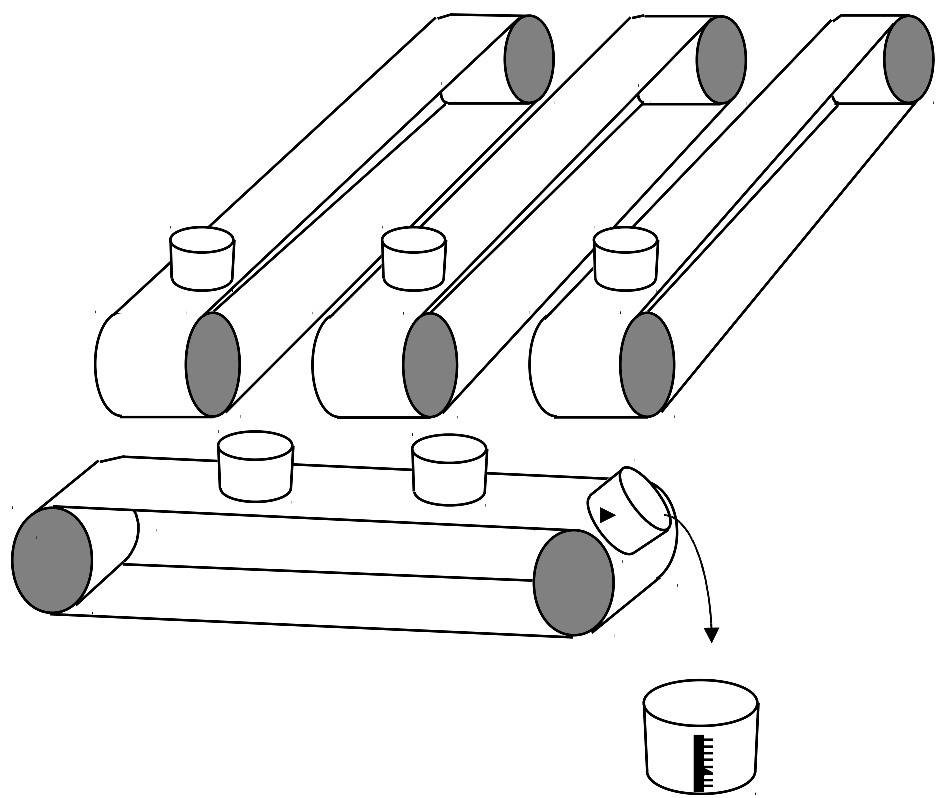
AS750 Observational Astronomy
Prof. Sebastian Lopez

A new set of empty buckets is set up on the horizontal conveyor and the process is repeated.

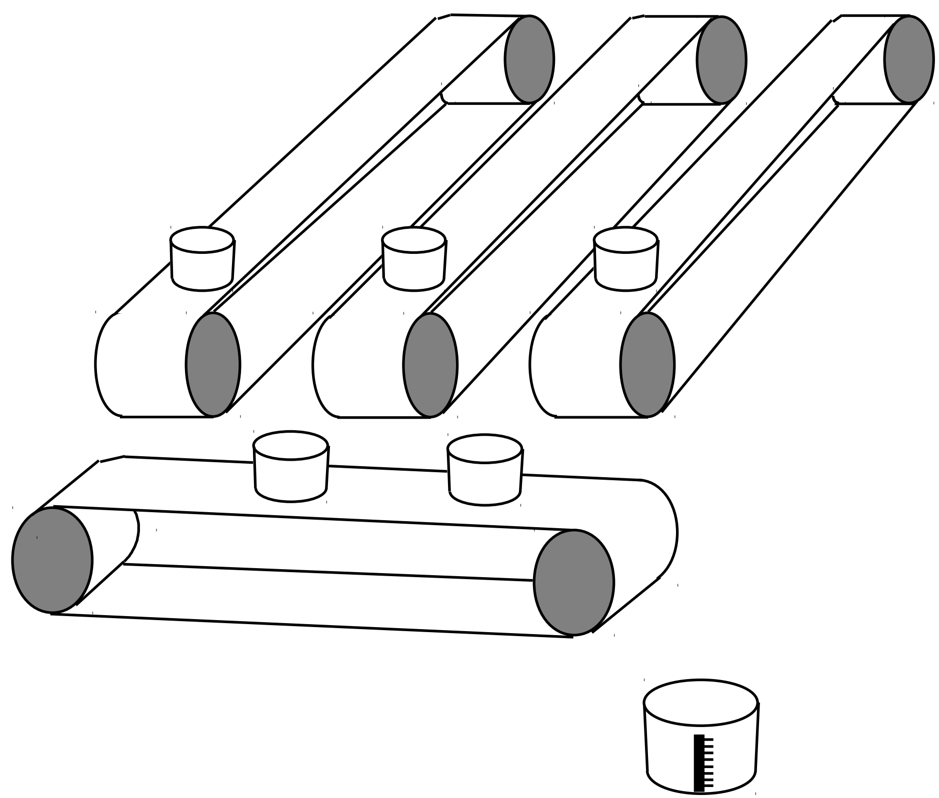




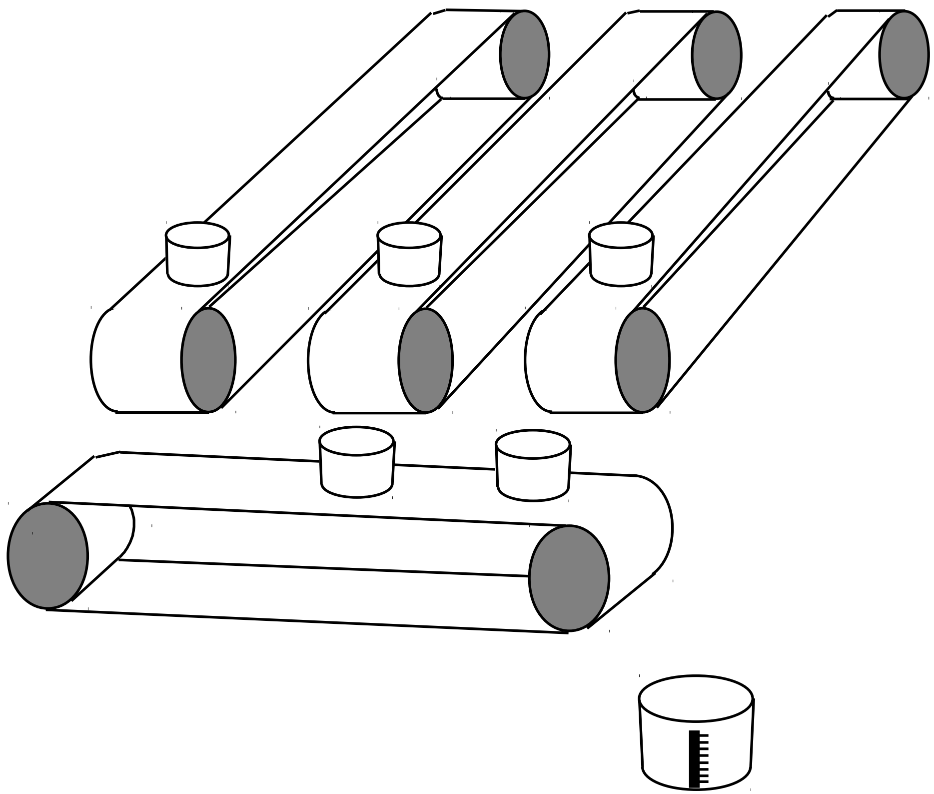
AS750 Observational Astronomy
Prof. Sebastian Lopez



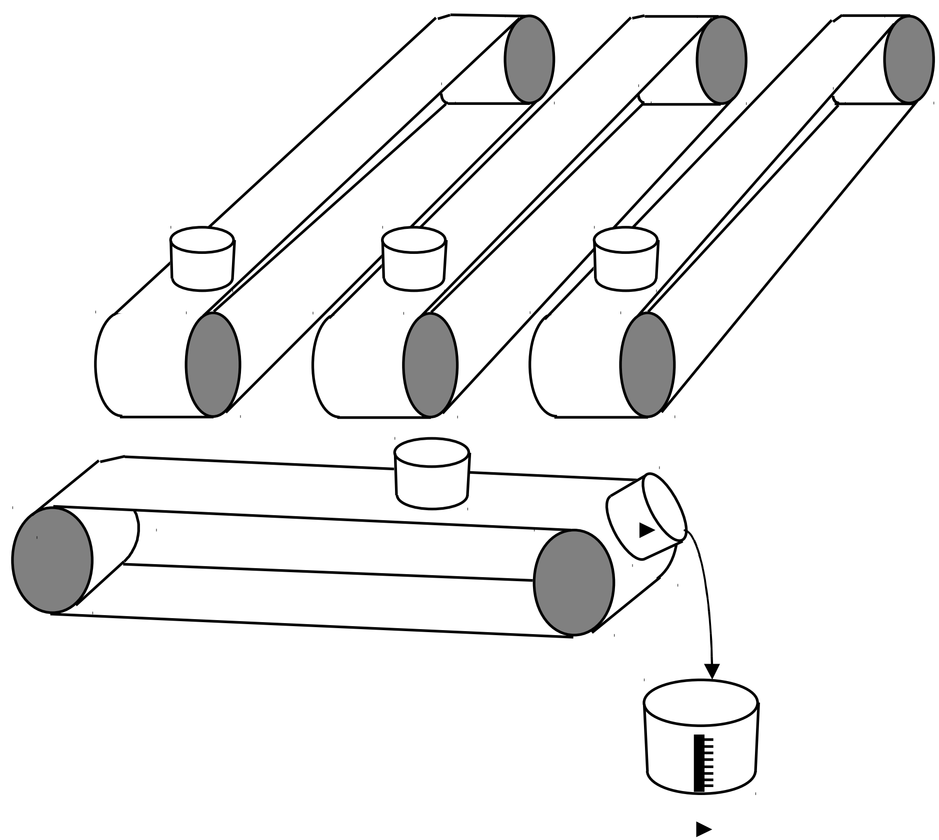
AS750 Observational Astronomy
Prof. Sebastian Lopez



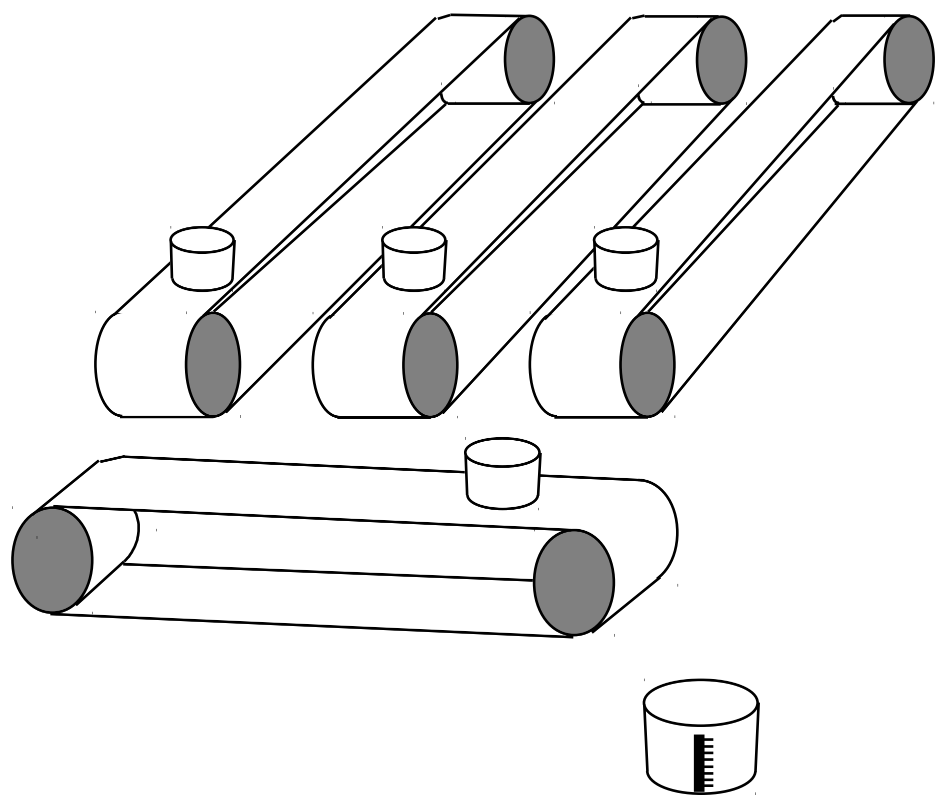
AS750 Observational Astronomy
Prof. Sebastian Lopez



