Star Tracker Focal Plane Evaluation for the JIMO Mission

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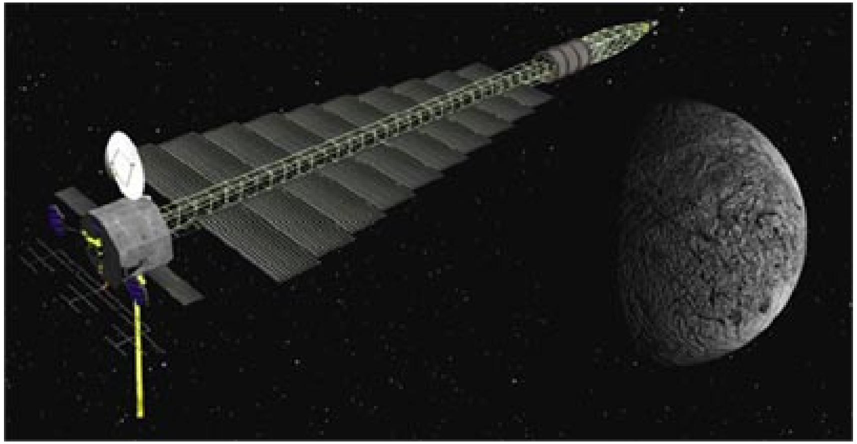
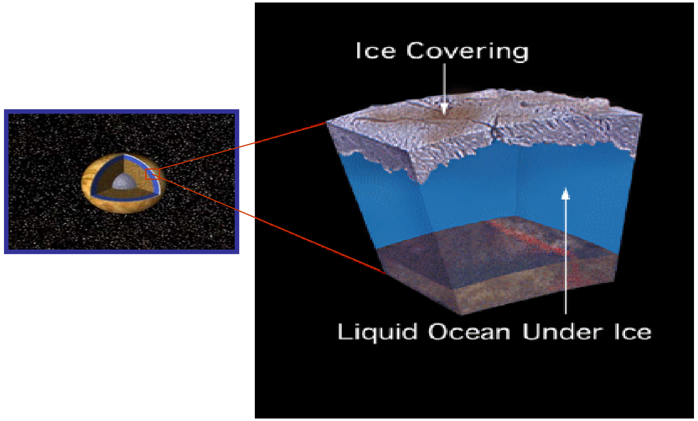
Introduction

- **Prior to its cancellation,**
  JIMO was to orbit and explore Jupiter's moons -
  Callisto, Ganymede, Europa



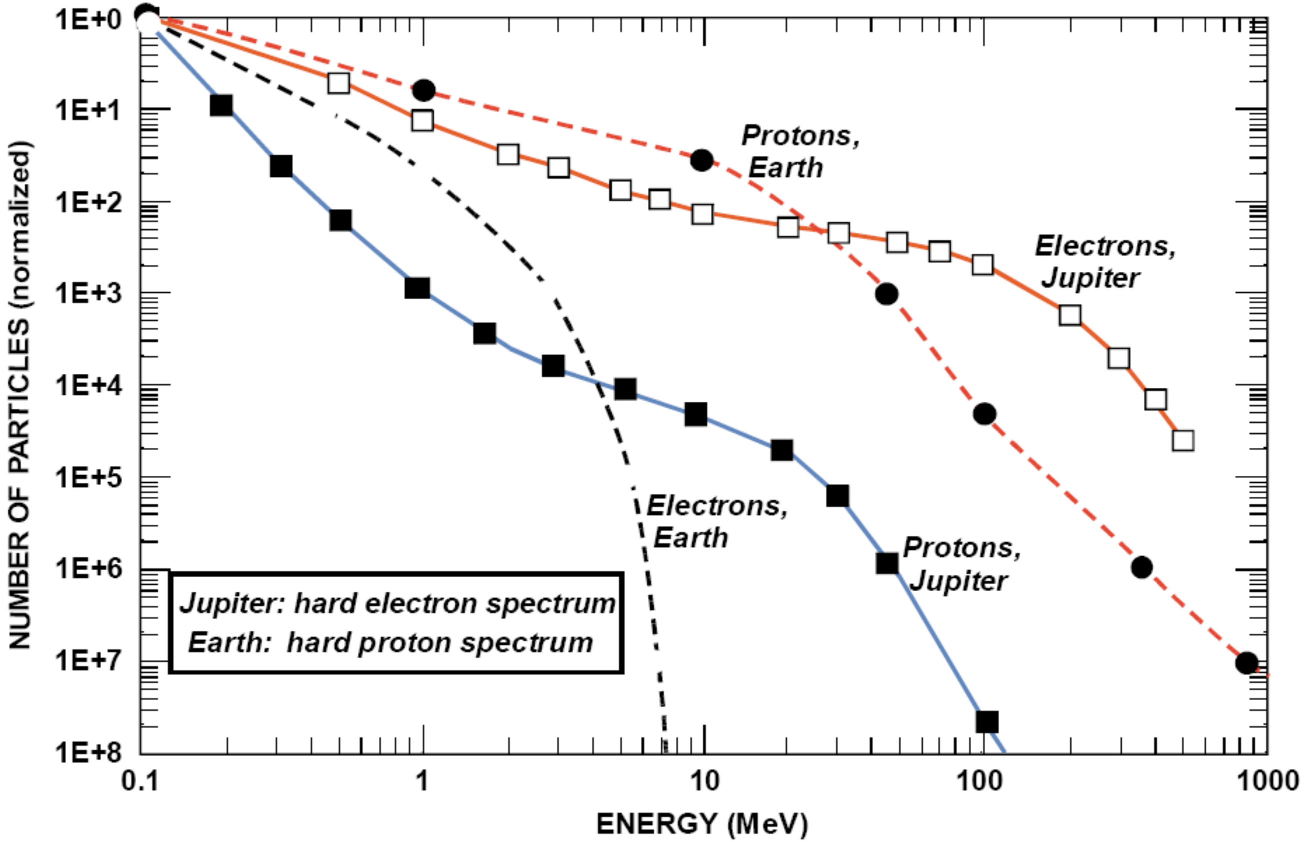
Europa



- **Voyager and Galileo spacecrafts data initiated plans to search for life beneath icy surfaces of Jovian moons**

