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Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

Dark Matter detectors

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Final report

25 September 2015

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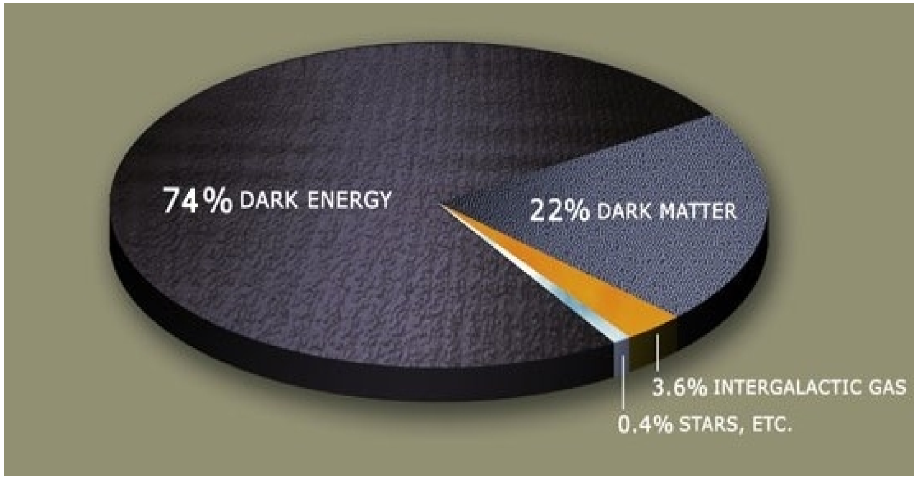
Introduction

We know only
a small part of
the universe !



DAMIC : “Dark Matter In CCDs”

Damic uses CCDs originally developed for the camera of the Dark Energy Survey.
The detectors can record snapshots of the electric charge that would be created if a dark matter particle were to collide with the detector material inside a CCD.

CCD as detector

CCD : Charge Coupled Device

• A CCD is a light-sensitive detector.
It consists of a matrix of detectors (pixels).
Each pixel accumulates an electrical charge depending on the amount of light falling upon it

• Although A CCD is a light-sensitive detector, using the photoelectric effect it <u>can also detect charged or uncharged particles by other physical effects</u> such as compton, electron scattering, electron or nuclear recoil, etc

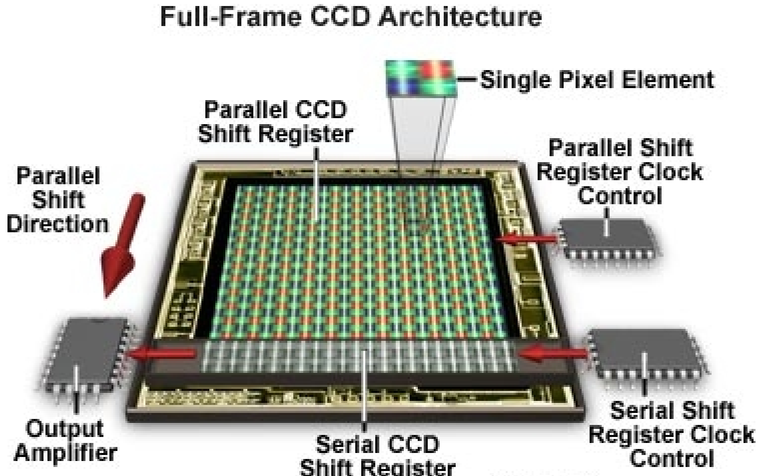
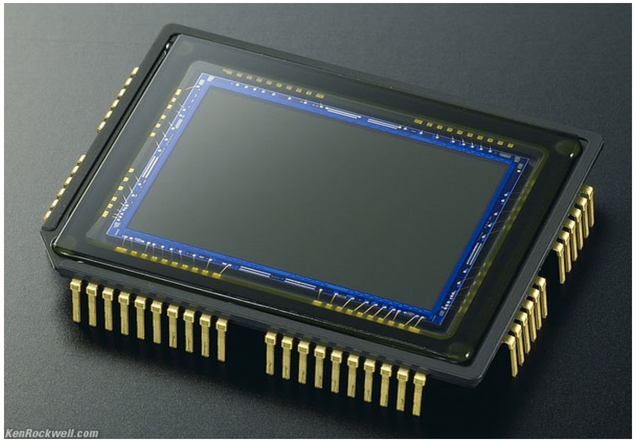
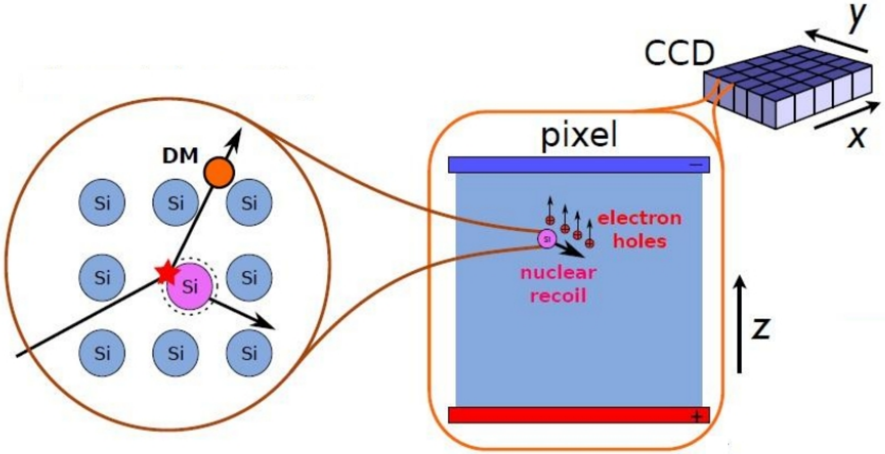


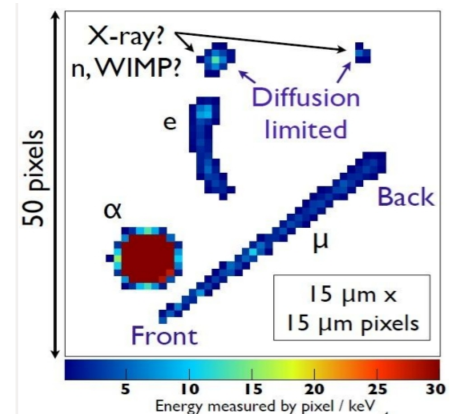
Figure 1

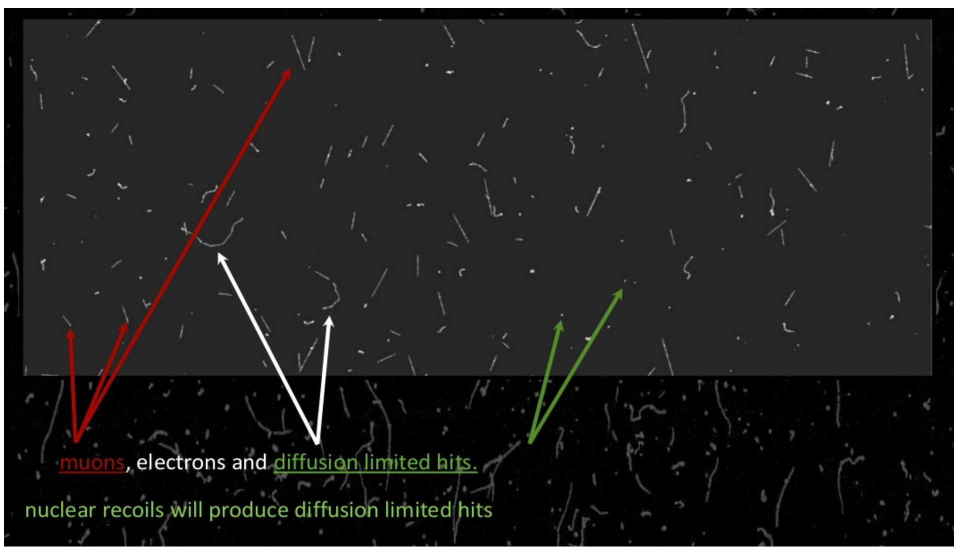


How our detector works

- Incident particles produce ionization in CCD bulk.