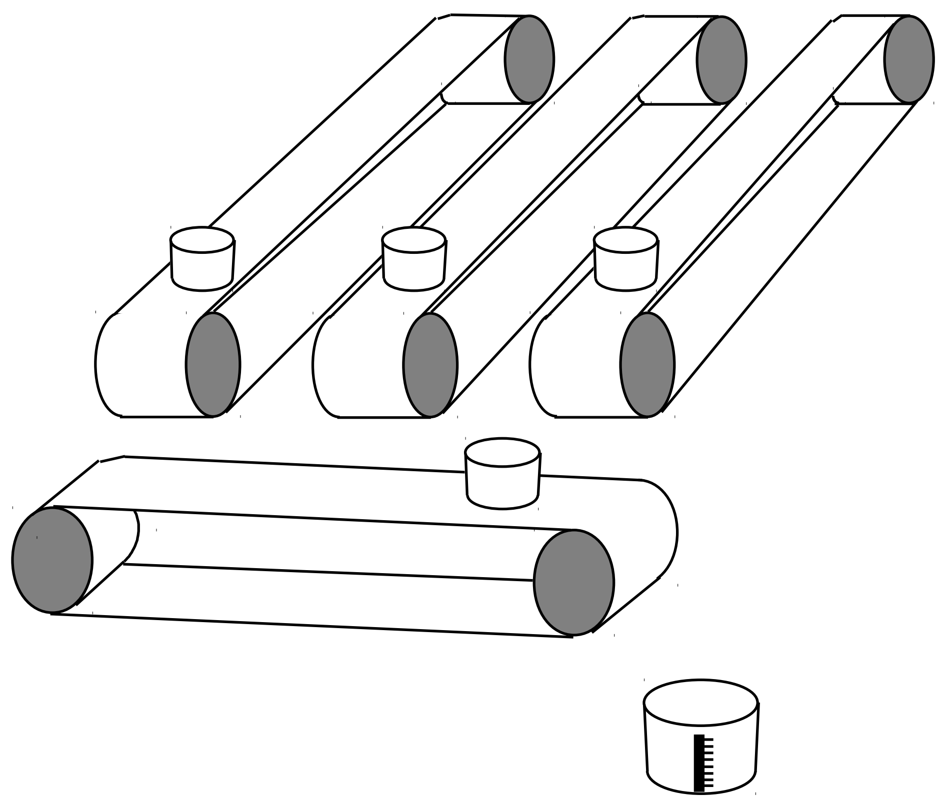
AS750 Observational Astronomy
Prof. Sebastian Lopez



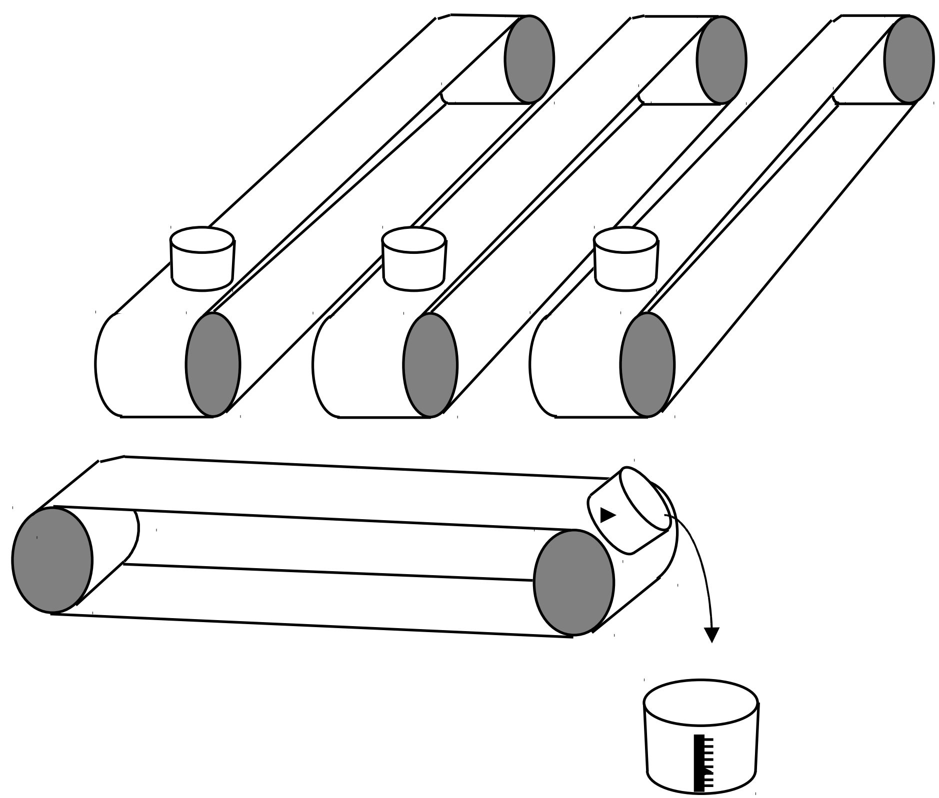
AS750 Observational Astronomy
Prof. Sebastian Lopez



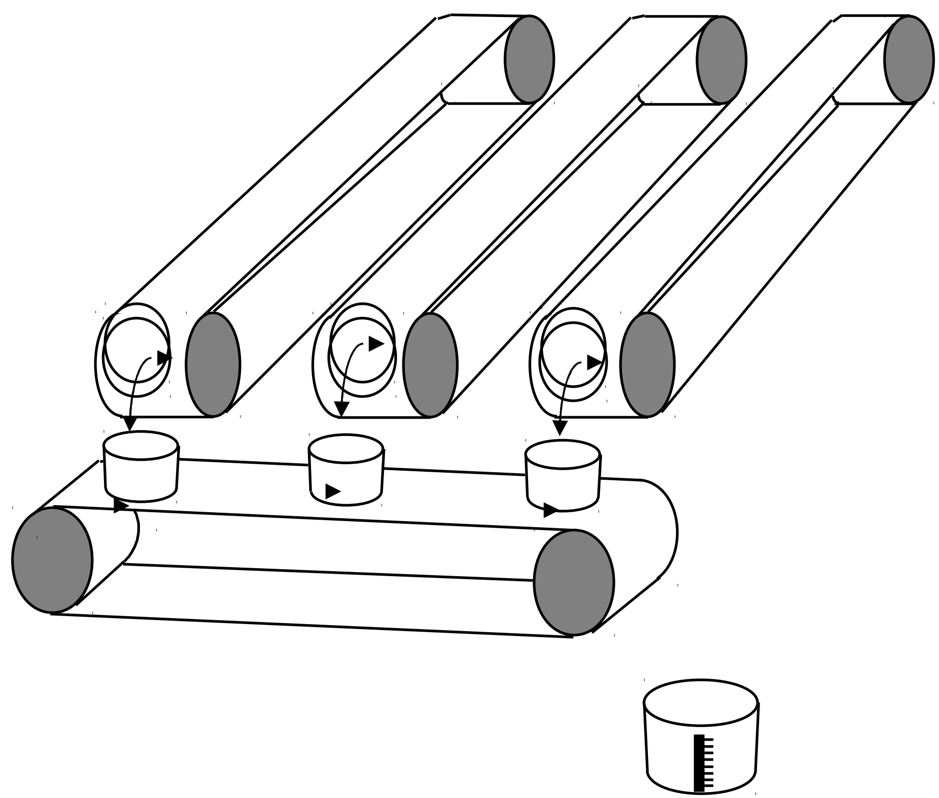
AS750 Observational Astronomy
Prof. Sebastian Lopez



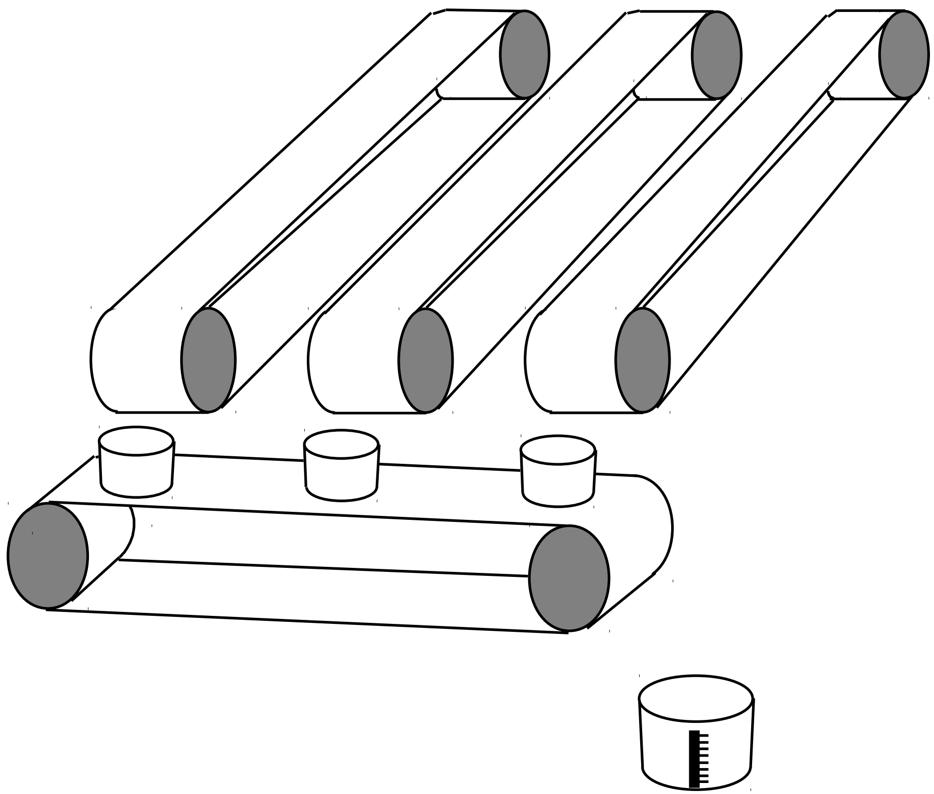
AS750 Observational Astronomy
Prof. Sebastian Lopez



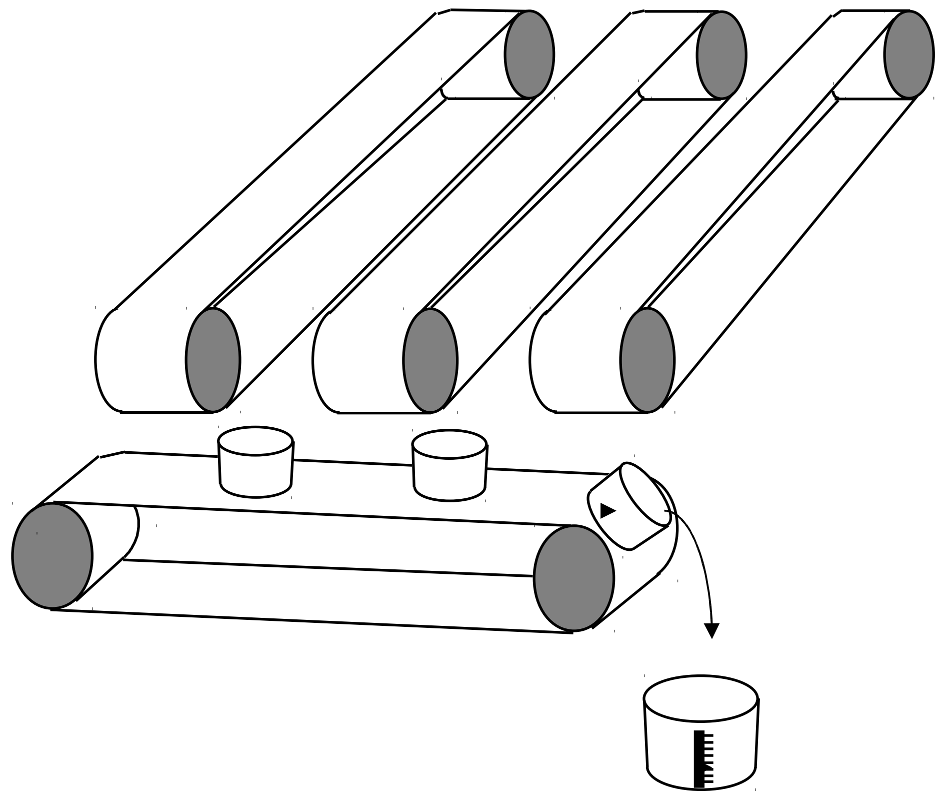
AS750 Observational Astronomy
Prof. Sebastian Lopez