Radiation Environment

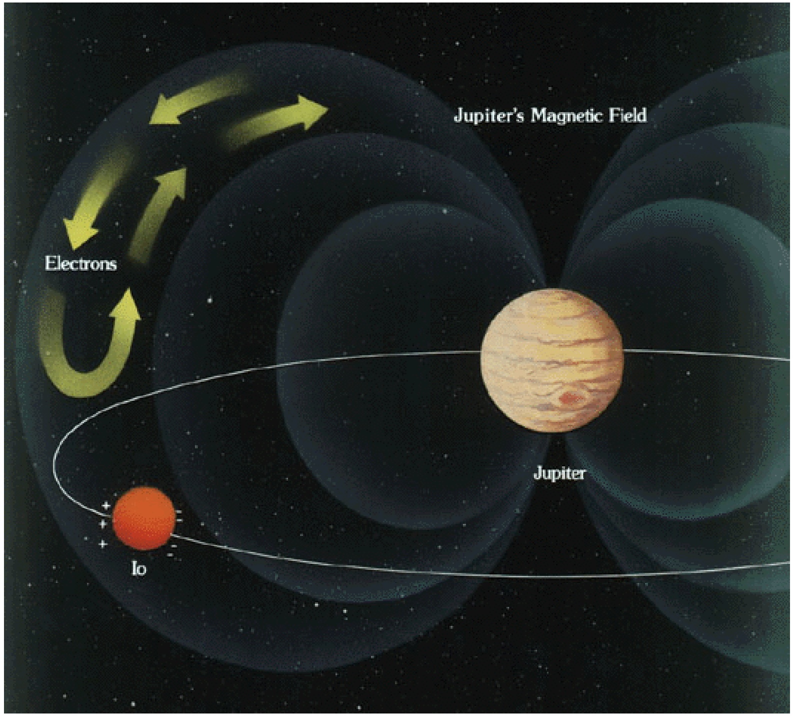
Trapped Belt Energy Distributions on Jupiter and Earth

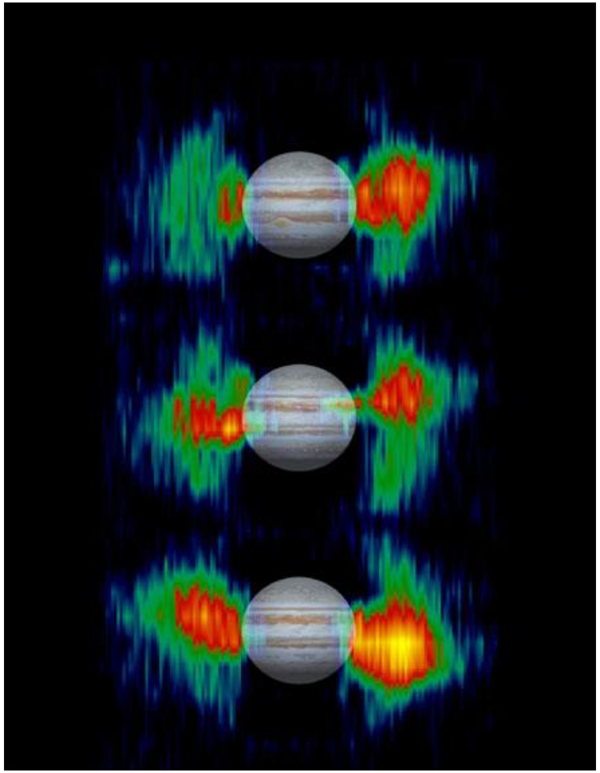


(“Space Radiation Effects on Microelectronics”, Section 514, JPL)

Radiation Challenge

- **Details in Jupiter radiation belts mapped by Cassini's spacecraft radar in a listen-only mode**