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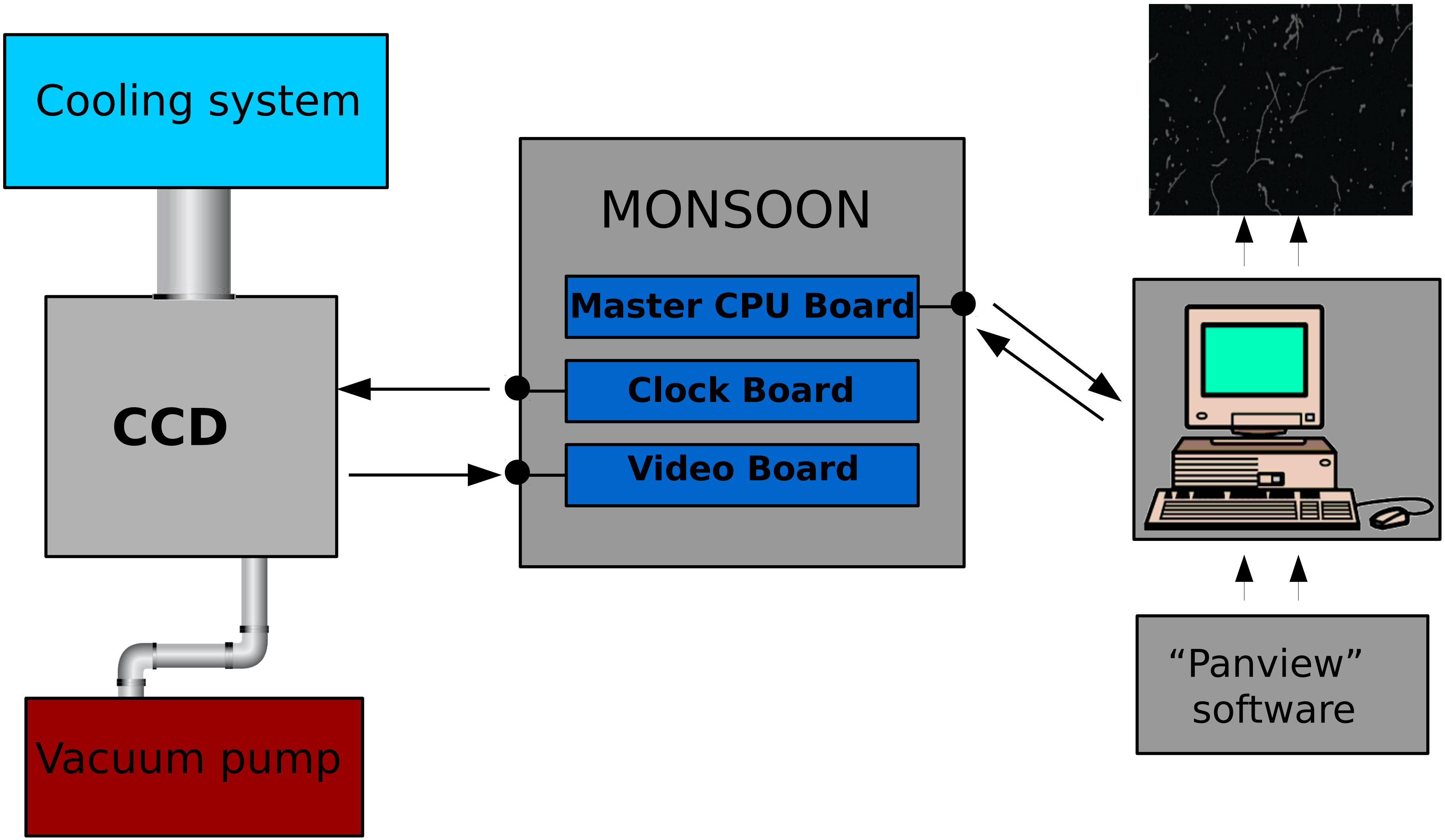
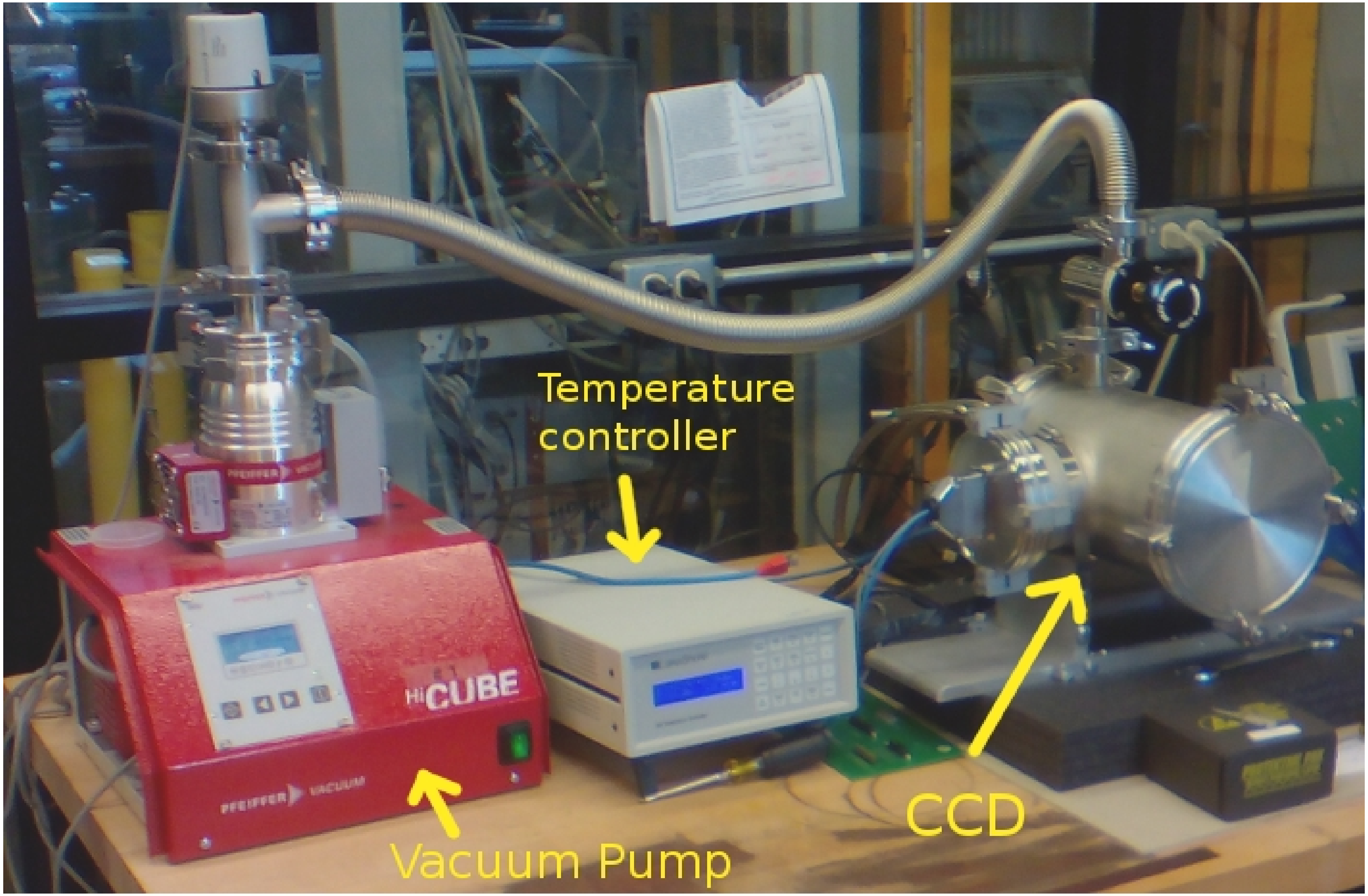
The SETUP


Cooling system
CCD
Vacuum pump
MONSOON
Master CPU Board
Clock Board
Video Board
"Panview" software

Our SETUP : Photo (SIDET : ”CCD Research and development laboratory”)