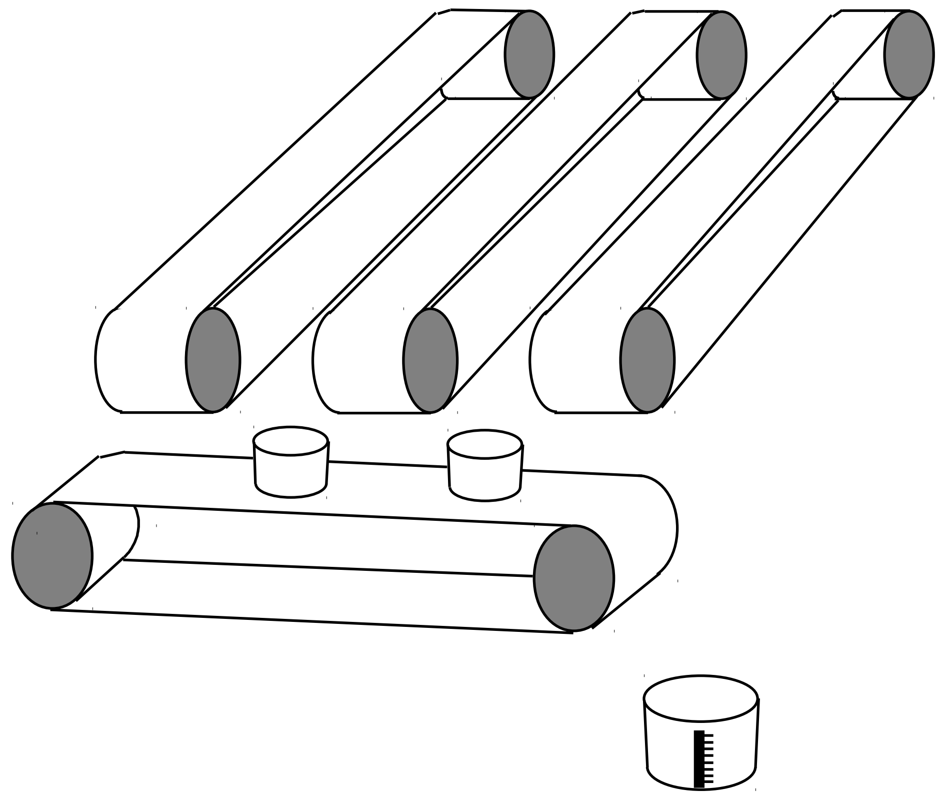
AS750 Observational Astronomy
Prof. Sebastian Lopez



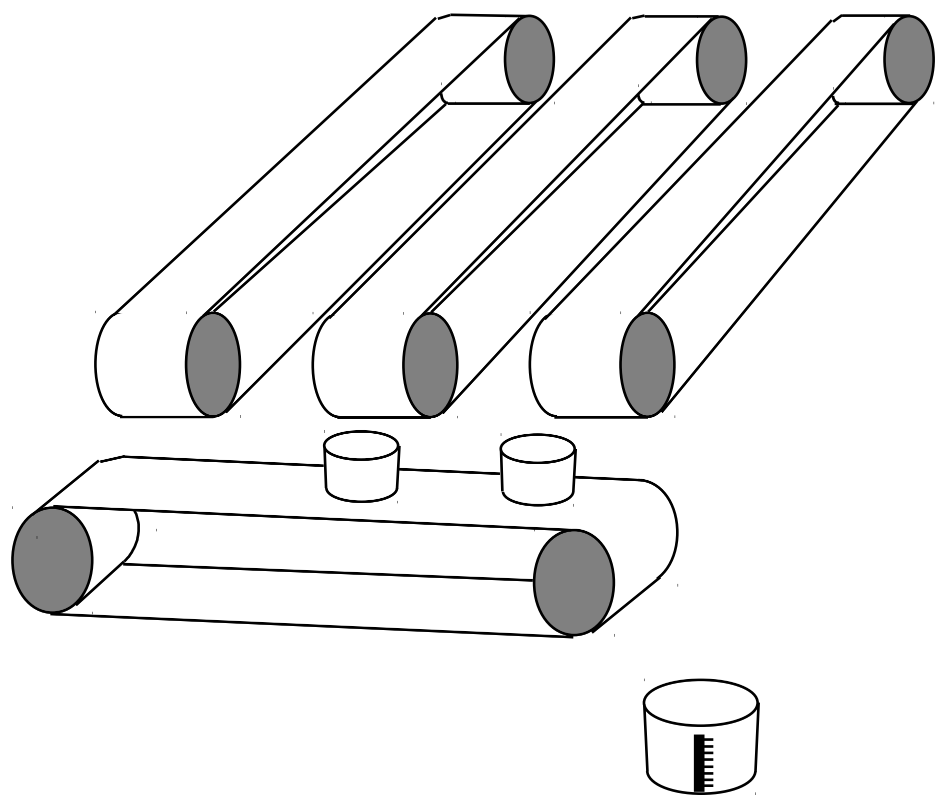
AS750 Observational Astronomy
Prof. Sebastian Lopez



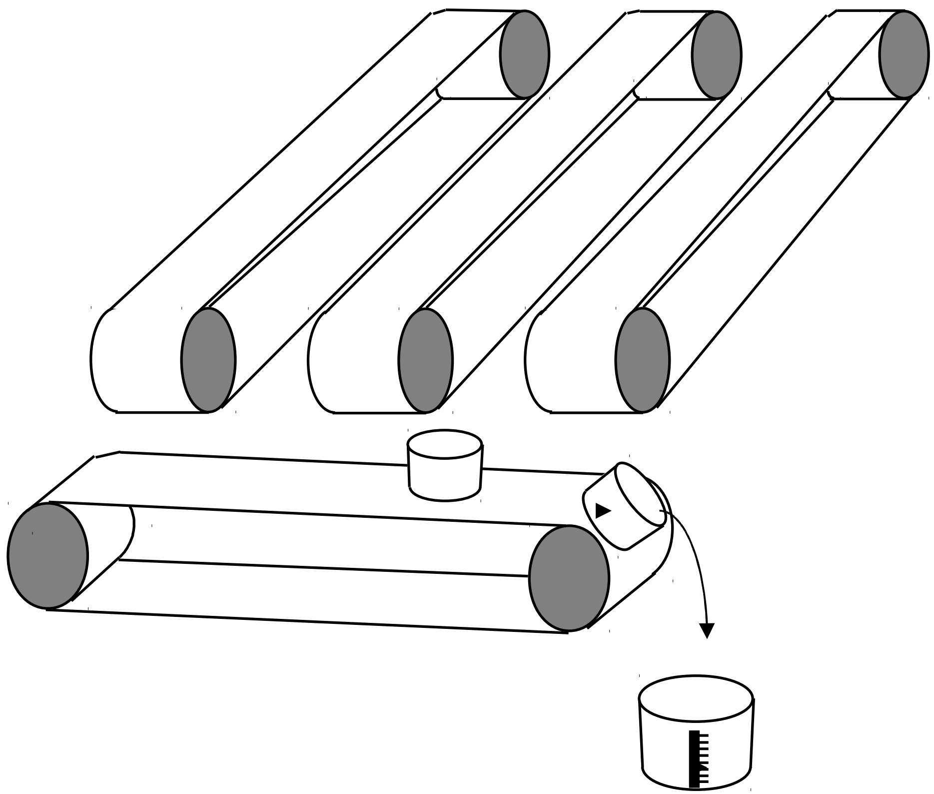
AS750 Observational Astronomy
Prof. Sebastian Lopez



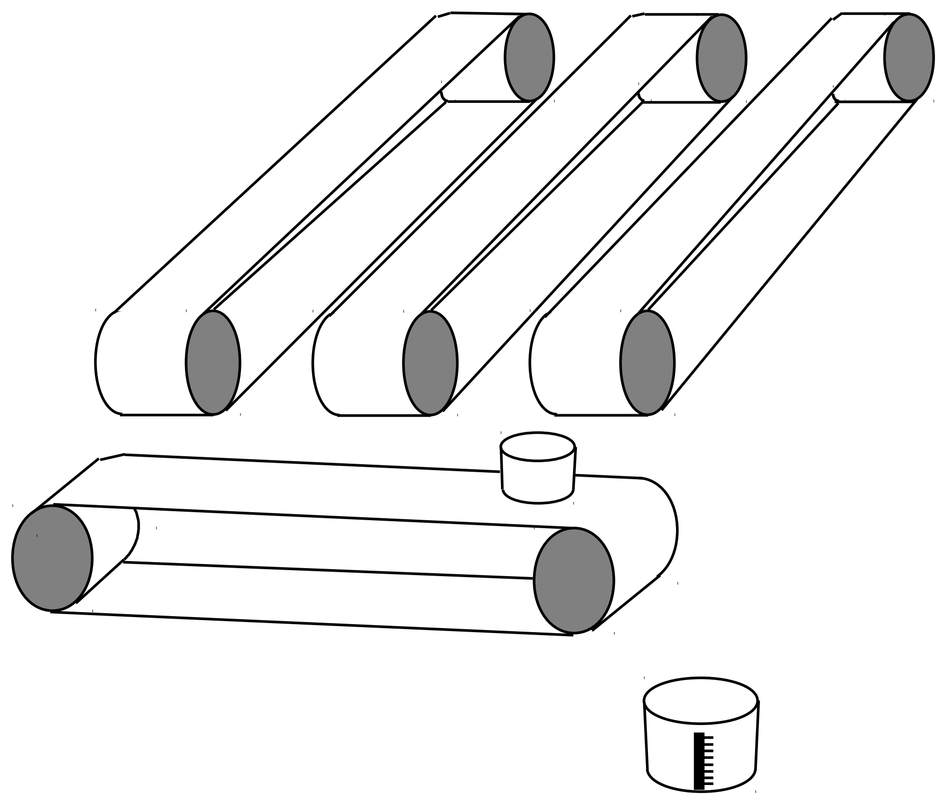
AS750 Observational Astronomy
Prof. Sebastian Lopez



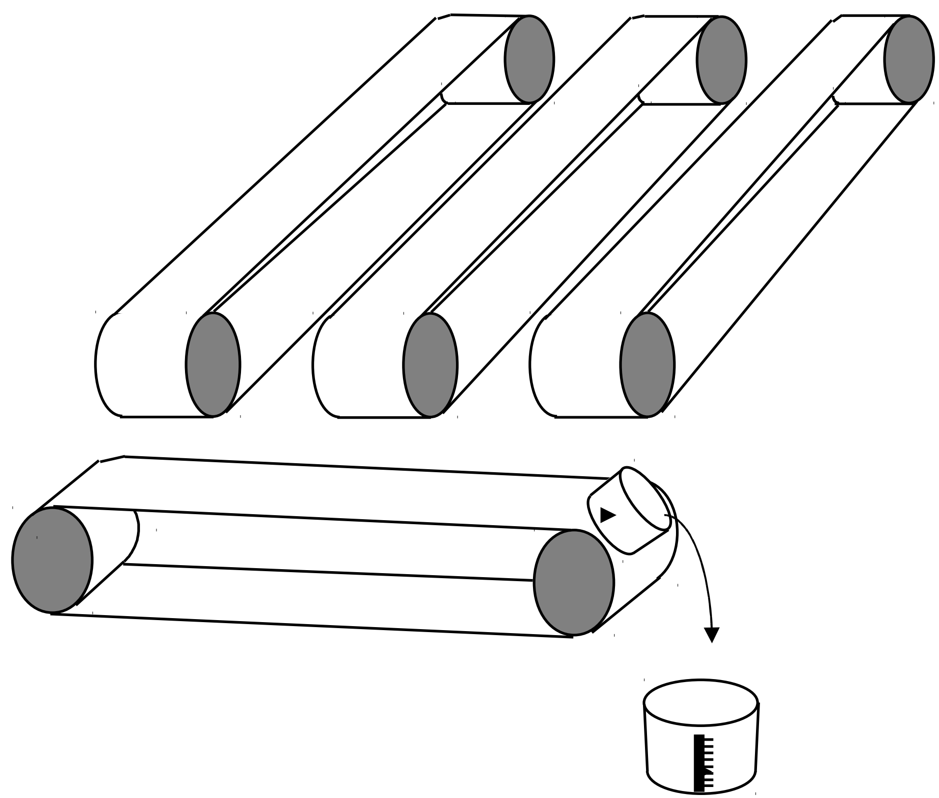
AS750 Observational Astronomy
Prof. Sebastian Lopez