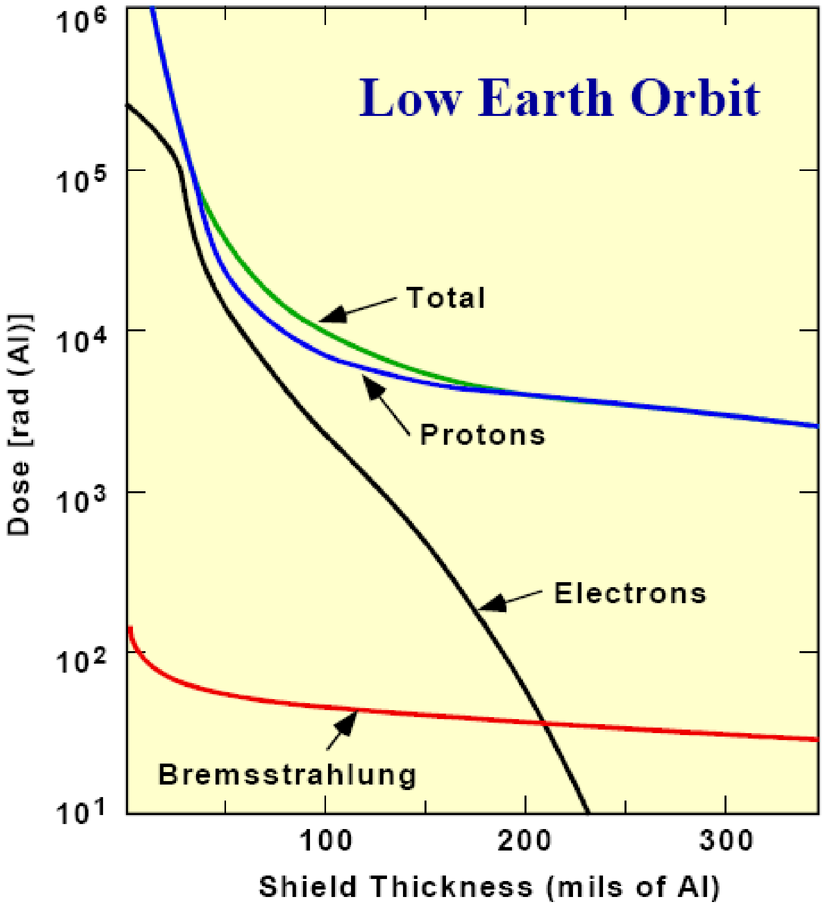


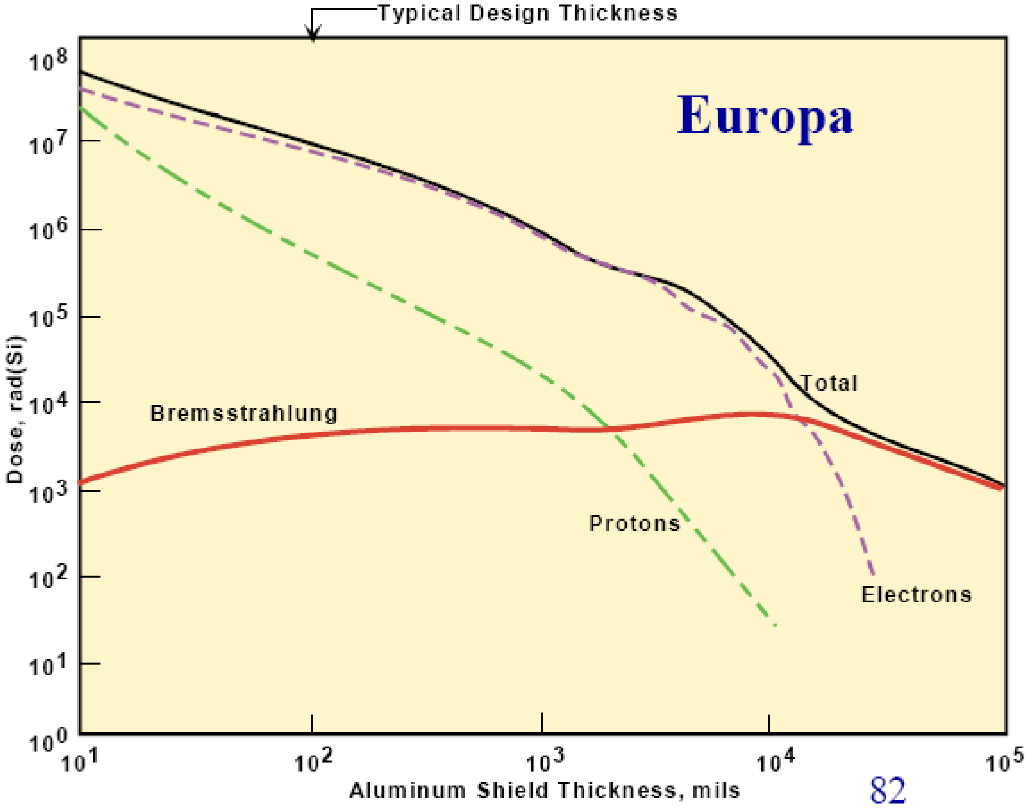


- **High-energy electrons trapped in magnetic field of Jupiter is a real challenge for spacecraft ACS sensors**

TID Shielding

- Electrons more effectively shielded than protons
- Incremental shielding gives diminished returns





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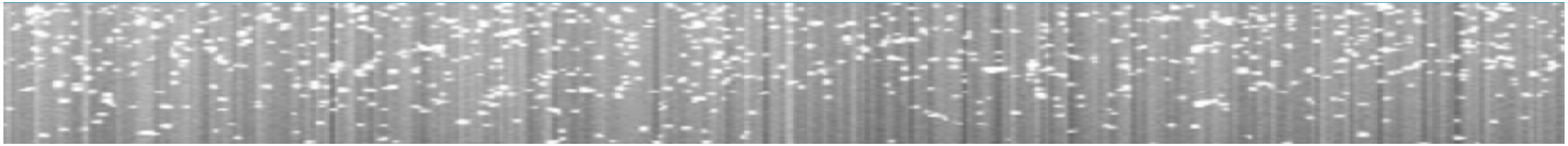
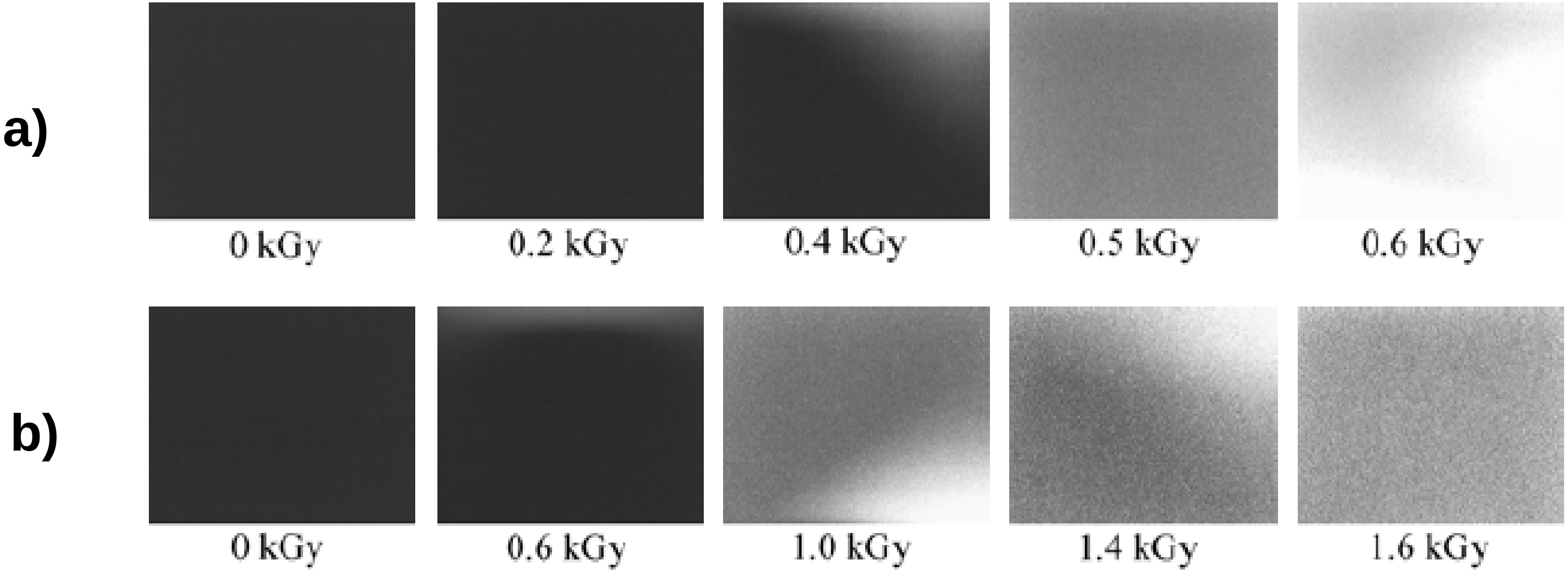
Radiation Damage



CCD imager under proton flux



Dark output images captured from CMOS sensors irradiated at different doses:

(a) Electron irradiation; (b) γ-ray irradiation. (Meng, X et al. Rare Metals, 23, No. 2, 2004)