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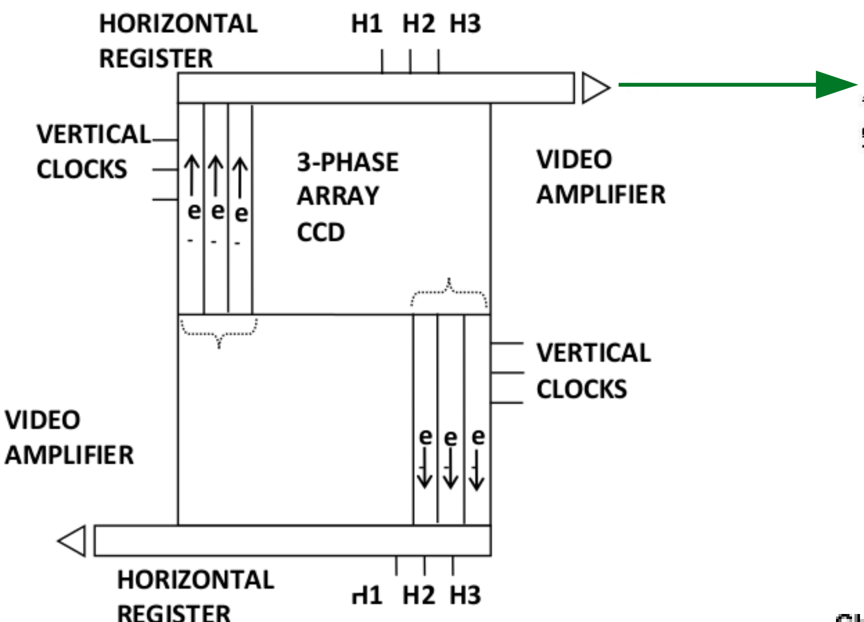
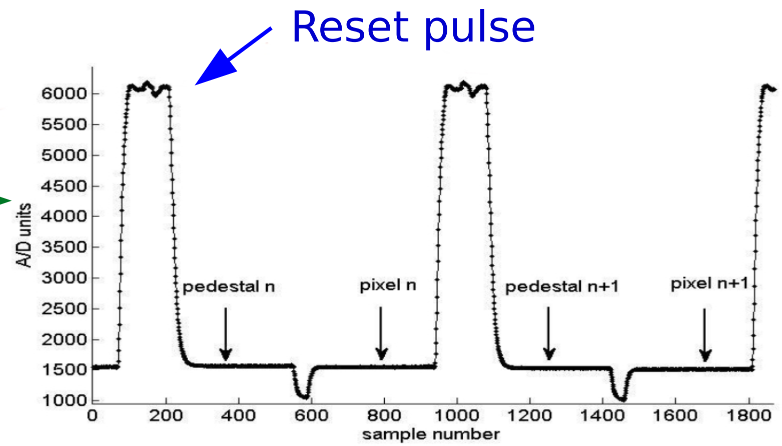
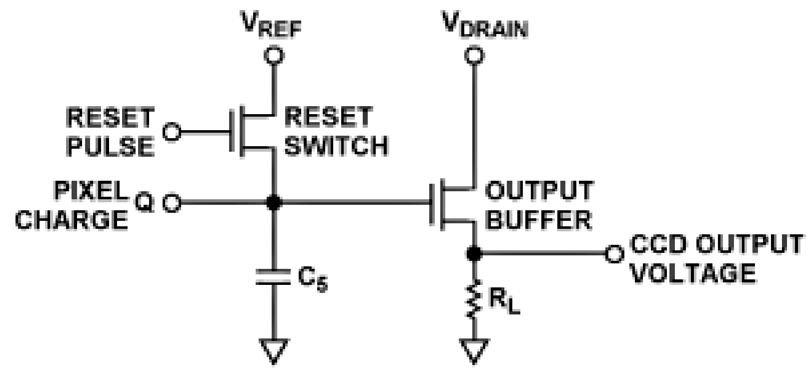
Camera CCD

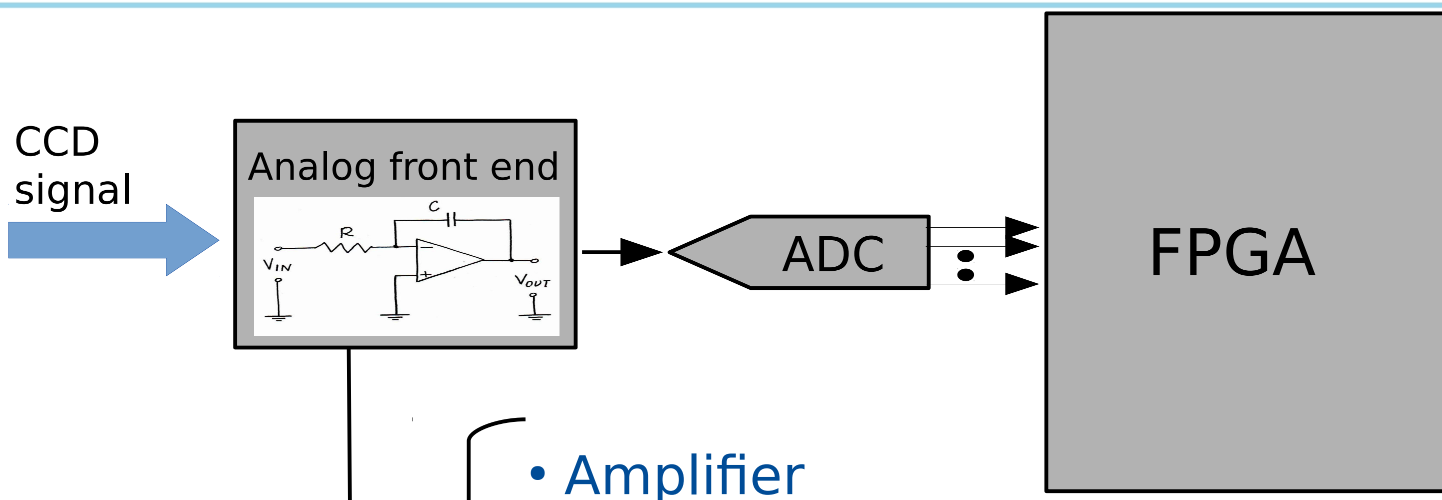
- Our CCD has a resolution of 8 Megapixel (4096 rows x 2048 columns)



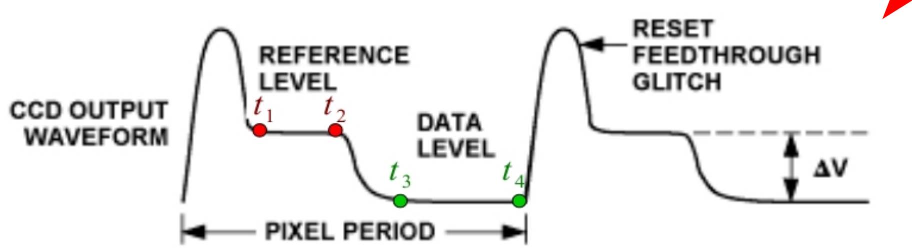




Monsoon system : acquisition board



- Amplifier
- Integrator
- Performs CDS (Correlated Double Sampling)

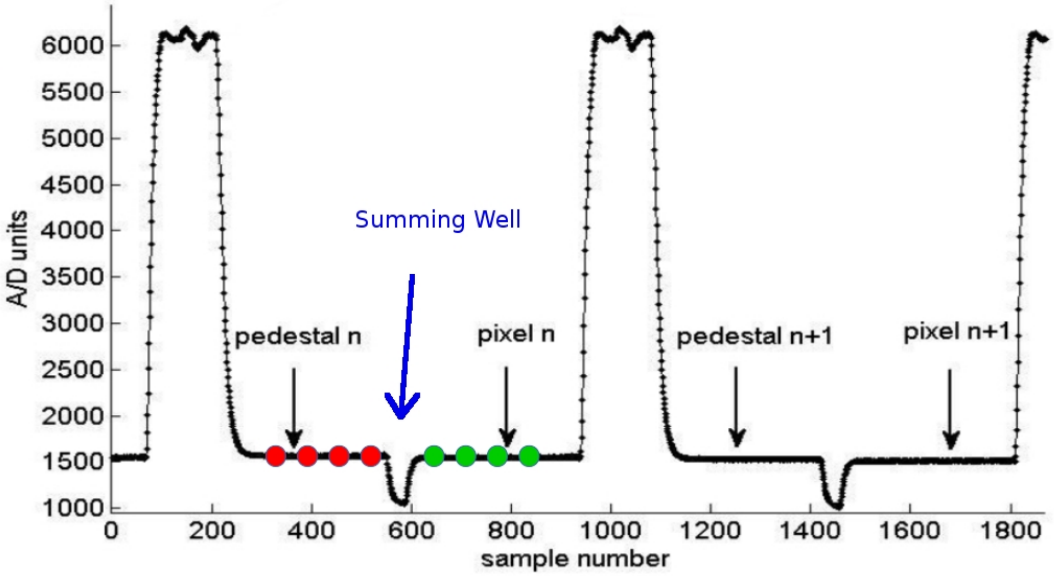


$$cds_i = \frac{1}{T}\int_0^T [Data_i(t) - Ref_i(t)]\,dt \Longrightarrow cds_i = \frac{1}{T}\left[\int_{t_3}^{t_4} x_i(t)\,dt - \int_{t_1}^{t_2} x_i(t)\,dt\right]$$

Digital correlated double sampling

GOAL : Substitute the analog integrator with a digital system which implements CDS in an FPGA.