AS750 Observational Astronomy
Prof. Sebastian Lopez

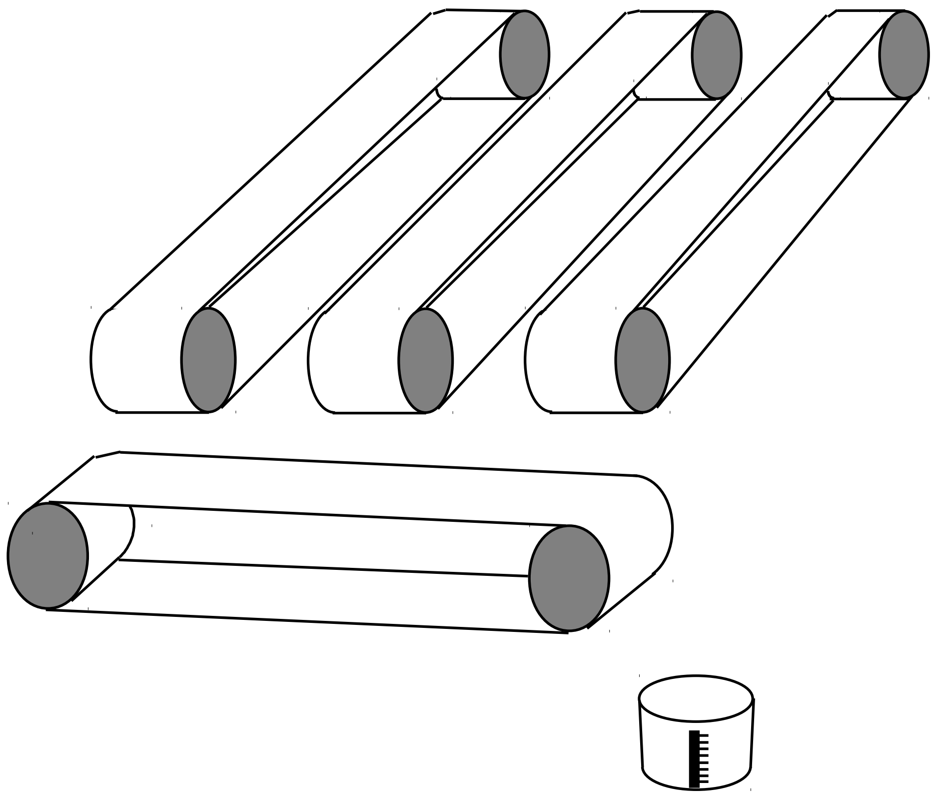


AS750 Observational Astronomy
Prof. Sebastian Lopez



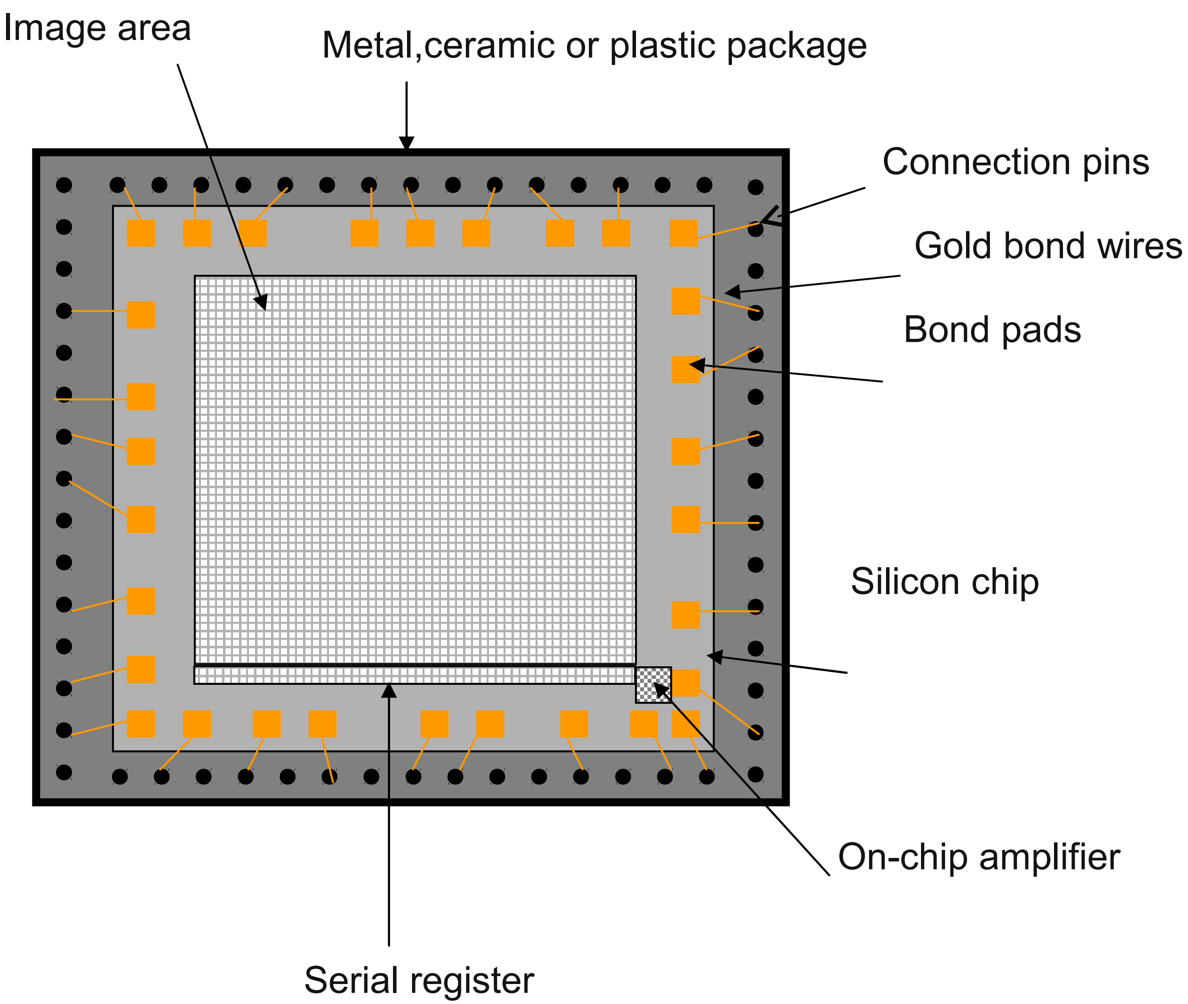
AS750 Observational Astronomy
Prof. Sebastian Lopez

Eventually all the buckets have been measured, the CCD has been read out.



Structure of a CCD 1.

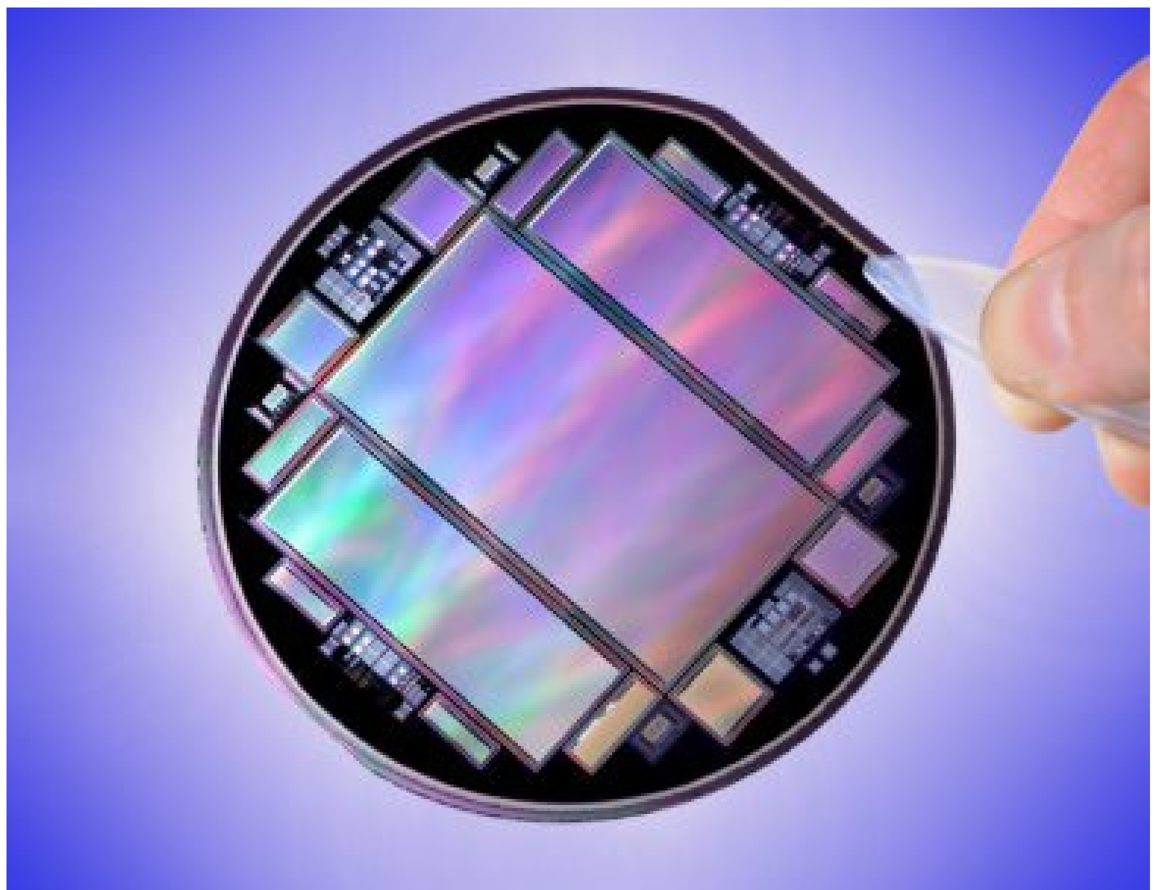
The image area of the CCD is positioned at the focal plane of the telescope. An image then builds up that consists of a pattern of electric charge. At the end of the exposure this pattern is then transferred, pixel at a time, by way of the serial register to the on-chip amplifier. Electrical connections are made to the outside world via a series of bond pads and thin gold wires positioned around the chip periphery.



Structure of a CCD 2.

CCDs are are manufactured on silicon wafers using the same photo-lithographic techniques used to manufacture computer chips. Scientific CCDs are very big ,only a few can be fitted onto a wafer. This is one reason that they are so costly.

The photo below shows a silicon wafer with three large CCDs and assorted smaller devices. A CCD has been produced by Philips that fills an entire 6 inch wafer! It is the worlds largest integrated circuit.