Mechanisms for Global Permanent Damage

Electrons and Protons Produce Ionization in Semiconductors

- Ionization excites carriers from conduction to valence band
- Charge is trapped at interface regions
- Units: rad(material) *1 rad = 100 ergs/g of material*
- Depends on bias conditions and device technology
- Typical effect: threshold shift in MOS transistors

Displacement Damage Also Occurs

- “Collision” between incoming particle and lattice atom
- Lattice atom is moved out of normal position
- Degrades minority carrier lifetime
- Typical effect: degradation of gain and leakage current in bipolar transistors

(“Space Radiation Effects on Microelectronics”, Section 514, JPL)

Displacement Damage

Effects of Displacement Damage in Semiconductors

- Minority carrier lifetime is degraded
  - Reduces gain of bipolar transistors
  - Also affects optical detectors and some types of light-emitting diodes
  - Effects become important for proton fluences above 1×10^{10} p/cm^2
- Mobility and carrier concentration are also affected

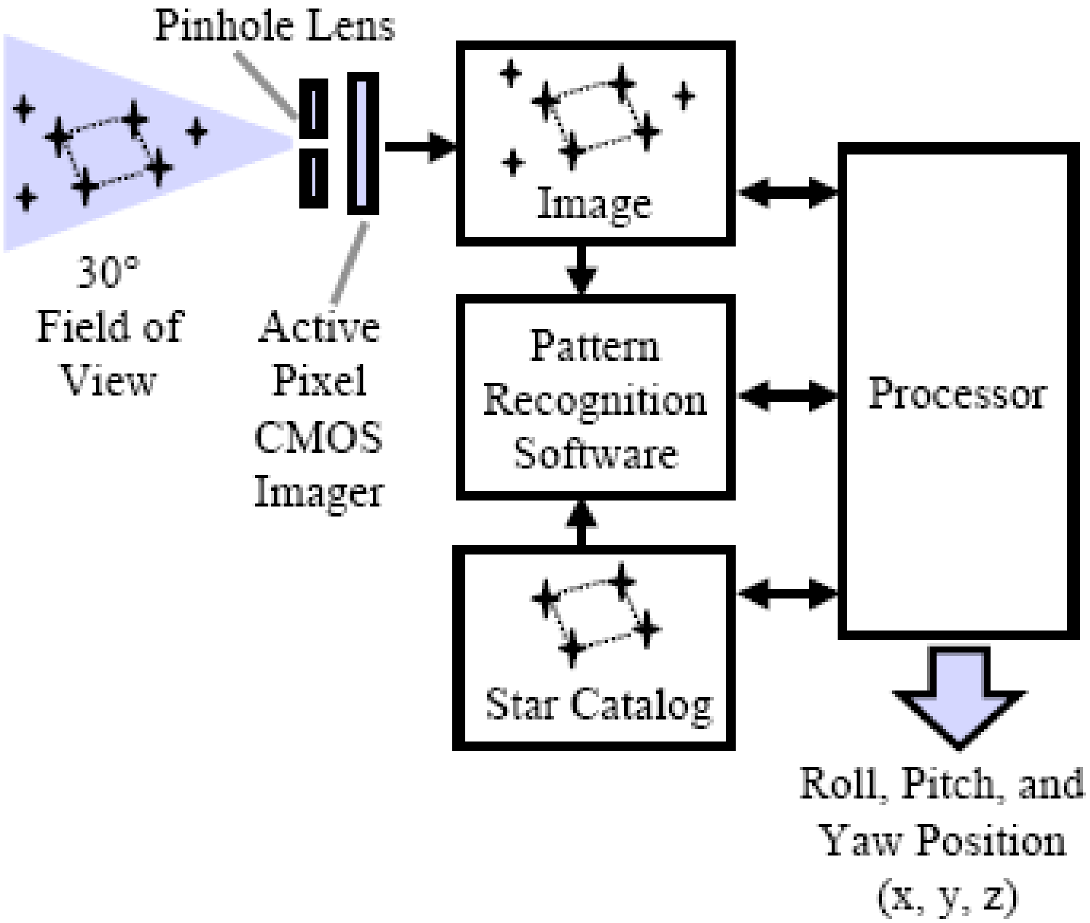
Particles Producing Displacement Damage

- Protons (all energies)
- Electrons with energies above 150 keV
- Neutrons (from on-board power sources)

(“Space Radiation Effects on Microelectronics”, Section 514, JPL)

Star Tracker Performances

- Field of View (FOV)
- Dim star limit
- Star intensity accuracy
- Accuracy
  - Bias
  - Noise equivalent angle
- Update rate



(Zenick R., SSC03-X-7)

Focal Plane Characteristics & Radiation Damage

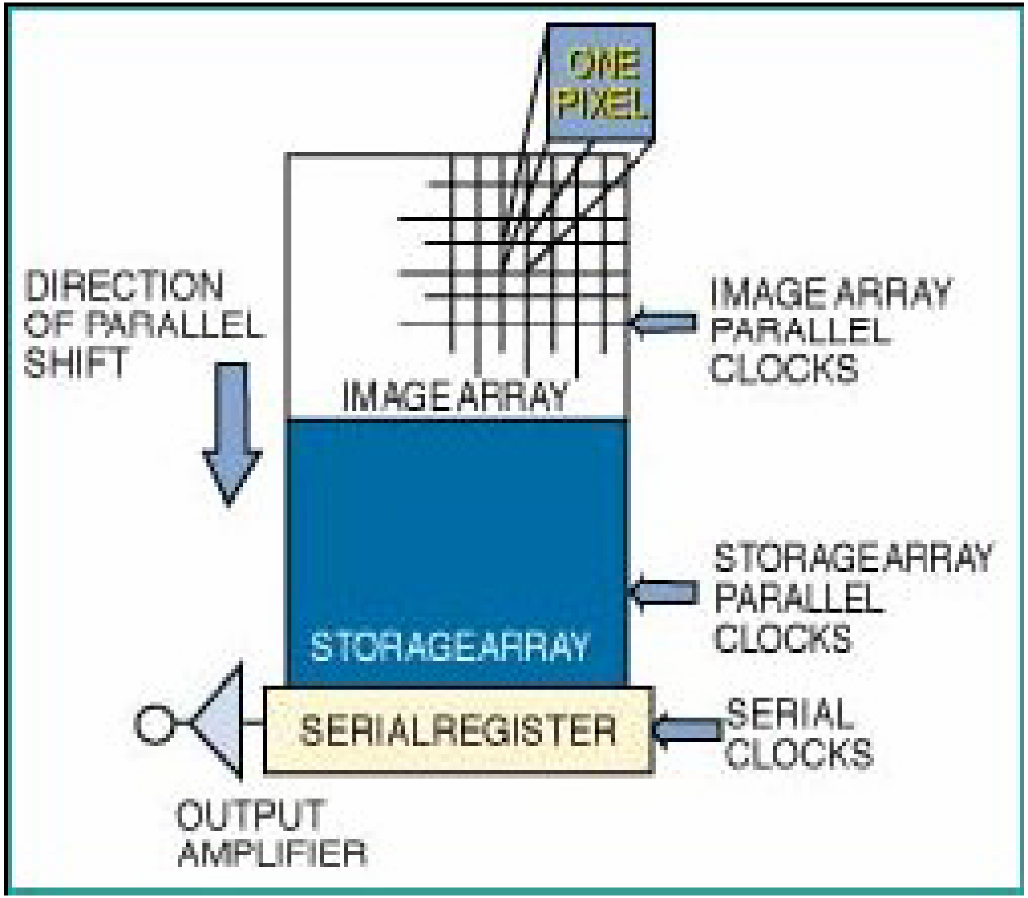
- **Responsivity**
- **Linearity**
- **Readout Noise**
- **Dark Current (DC)**
- **DC Variation**
- **Frame Rate**
- **Quantum Efficiency (QE)**
- **Fill Factor (FF)**
- **Full Well (FW) Capacity**
- **Imager/Pixel Size**
- **Amount/Kind of Defects**