- Take N samples of the pedestal and the pixel values during the observation time T
- Digital Signal Process the data
- Apply a digital CDS to the processed data



$$cds_i = \frac{1}{N_s}\left[\sum_{ns} pixel_i(ns) - \sum_{ns} pedestal_i(ns)\right]$$

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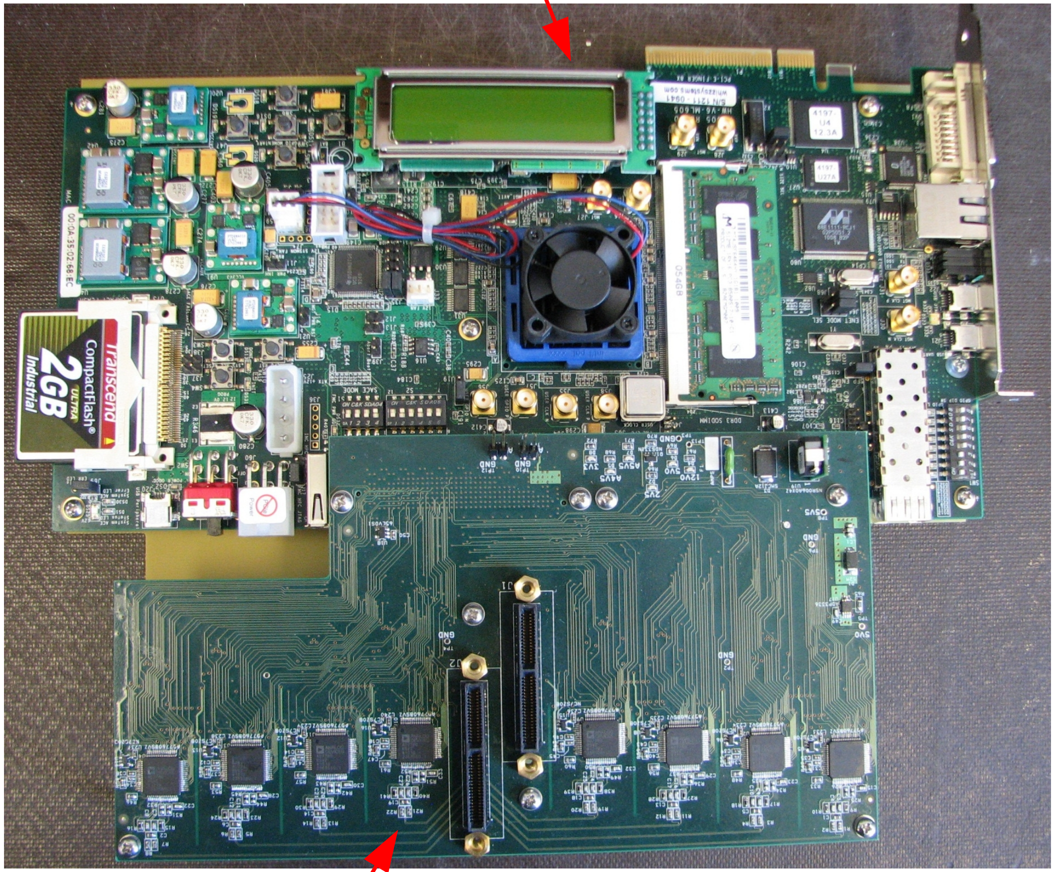
FPGA SETUP

- Xilinx ML605 evaluation board with Virtex-6 XC6VLX240T-1FFG1156 FPGA
- Analog to digital converter board developed by FNAL and ESE
  - Low noise
  - 8 Channels
  - Fs : 2.5 MHz
  - 24 bit
  - FIR filter