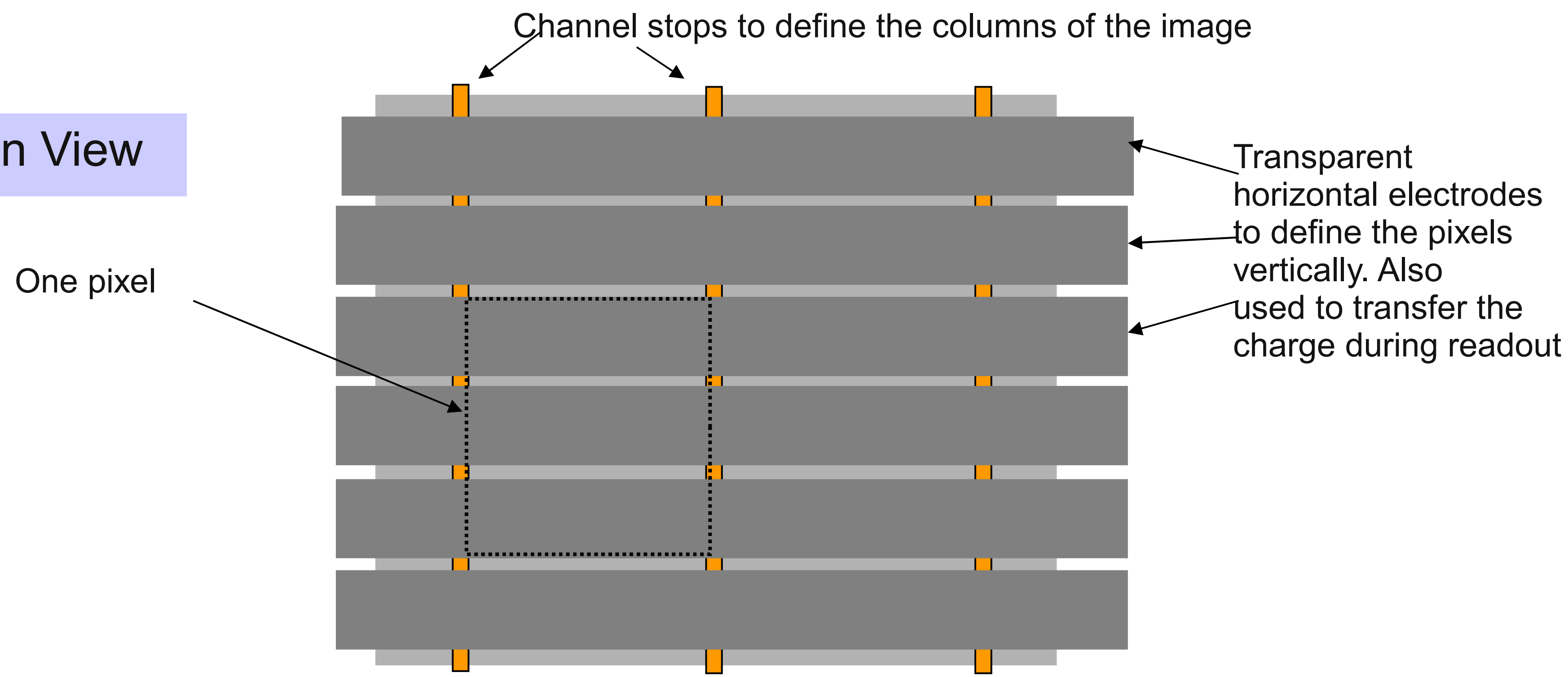


Don Groom LBNL

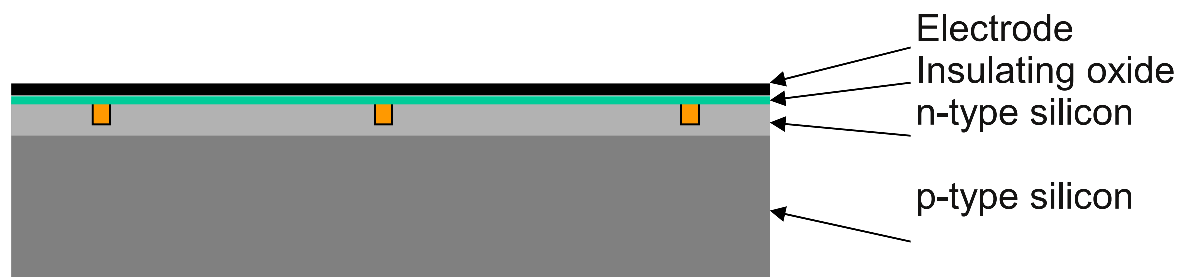
Structure of a CCD 3.

The diagram shows a small section (a few pixels) of the image area of a CCD. This pattern is reapeated.

Plan View



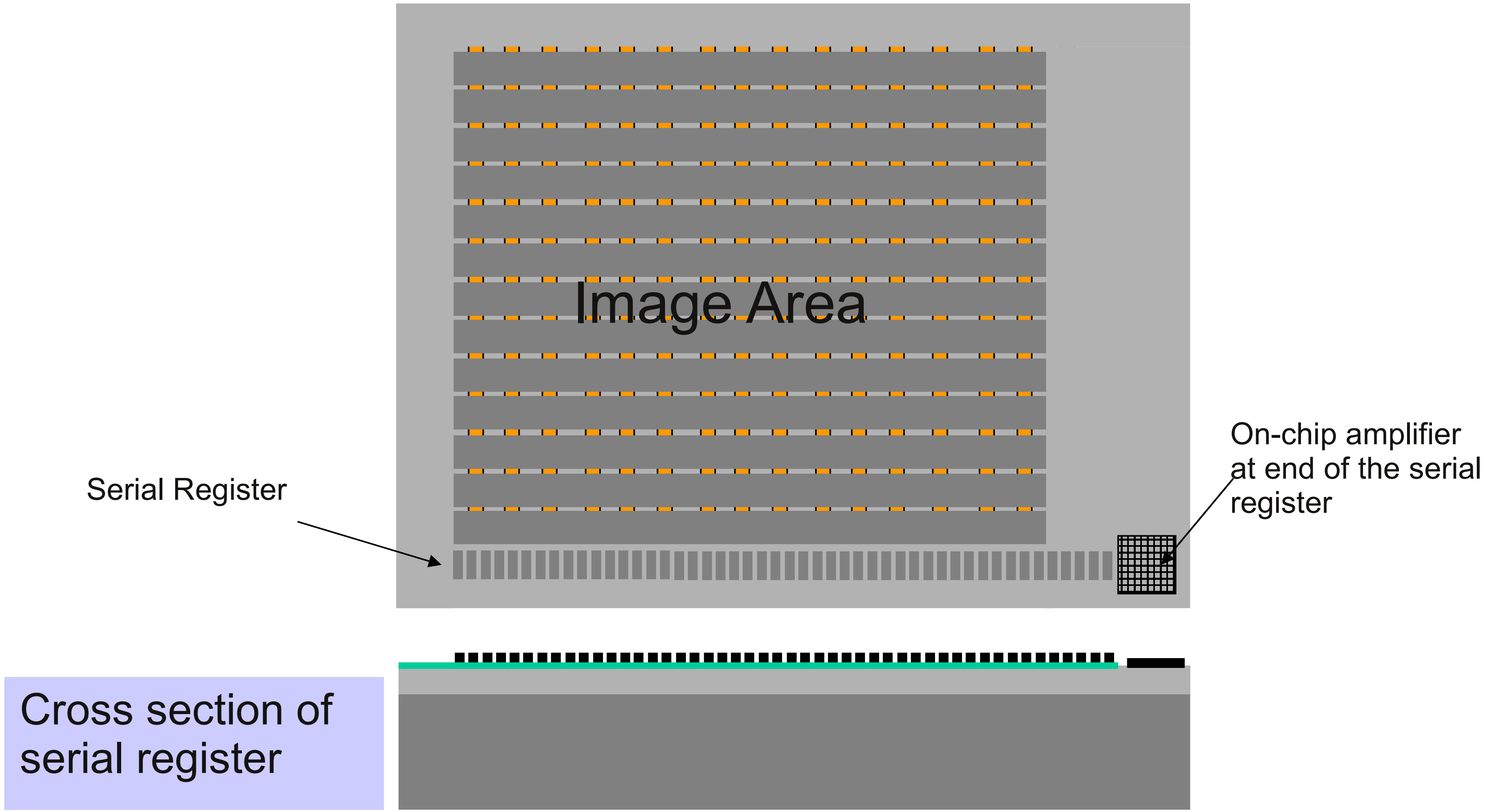
Cross section



Every third electrode is connected together. Bus wires running down the edge of the chip make the connection. The channel stops are formed from high concentrations of Boron in the silicon.

Structure of a CCD 4.

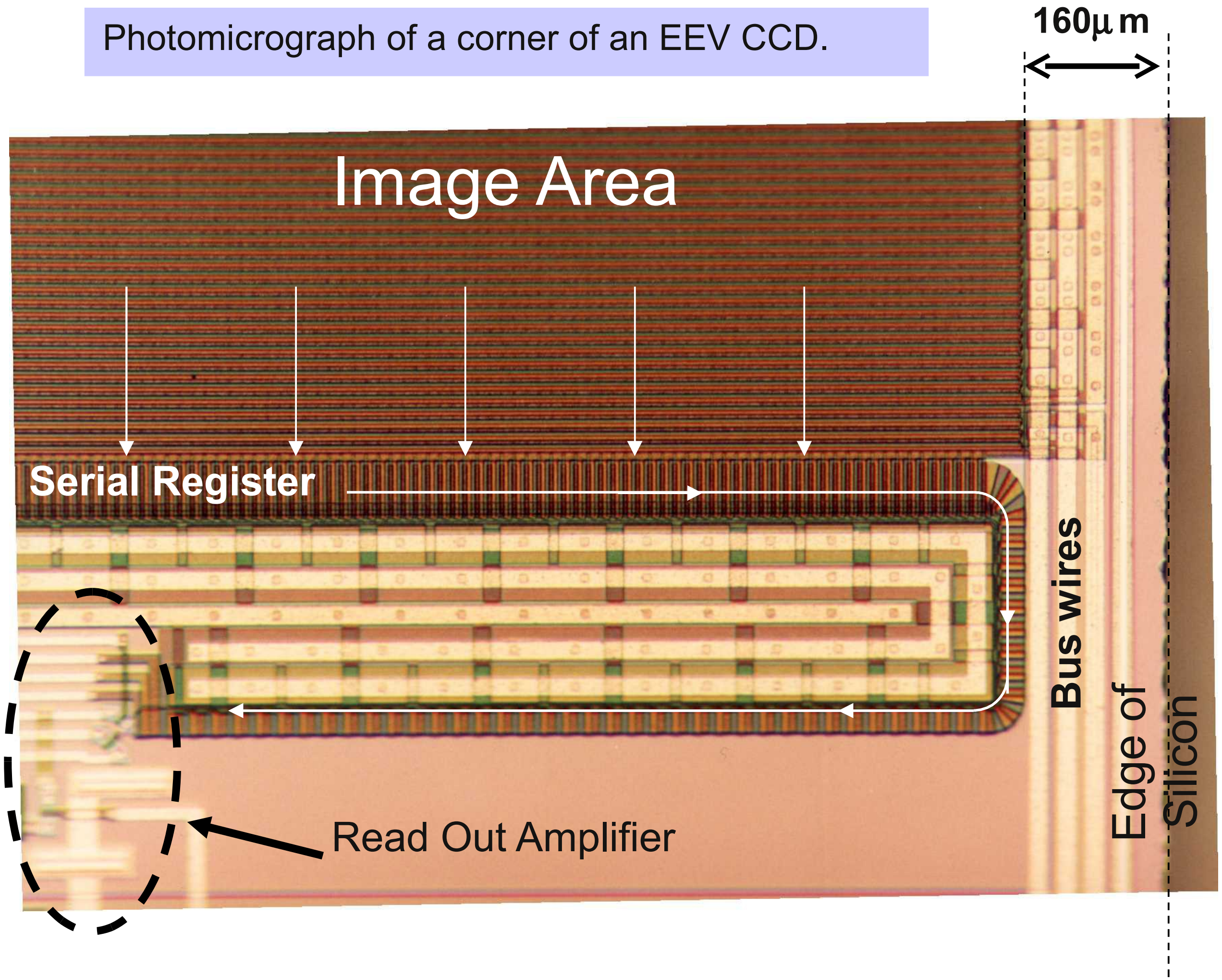
Below the image area (the area containing the horizontal electrodes) is the ‘Serial register’ . This also consists of a group of small surface electrodes. There are three electrodes for every column of the image area



Once again every third electrode is in the serial register connected together.

Structure of a CCD 5.

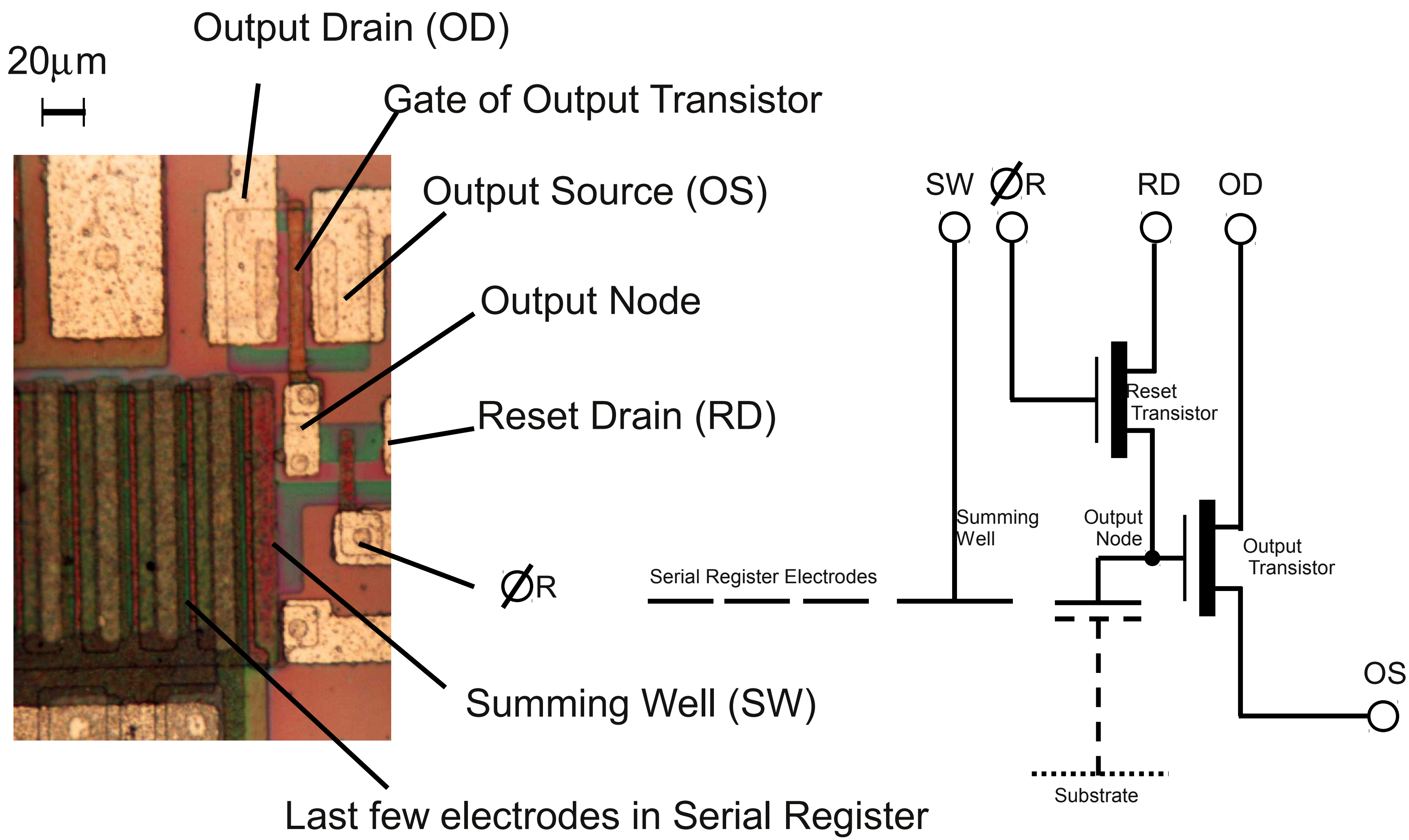
Photomicrograph of a corner of an EEV CCD.