Responsivity Decrease
“Hot Pixels” Growth
DC Rate/Non-uniformity Increase
FW Capacity Reduction
QE Degradation

Charge-Coupled Device (CCD)

- **CCD can be defined as a monolithic array of closely spaced MOS capacitors**

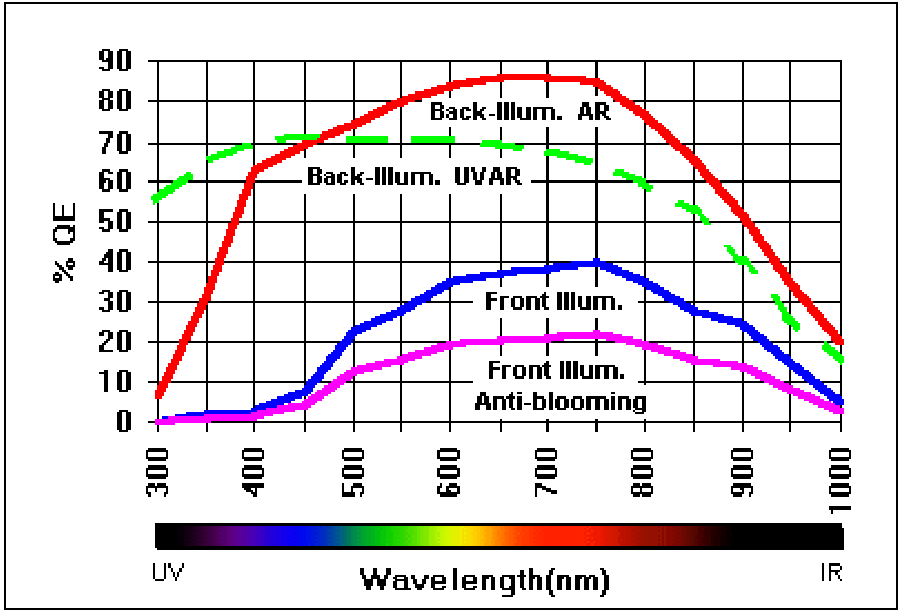
- **CCD Imaging Process:**
- **Exposure to Light (charge collection)**
- **Charge Transfer**
- **Charge to Voltage (conversion and output amplification)**



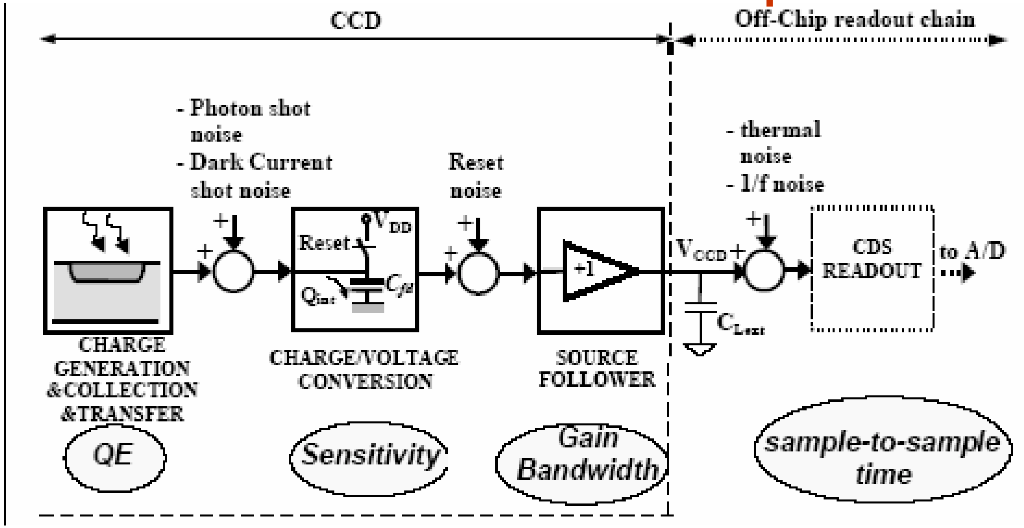
Frame –Transfer CCD Architecture (KODAK, #KCP-001)

CCD

- Current CCD technologies are mature
  - High QE (~90%)
  - Low read out noise (2-3 e^- rms)
  - low DC(10-20 pA/cm^2)
  - High dynamic range (~75 dB)
- But Displacement and Ionization Damage have the most severe consequences for CCD