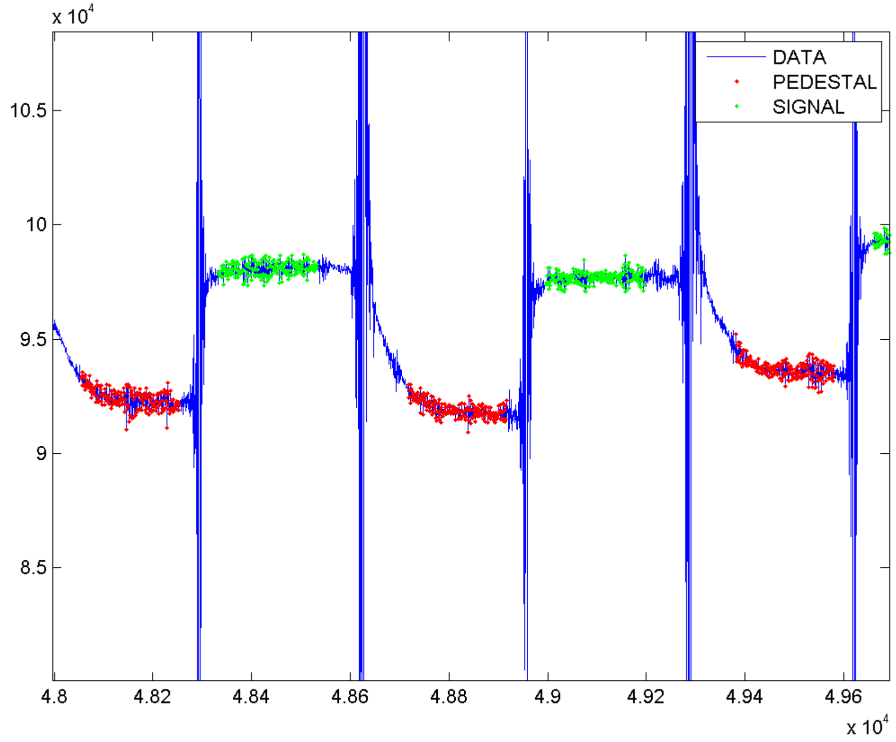
Xilinx ML605



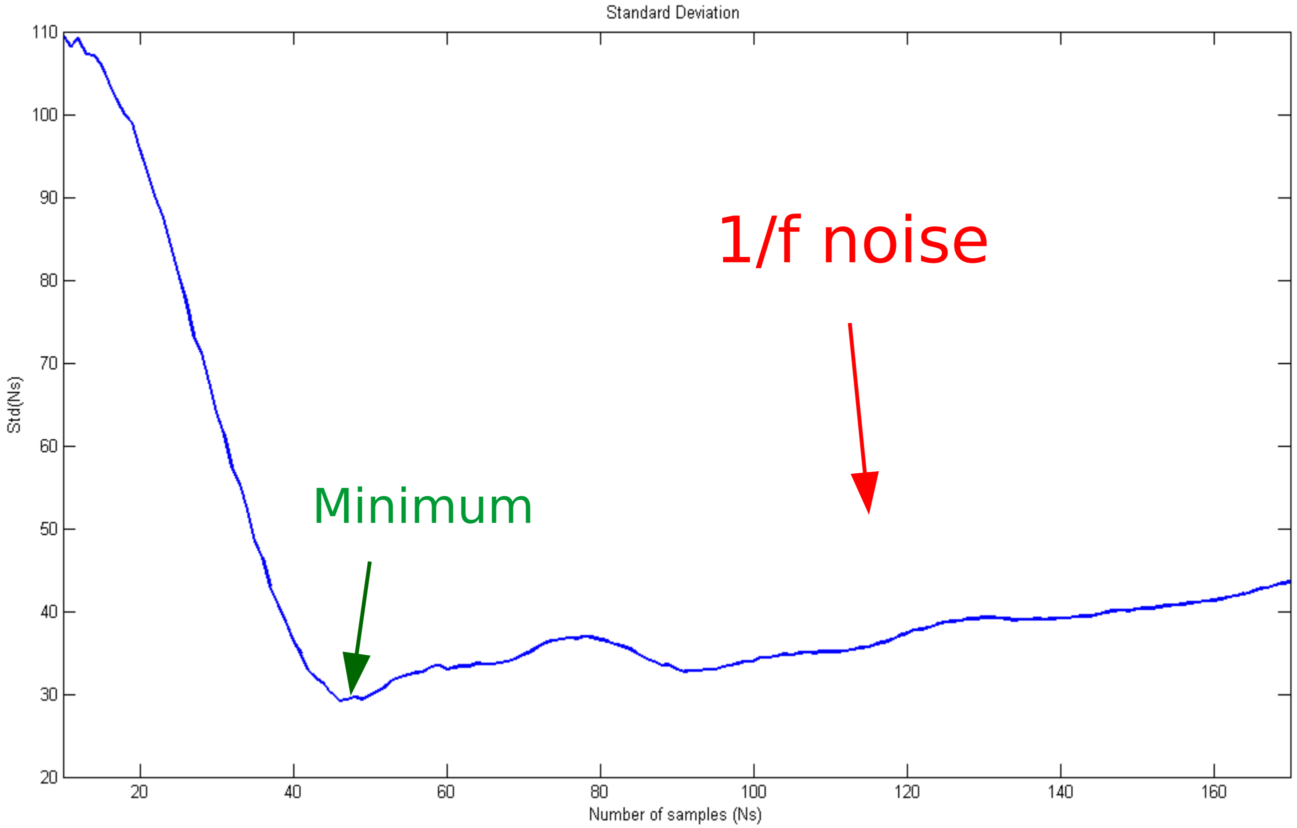
FNAL/ESE 8 channel A/D low noise board

Data analysis

- Analyze the digitized CCD signal with Matlab.
- Recognize "pedestal" and "pixel" values.
- Measure pixels value by <u>digital correlated double sampling</u> method.
- Calculate and plot the standard deviation of pixels for several integration time values.

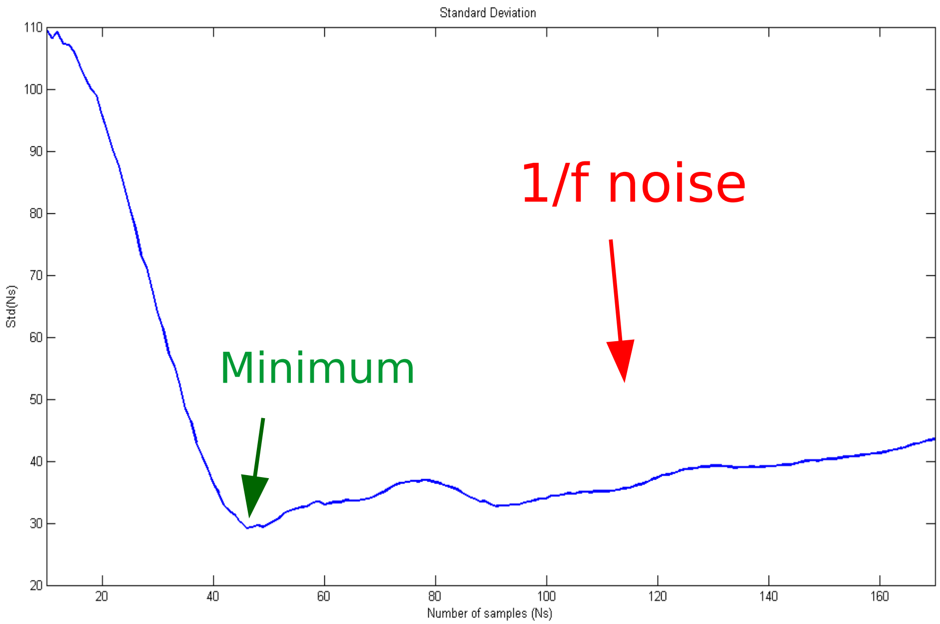


Standard deviation and noise



- 1/f noise or “pink noise” is often the S/N limitation to achieve lower energy detection in cosmology and other areas of physics and engineering.
- Digital signal processing beyond CDS can improve noise below 1/f limit.

Noise measurement

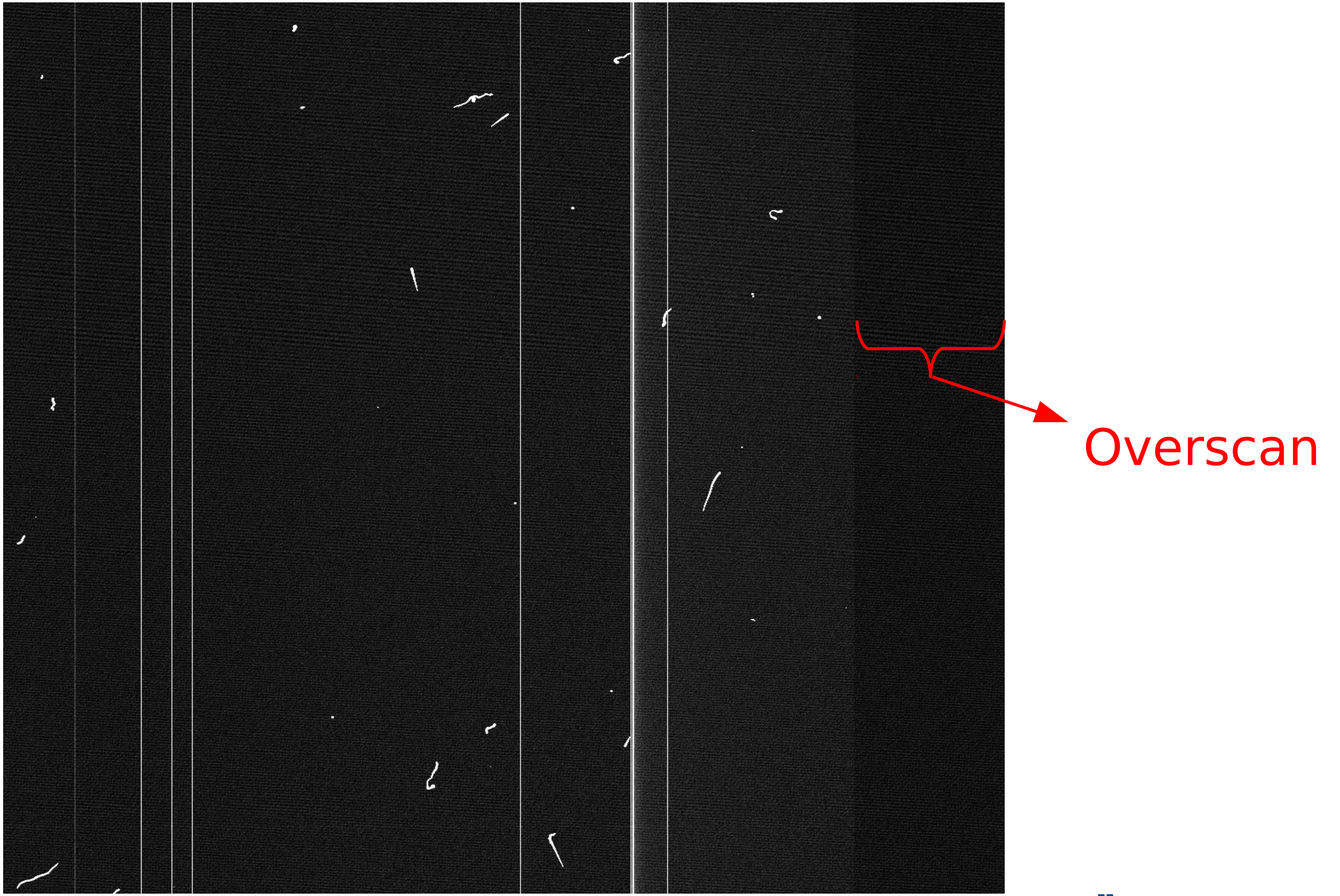


Minimum value : ~ 25 ADU for 45 samples.