The serial register is bent double to move the output amplifier away from the edge of the chip. This useful if the CCD is to be used as part of a mosaic.The arrows indicate how charge is transferred through the device.

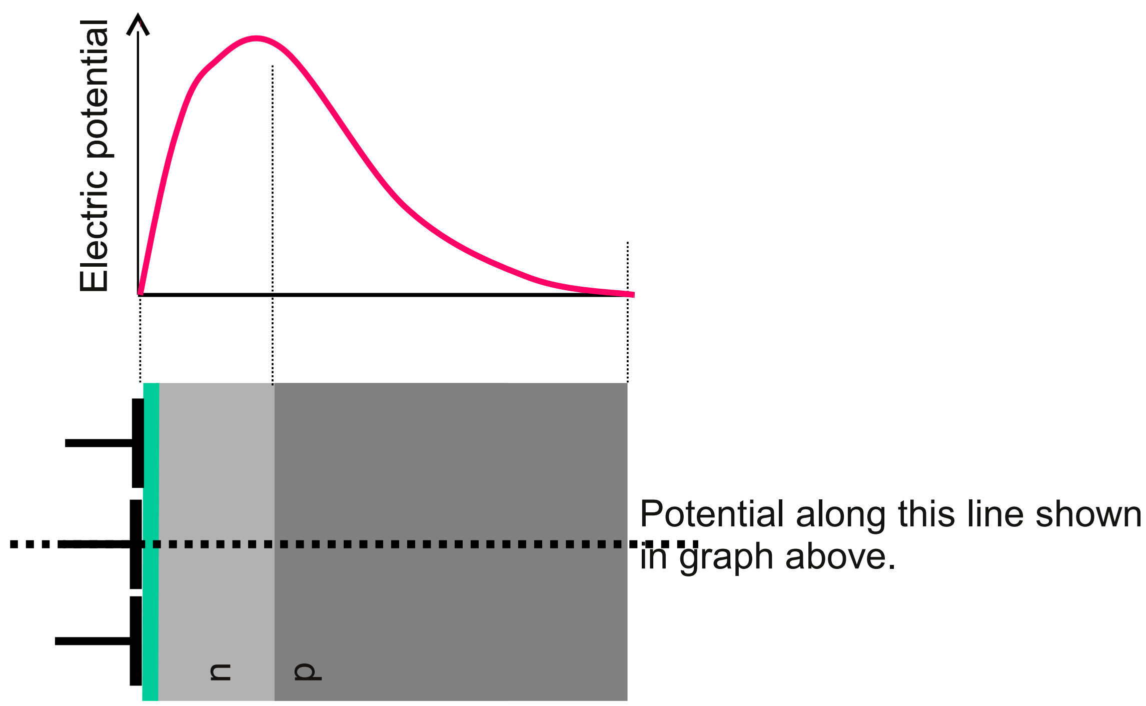
Structure of a CCD 6.

Photomicrograph of the on-chip amplifier of a Tektronix CCD and its circuit diagram.



Electric Field in a CCD 1.

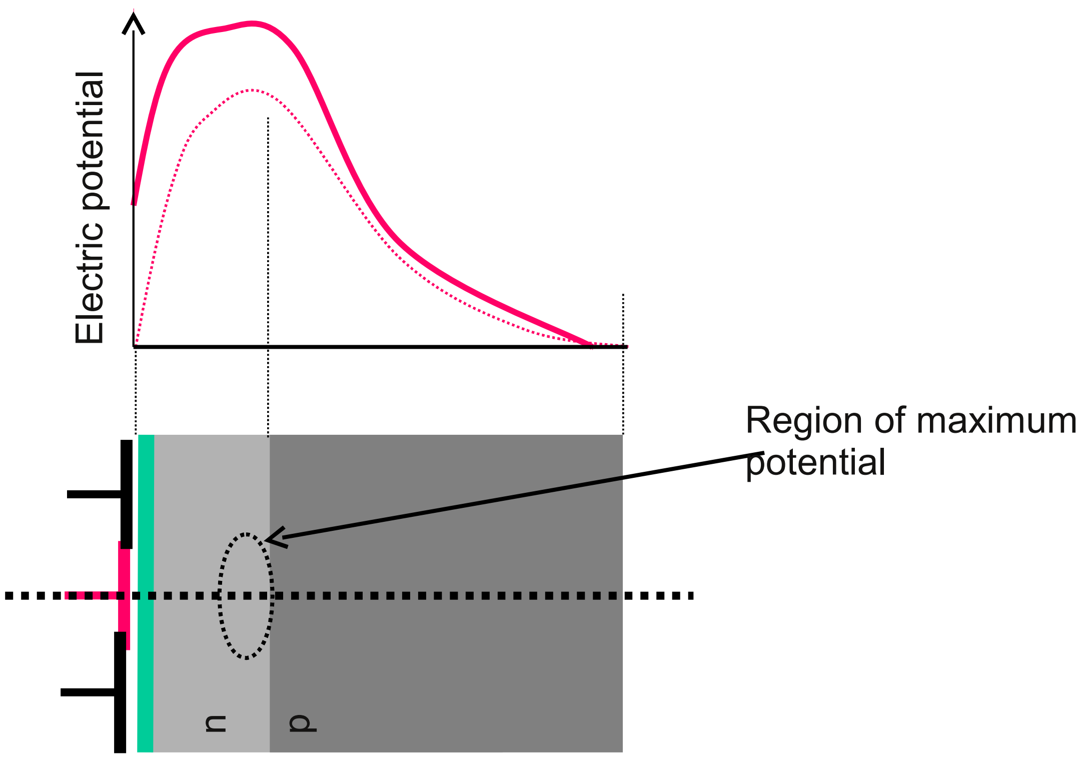
The n-type layer contains an excess of electrons that diffuse into the p-layer. The p-layer contains an excess of holes that diffuse into the n-layer. This structure is identical to that of a diode junction.
The diffusion creates a charge imbalance and induces an internal electric field. The electric potential reaches a maximum just inside the n-layer, and it is here that any photo-generated electrons will collect.
All science CCDs have this junction structure, known as a 'Buried Channel'. It has the advantage of keeping the photo-electrons confined away from the surface of the CCD where they could become trapped.
It also reduces the amount of thermally generated noise (dark current).



Cross section through the thickness of the CCD

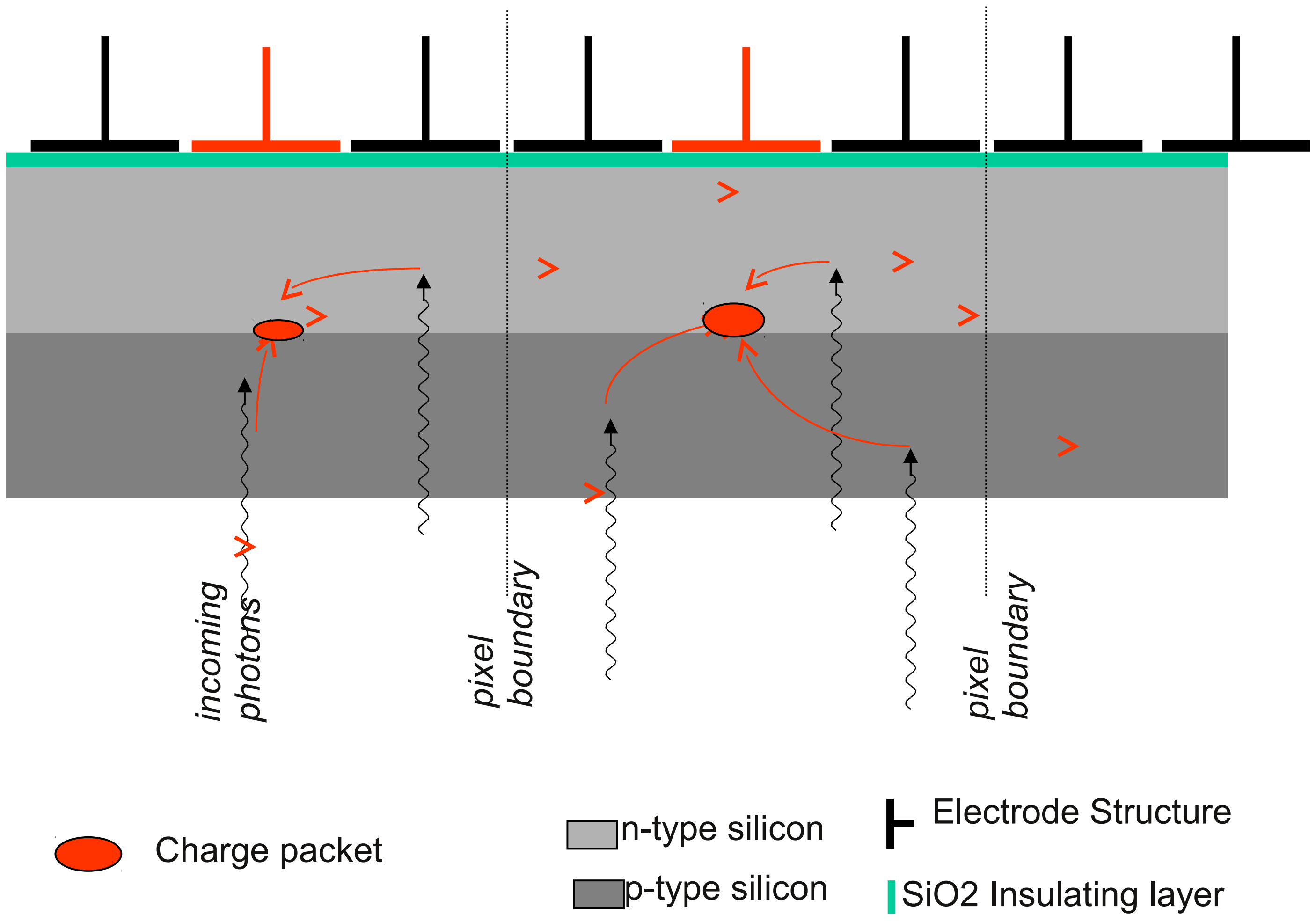
Electric Field in a CCD 2.

During integration of the image, one of the electrodes in each pixel is held at a positive potential. This further increases the potential in the silicon below that electrode and it is here that the photoelectrons are accumulated. The neighboring electrodes, with their lower potentials, act as potential barriers that define the vertical boundaries of the pixel. The horizontal boundaries are defined by the channel stops.



Charge Collection in a CCD.