Apogee Instruments Inc. Quantum efficiency data

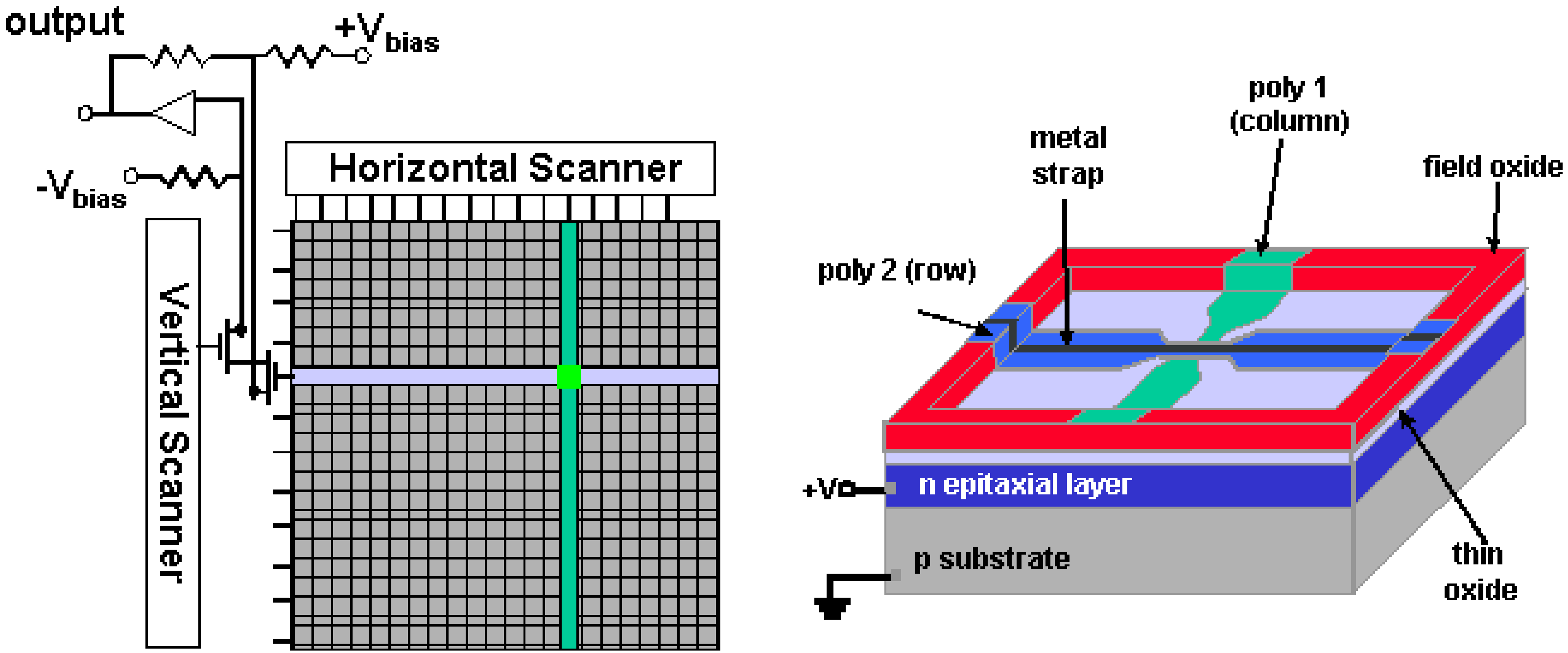


(P. Magnan, Nucl. Instr. Meth. Phys. Res. A504, 2003)

The quality of acquired signal depends on key parameters – QE, Sensitivity, gain and bandwidth of source follower amplifier

Charge Injection Device (CID)

- **Two-dimensional arrays of MOS coupled capacitors**
- **Non-destructive readout operation is presented either by parallel charge injection or row readout technique to increase the tolerance to radiation**



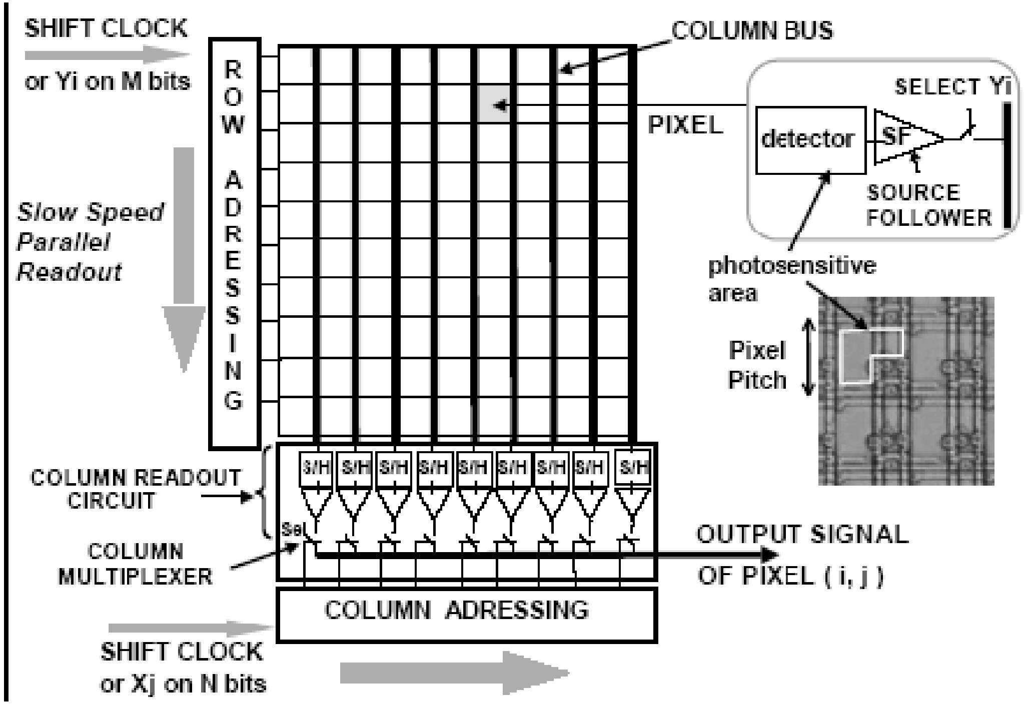
(a) (b)

Structure of a CID (a) and its individual pixel (b). Pixel boundaries are created by the field oxide which reduces the electric field in the epitaxial region under the polysilicon runs and creates pixels.