- Gain of the electronic system : 13.2 [next slides]

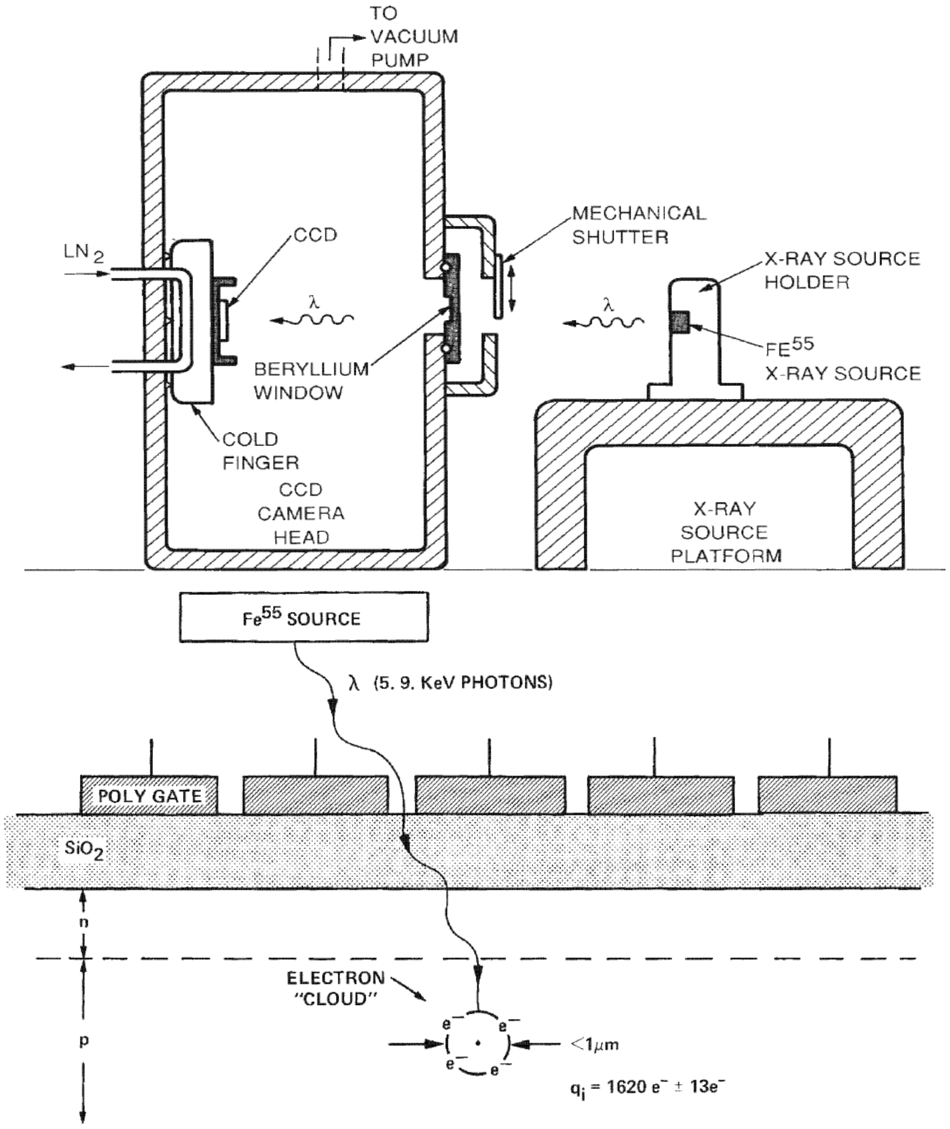
$$Noise \approx \frac{25}{13.2} \approx 1.89\,electrons$$

Processed image in Matlab



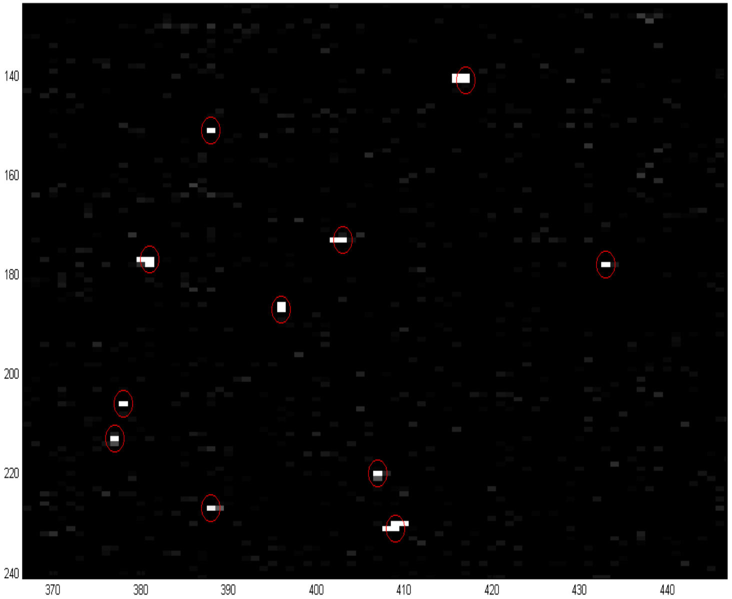
X-ray calibration

- The current CCD technology does not permit accurate measurement of small charge units.
- We use an alternative calibration : <u>x-ray illumination with **Fe-55** source</u>, placed in front of CCD.
- The high energy of x-ray is absorbed by silicon and multiple e-h pairs are generated.
- In contrast to the visible light case, the electrons are generated in a very small cloud diameter.



X-ray image and clustering

- Group the bright pixels in clusters.
- Calculate the total energy for each cluster.
- Make an histogram of clusters energy.



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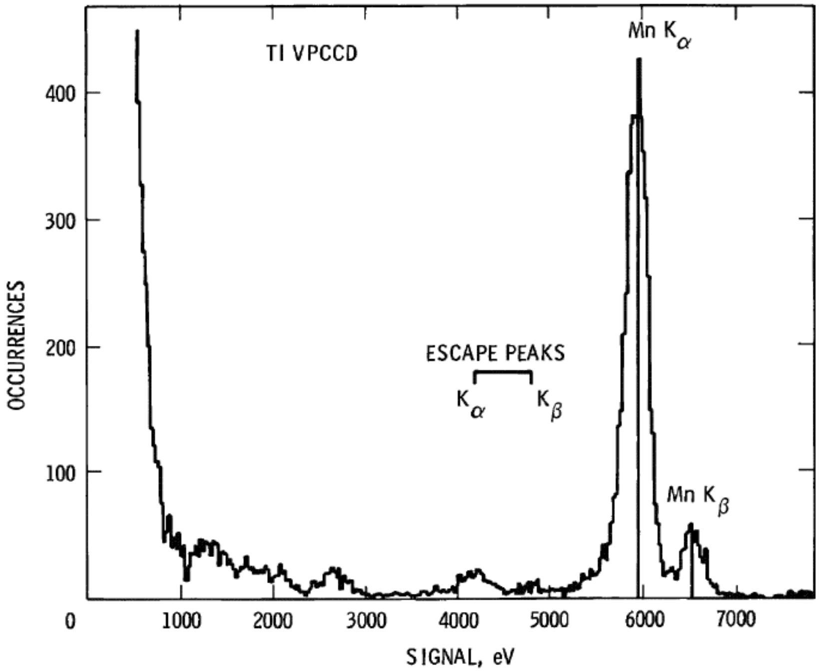
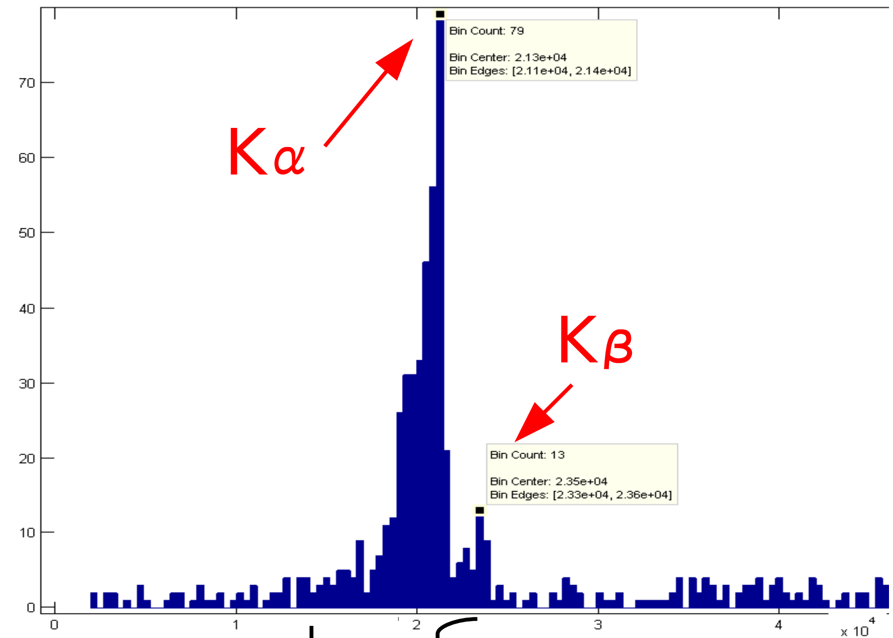
Histogram and gain