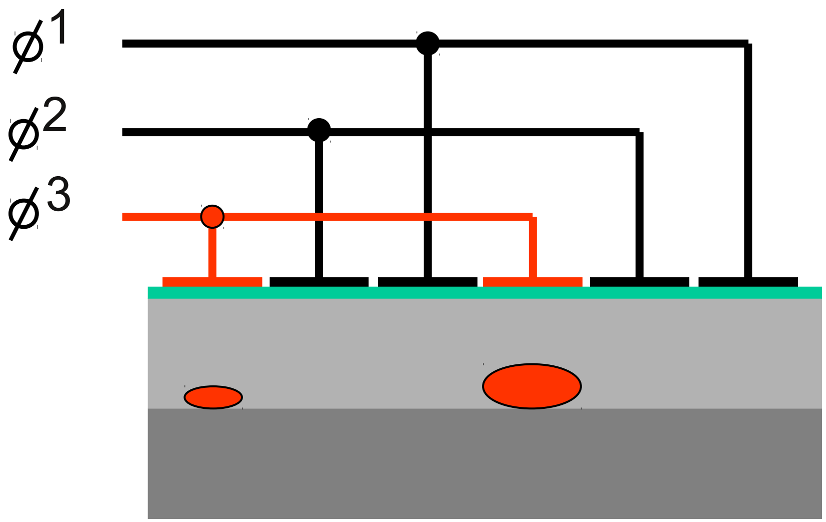
Photons entering the CCD create electron-hole pairs. The electrons are then attracted towards the most positive potential in the device where they create 'charge packets'. Each packet corresponds to one pixel



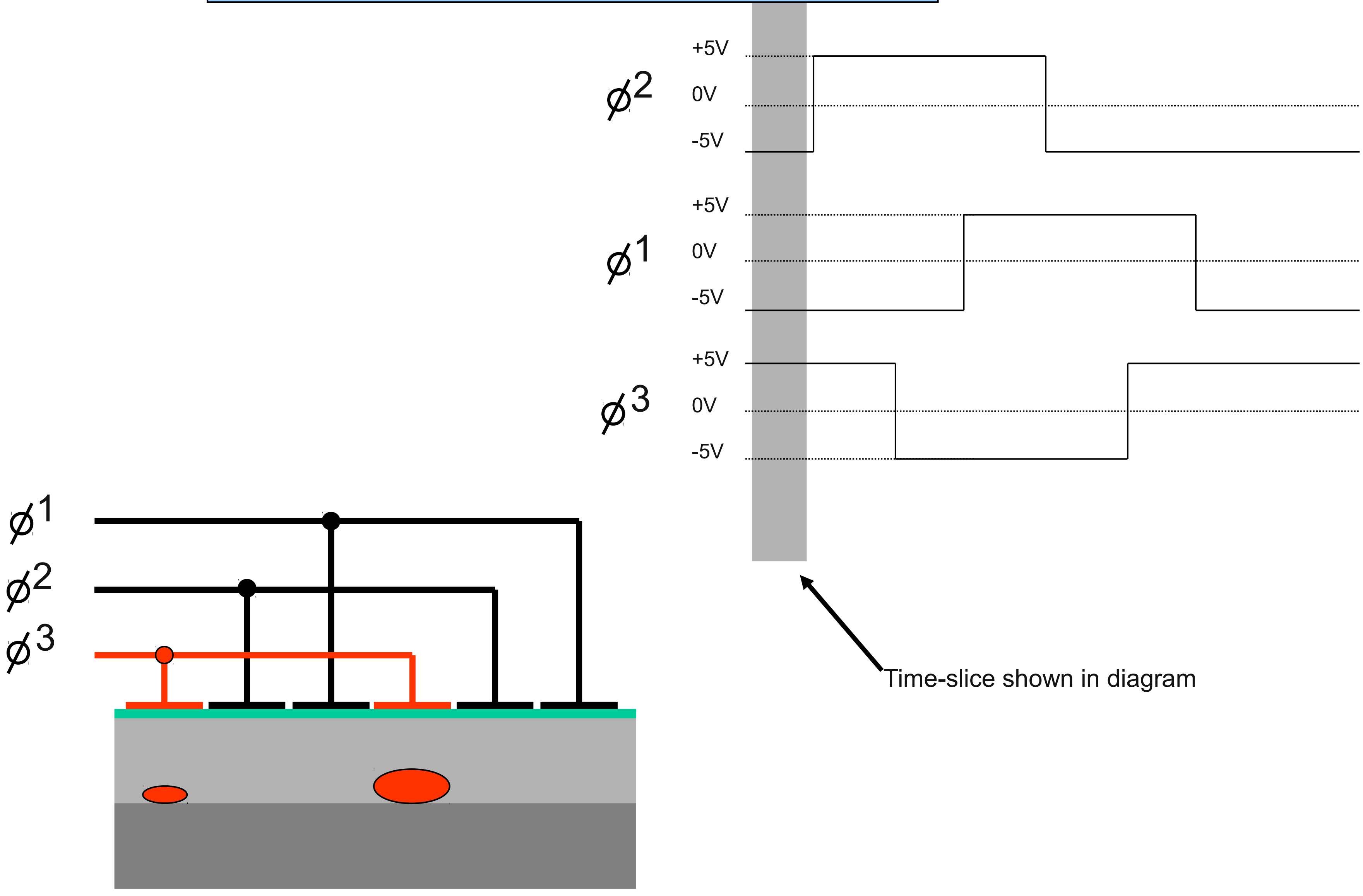
Charge Transfer in a CCD 1.

In the following few slides, the implementation of the 'conveyor belts' as actual electronic structures is explained.

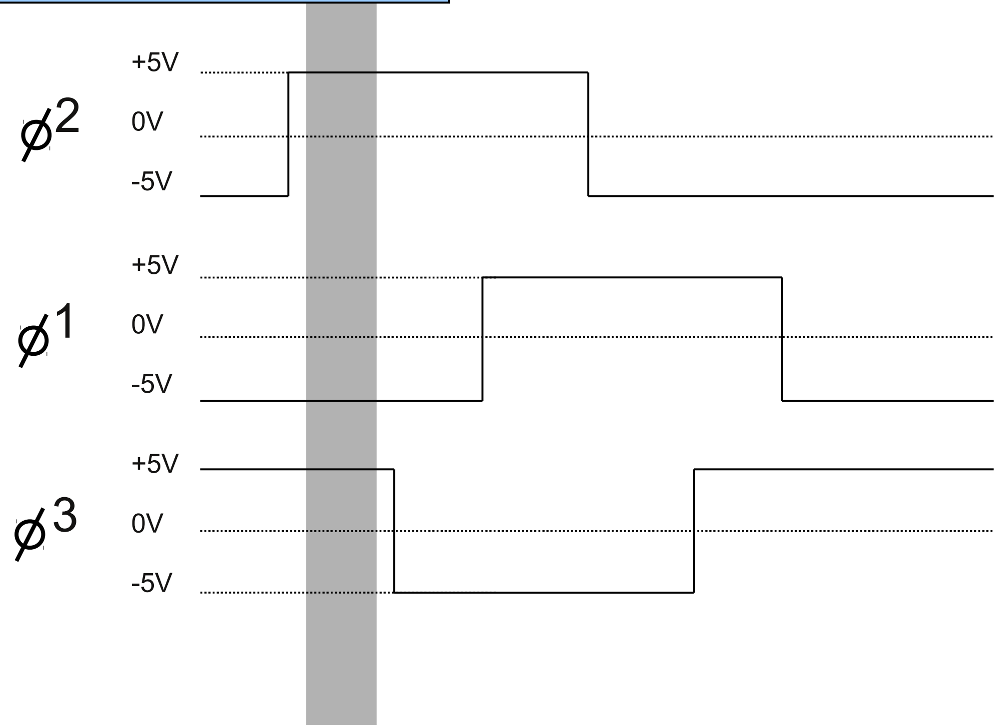
The charge is moved along these conveyor belts by modulating the voltages on the electrodes positioned on the surface of the CCD. In the following illustrations, electrodes colour coded red are held at a positive potential, those coloured black are held at a negative potential.

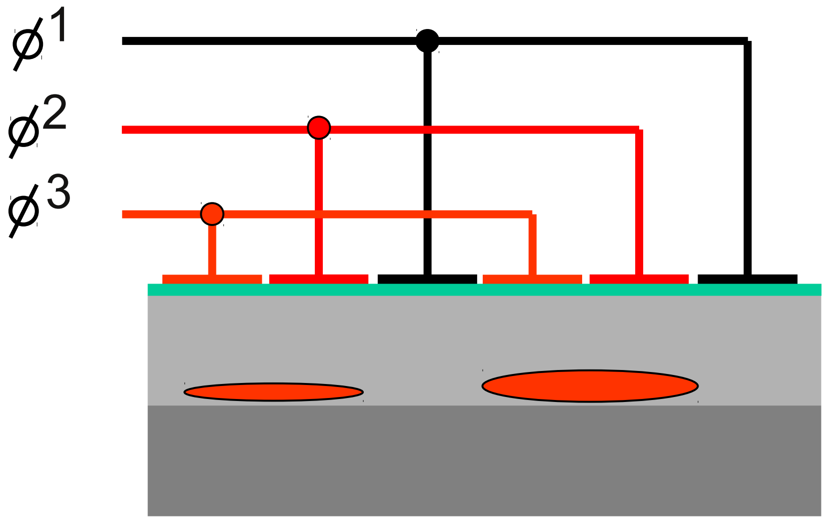


Charge Transfer in a CCD 2.

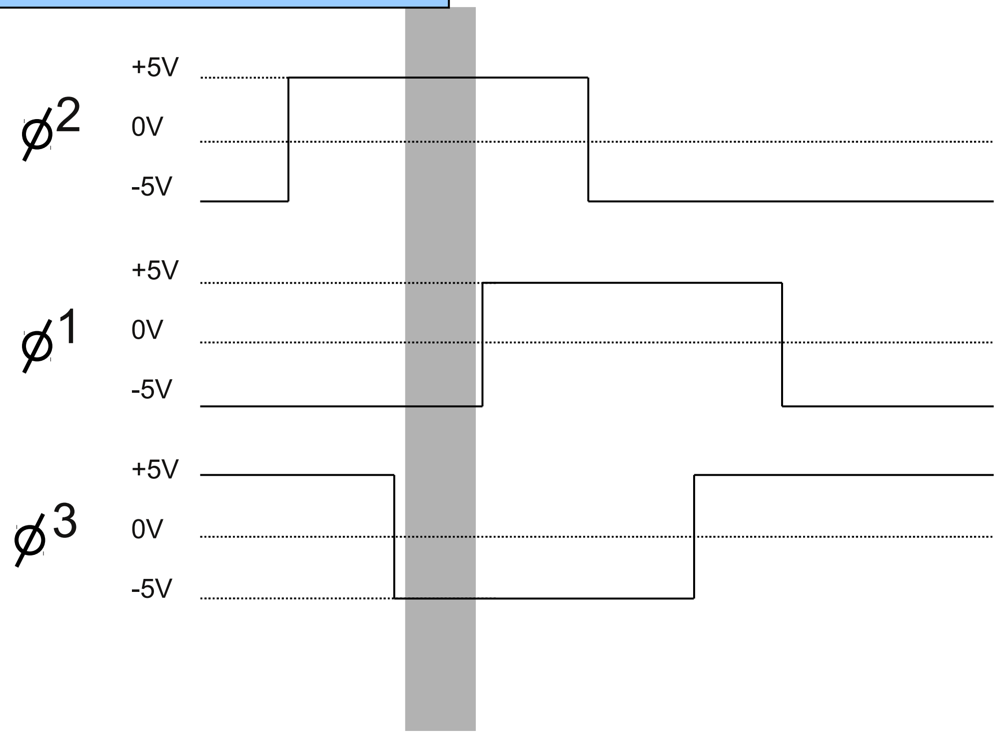


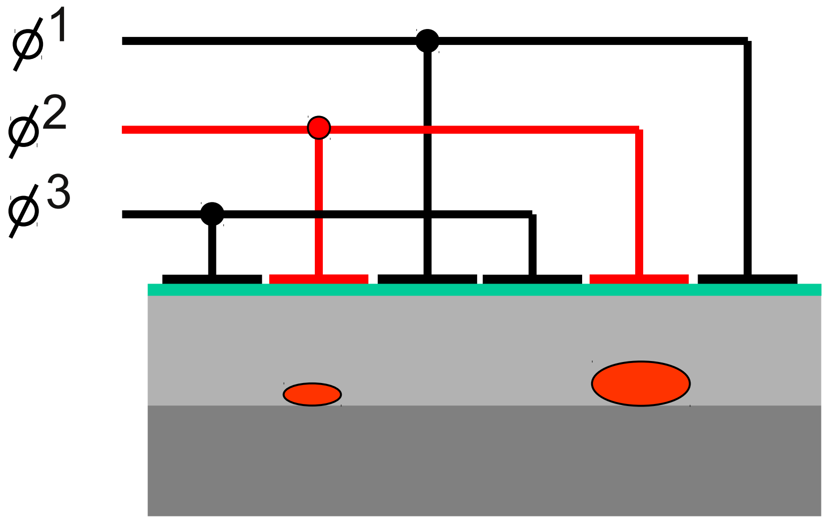
Charge Transfer in a CCD 3.