(B. Backer et al., Characterization of CID-38, Rochester Inst. of Techn., NY)

Active Pixel Sensor (APS)

- **An insertion a transfer gate between the sensing and storage photo-gates in CID pixel brought to life a new class of imagers – APS**
- **With a pre-amplifier per pixel, row selection and preset switches, APS architecture was expected to eliminate crosstalk, reduce a FPN and increase dynamic range.**
- **CMOS fabrication process brought DC values to 50-200 pA/cm^2, ensured DC uniformity, reduced readout noise to 37-74 e$^-$ rms.**

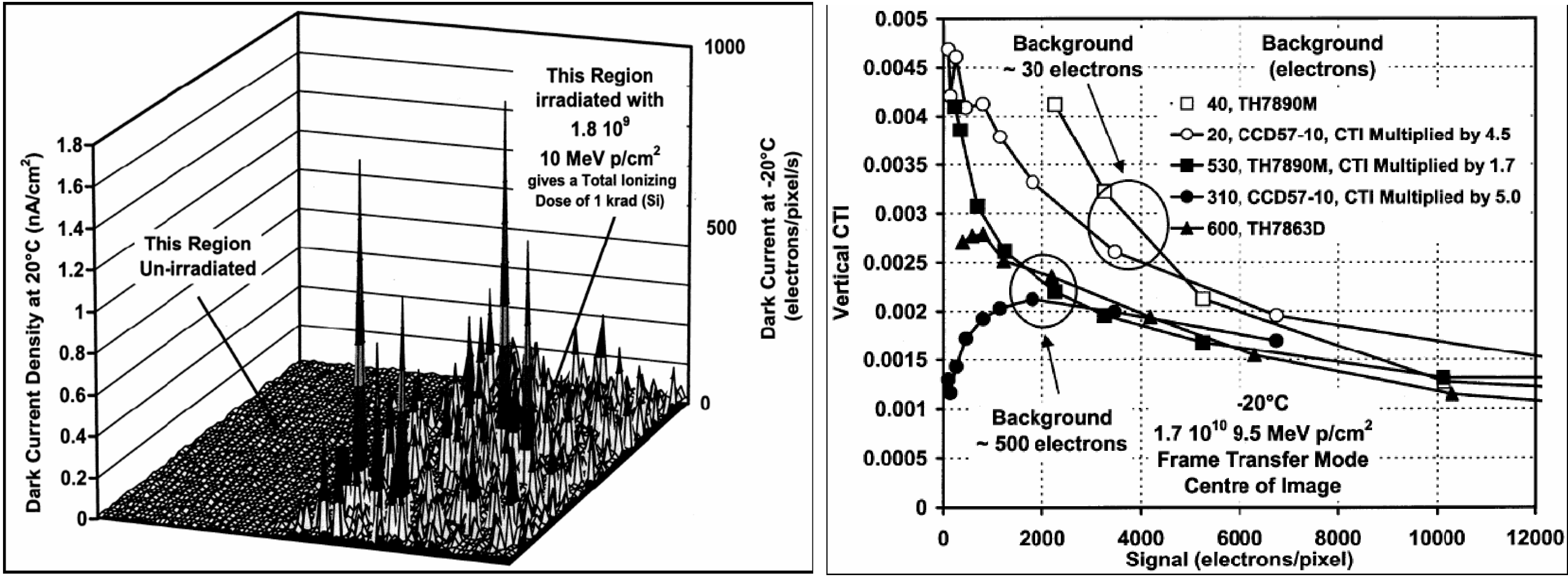


CMOS APS Architecture

(P. Magnan, Nucl. Instr. Meth. Phys. Res. A504, 2003)

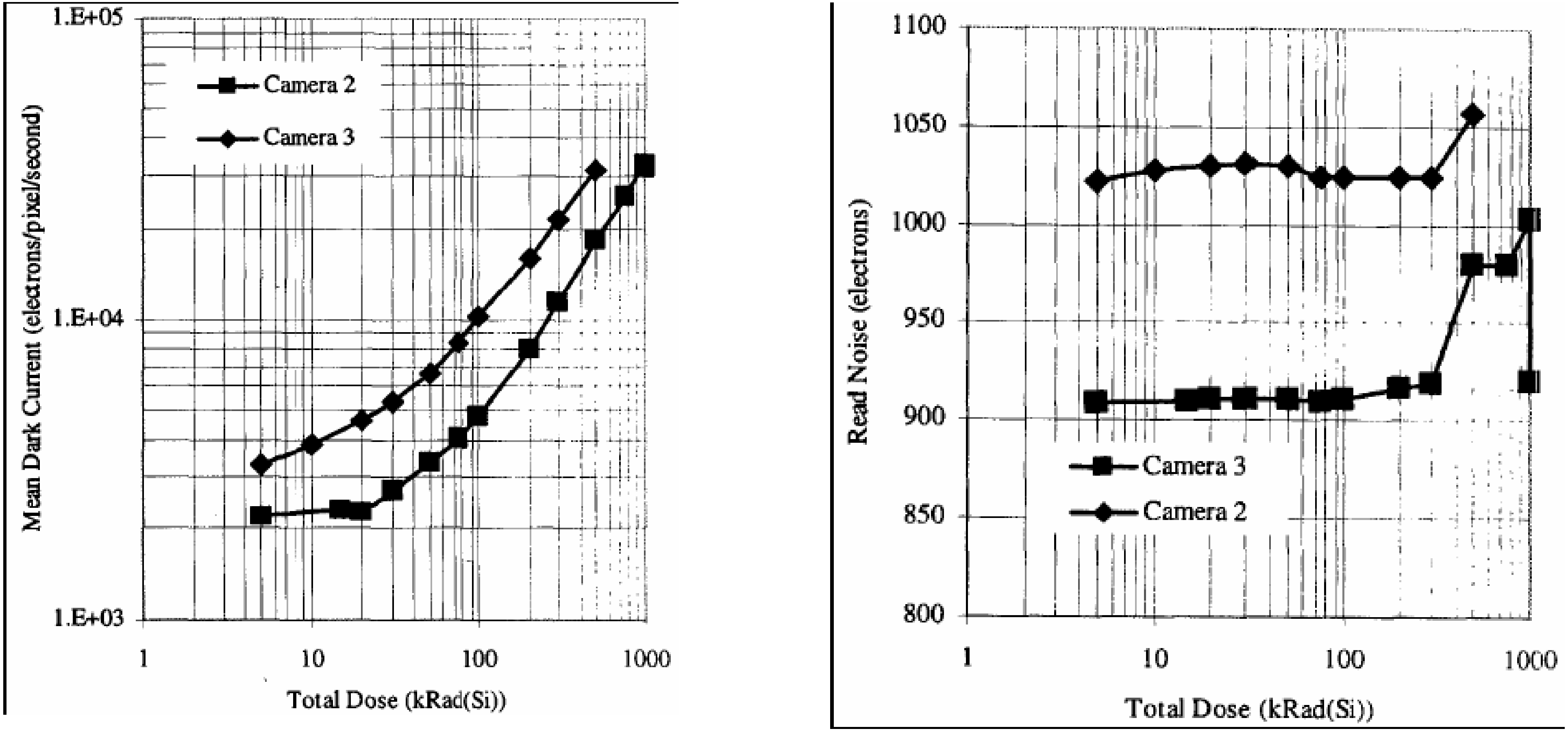
- **Co-60 γ-source experiments with TID up to 10.2 Mrad (Si) have proven a reasonable APS radiation resistance**