Kα = 2.13e4 ADU

Kβ = 2.35e4 ADU

Kα [FE-55] = 1620 e-

Kβ [FE-55] = 1778 e-

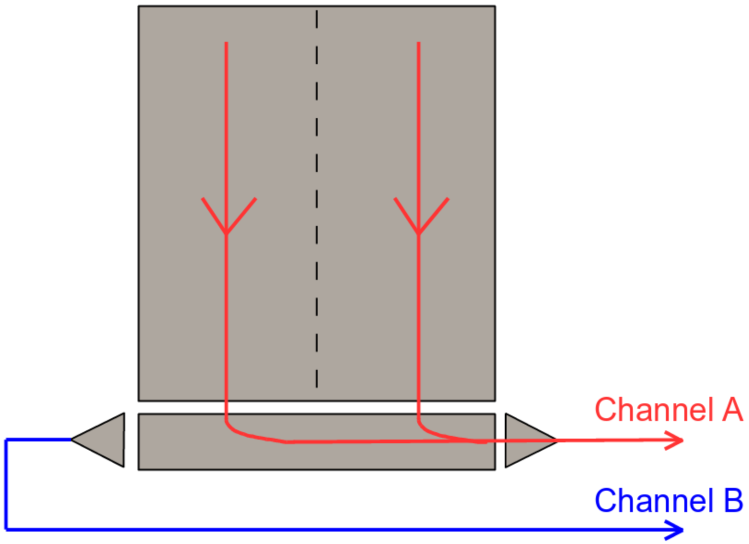
$$Gain' = \frac{2.13e4}{1620} = 13.15$$

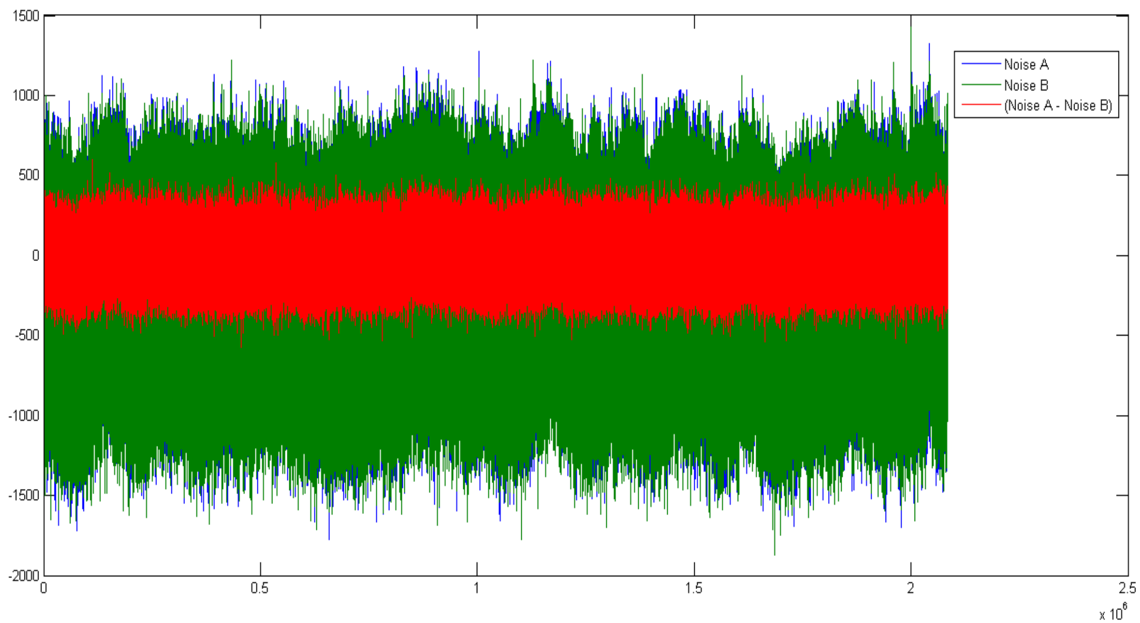
$$Gain'' = \frac{2.35e4}{1778} = 13.22$$

$$\boxed{Gain \approx 13.2 \frac{ADU}{electron}}$$

Noise consideration

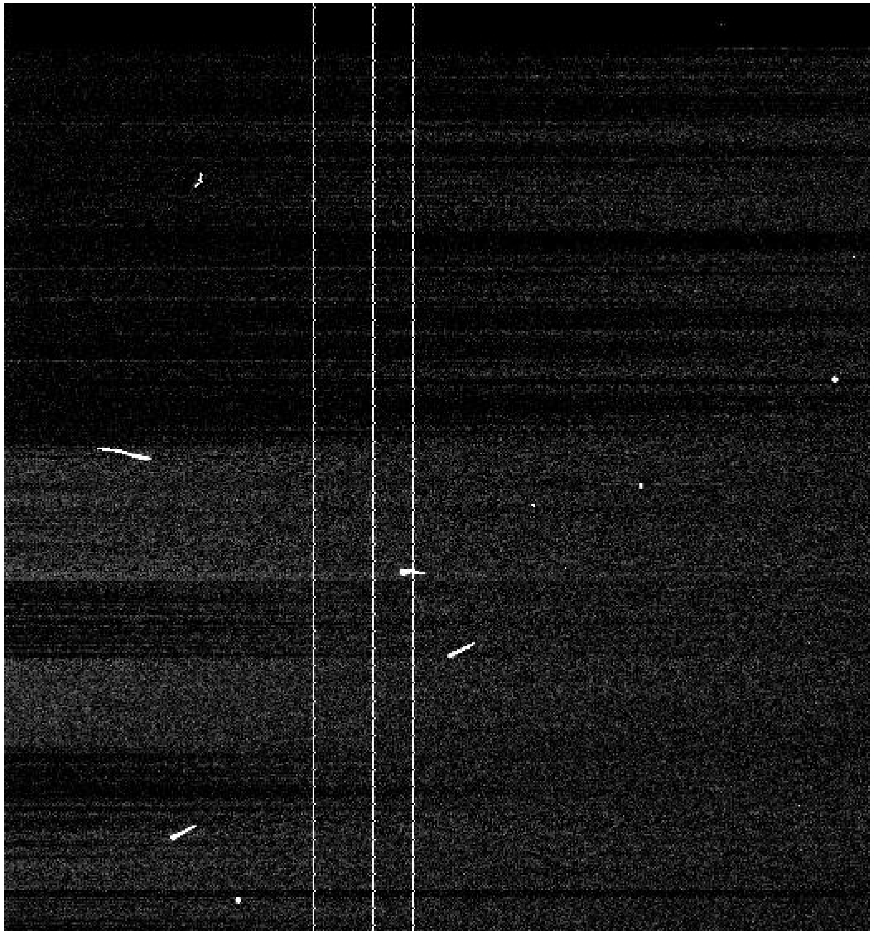
- In our CCD the image is only transferred into one of the two horizontal registers.
- In the other amplifier there'll be only the noise of CCD.