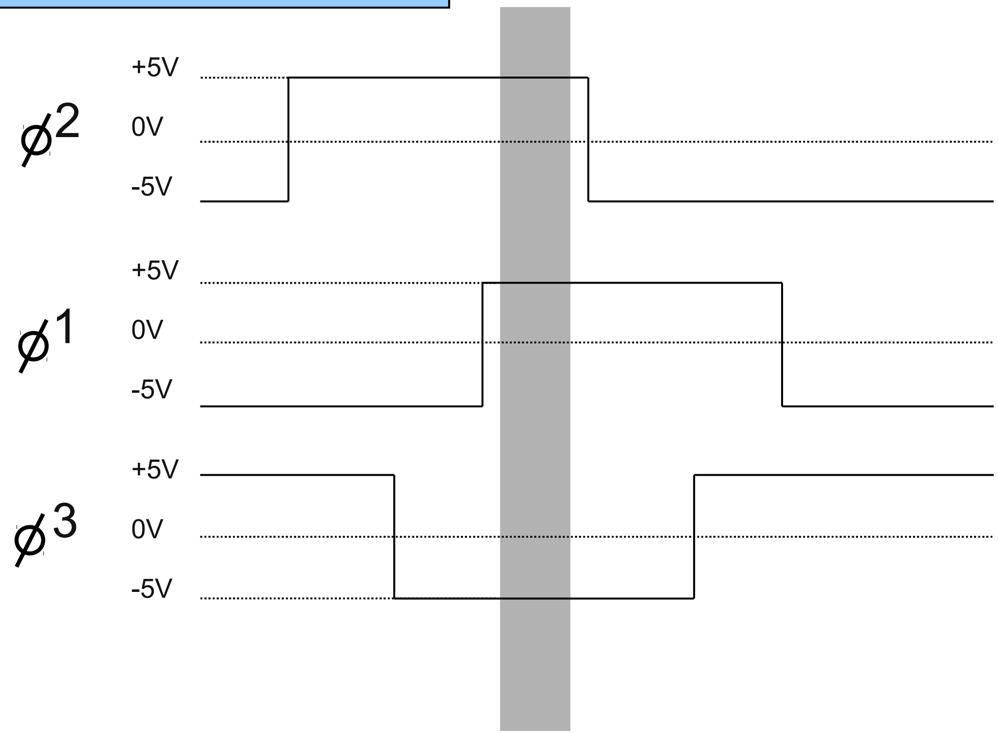


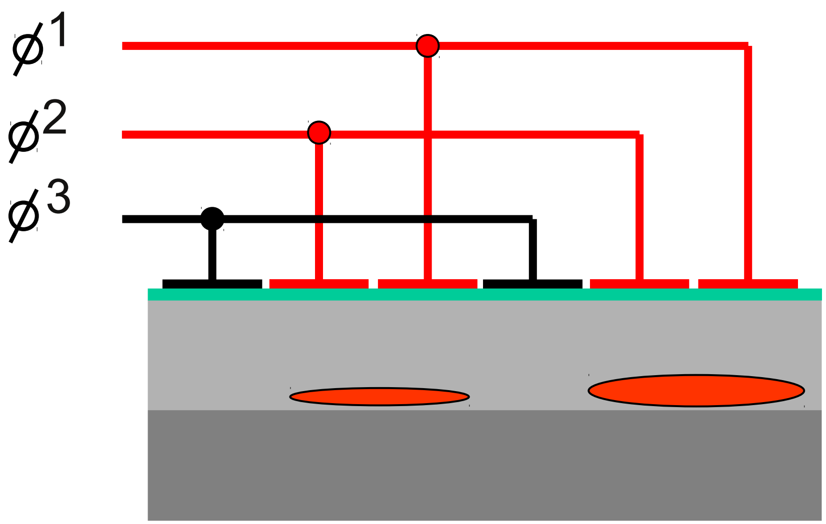
Charge Transfer in a CCD 4.



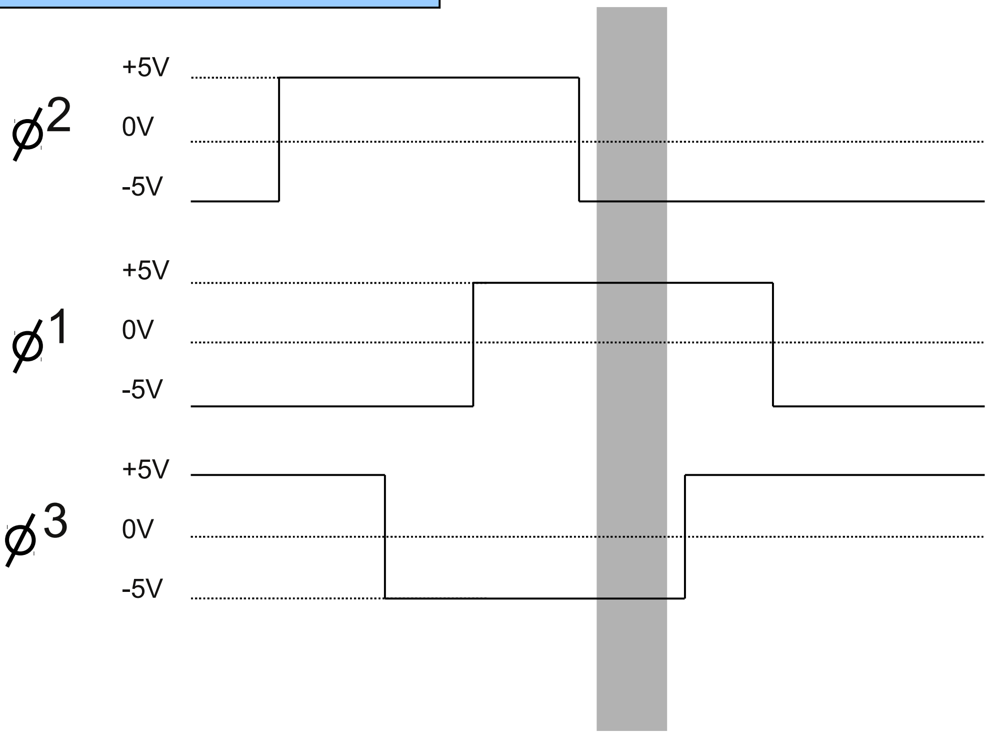


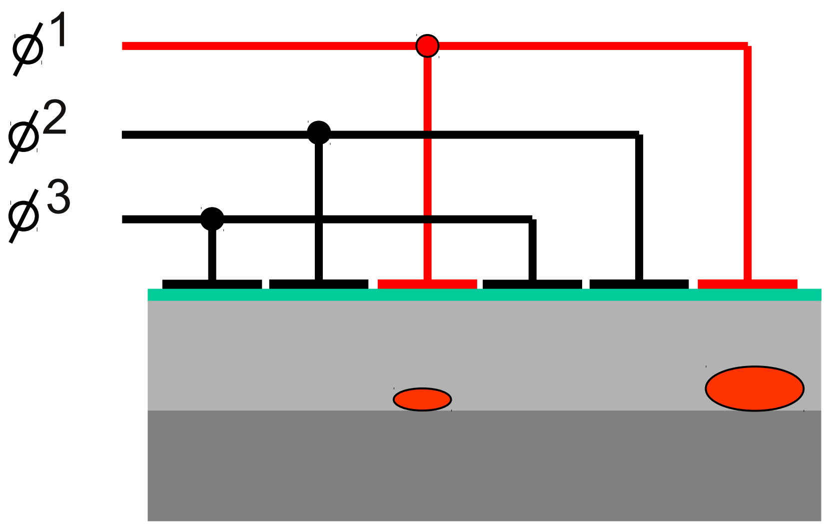
Charge Transfer in a CCD 5.



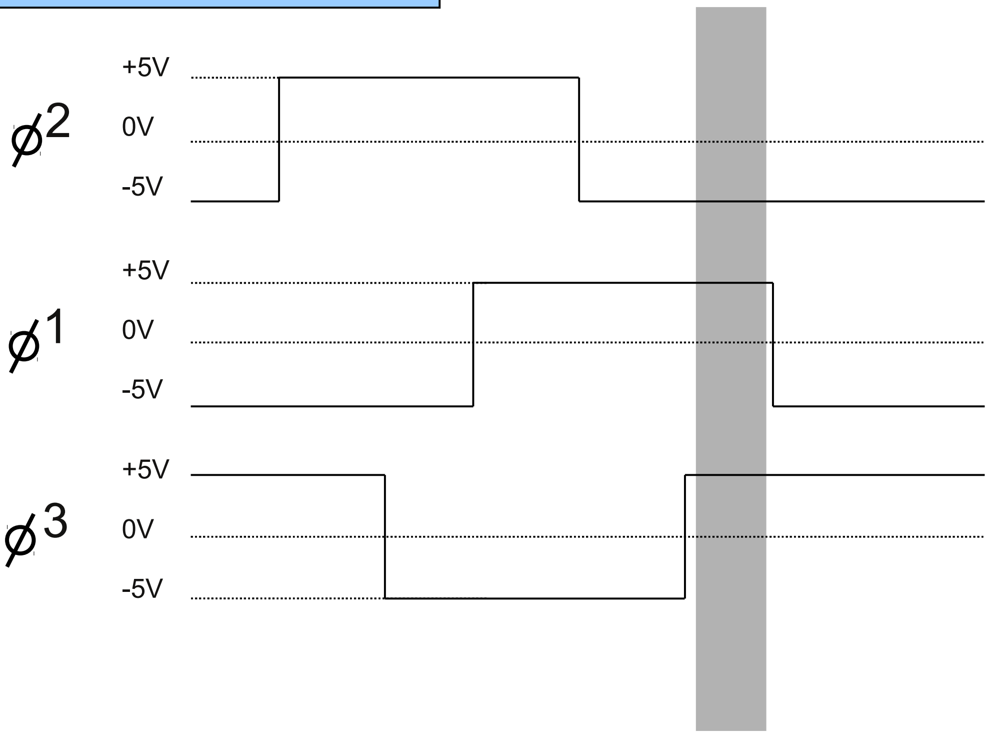


Charge Transfer in a CCD 6.

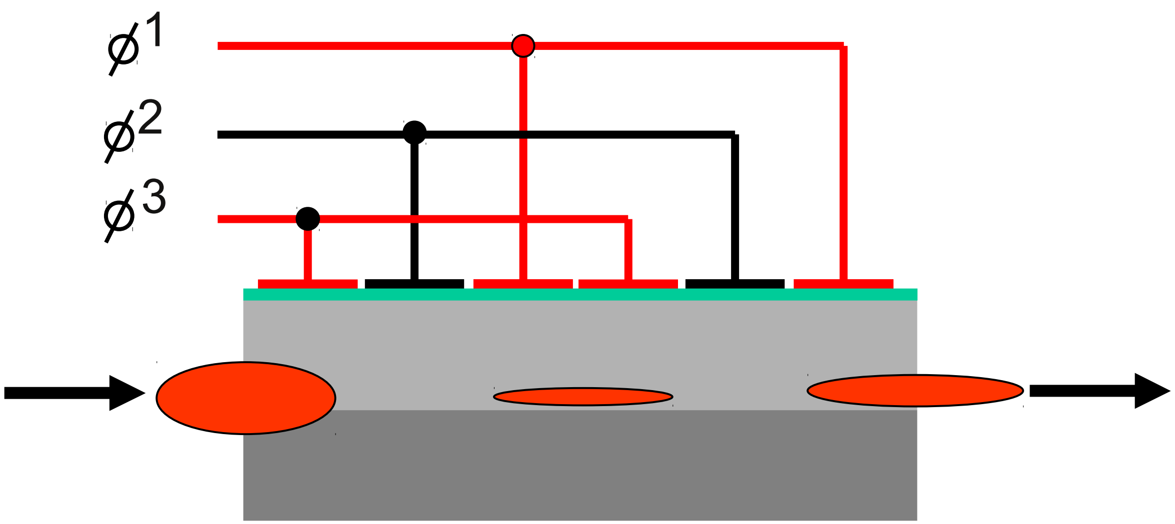




Charge Transfer in a CCD 7.



Charge packet from subsequent pixel enters from left as first pixel exits to the right.



Charge Transfer in a CCD 8.