Proton Irradiation Data (CCD)



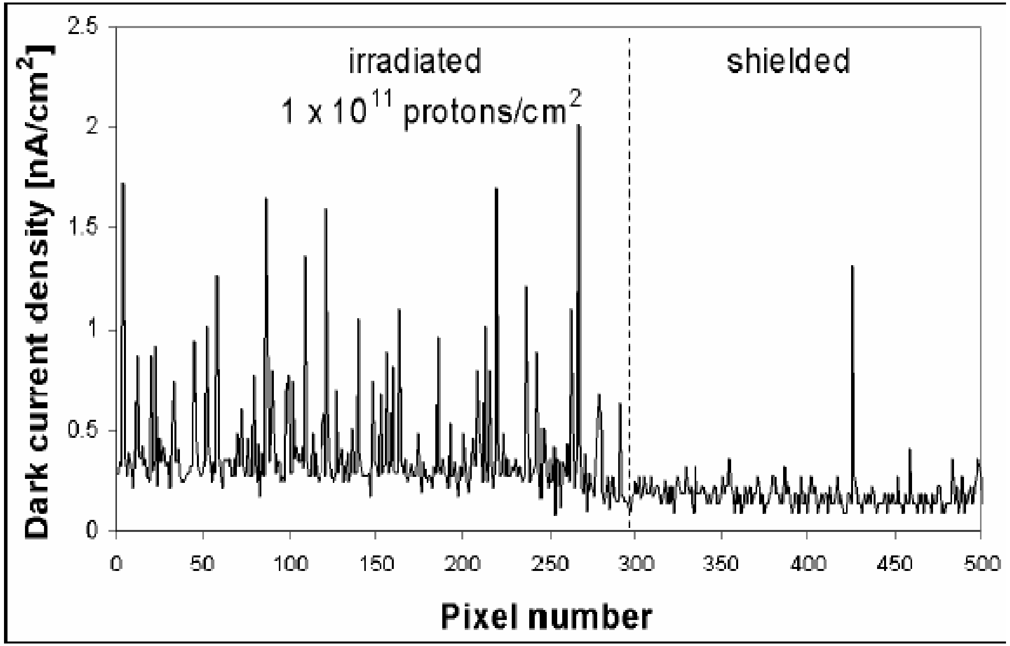
Proton-induced dark current spikes (left) (J. C. Pickel et al., IEEE Trans. Nucl. Sci., 50, pp. 671-688, 2003) and comparison of vertical CTI values for CCD57-10, TH7890M, and TH7863D (right) at two background levels (G. R. Hopkinson and A. Mohammadzadeh, IEEE Trans. Nucl. Sci., 50, pp. 1960-1967,2003)

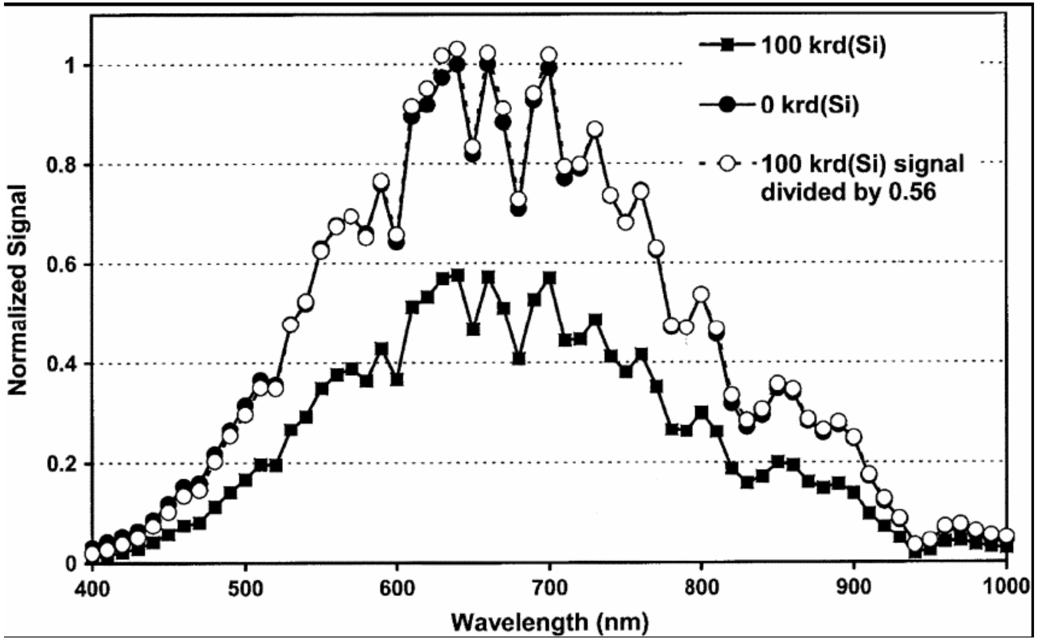
Electron Irradiation Data (CID)



CID22Q Mean dark current (left) and read noise (right) measurements during 30 MeV Electron irradiation at a dose rate of 50 rad (Si)/sec (K. B. Miller et al., Radiation Effects Data Workshop, Reno, NV, July, 2000, p.158-162)

Proton Irradiation Data (APS)





STAR-250 DDD (left) induced dark current density caused by 11.7 MeV proton radiation with a fluence of 1e11 p/cm^2 (J. Bogaerts et al., IEEE Trans. Electron Dev., 50, pp. 84-90, 2003) and Spectral response (right), before and after 9.5 MeV proton irradiation (right) (G. R. Hopkinson et al., IEEE Trans. Nucl. Sci., 51, pp. 2753-2762, 2004)

Summary

- Recent progress in CMOS technology allows APS to become an attractive candidate for space applications which are facing a harsh radiation environment

- Several programs have already been funded by ESA to support the development of APS-based ACS sensors and vision cameras utilizing STAR250 APS

- Radiation characteristics of the future mission star tracker are expected to be improved and finally tested by electron irradiation to reflect the existing severe Jovian environment.