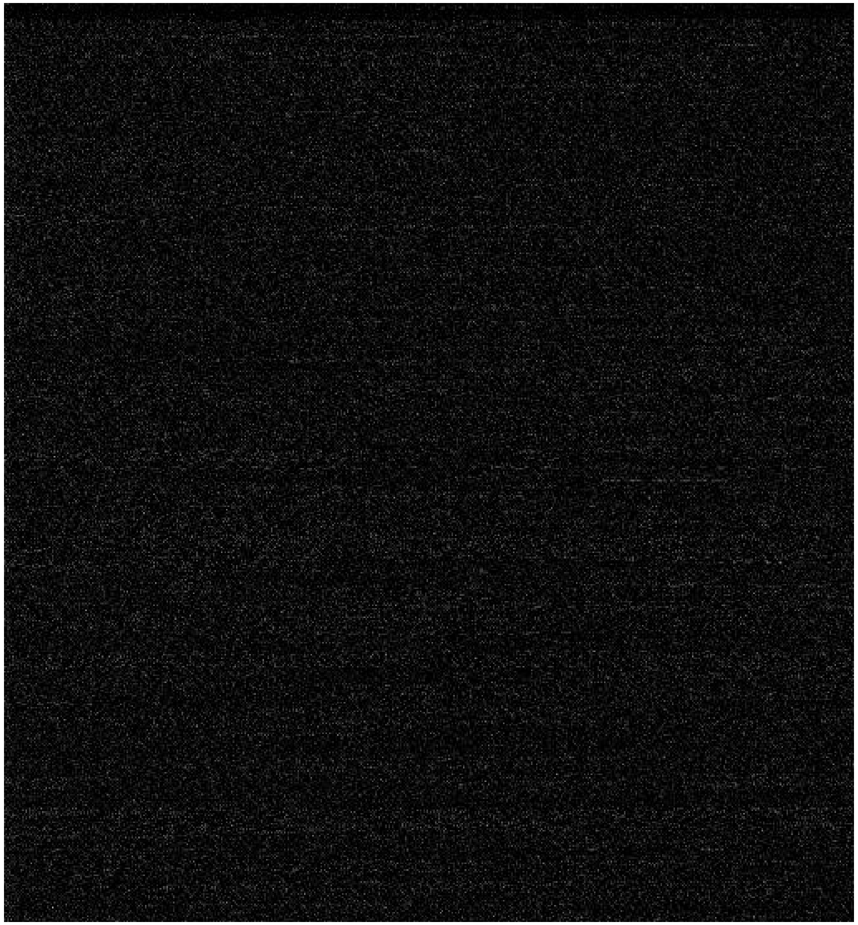


The noise of the two channels are correlated !

Two channels acquisition (data and noise)

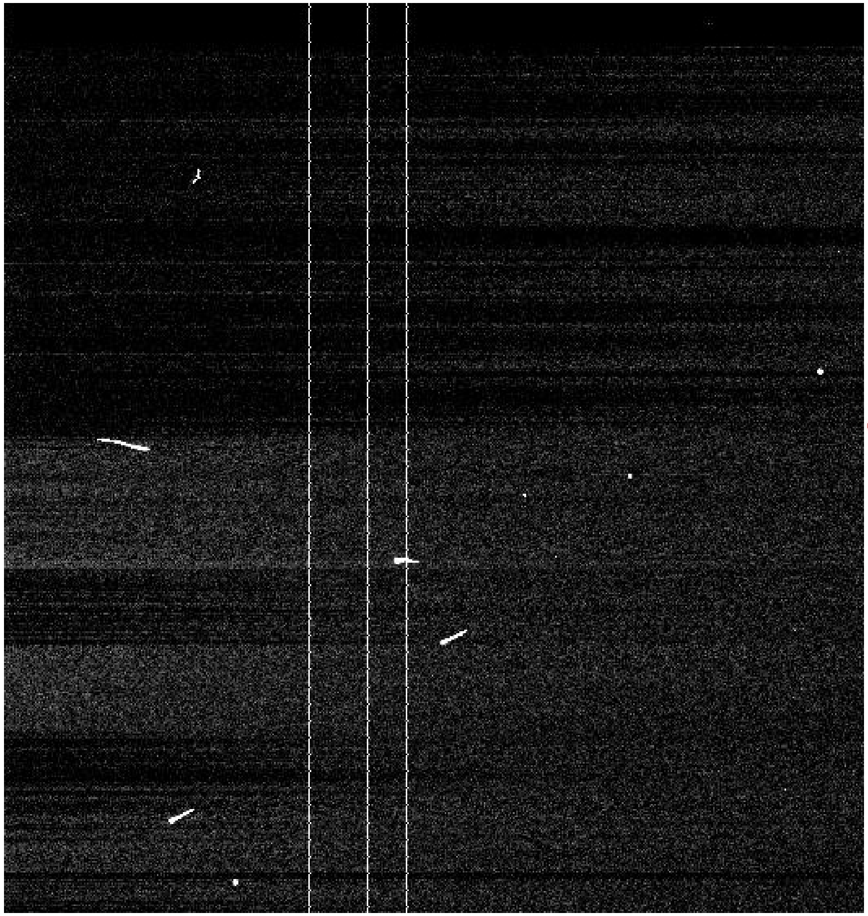


Channel A

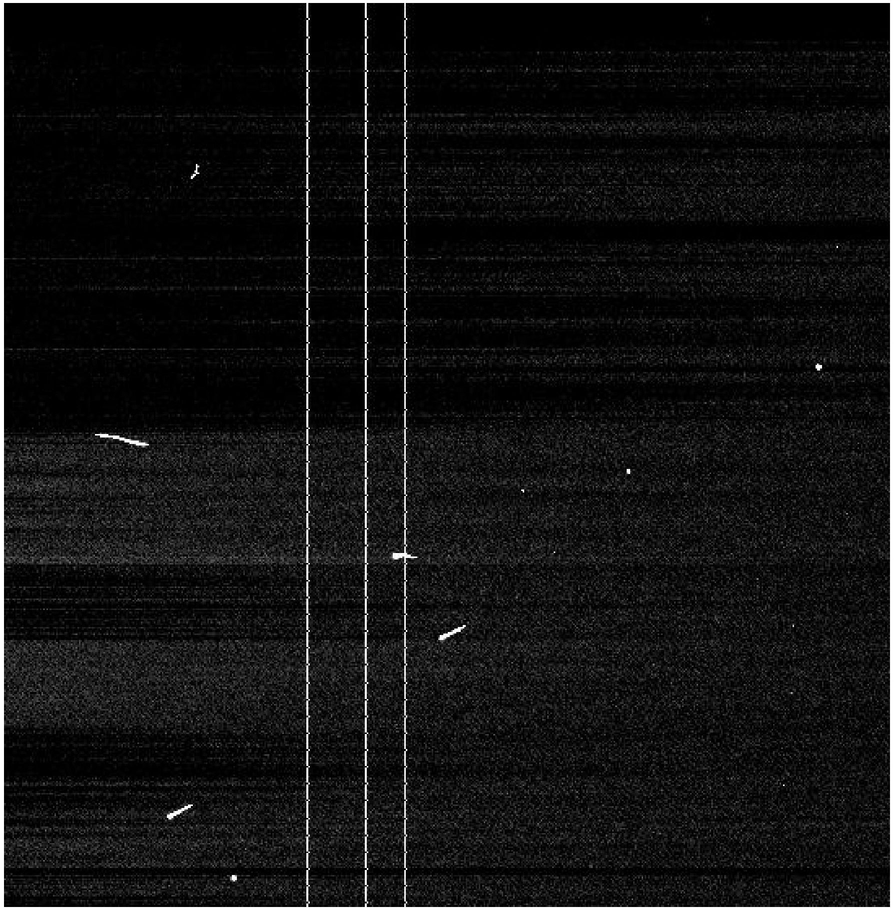


Channel B

Image noise improvement



Channel A



Channel A - Channel B

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Thank you