Ultraviolet Detectors for Low Surface Brightness Astronomy

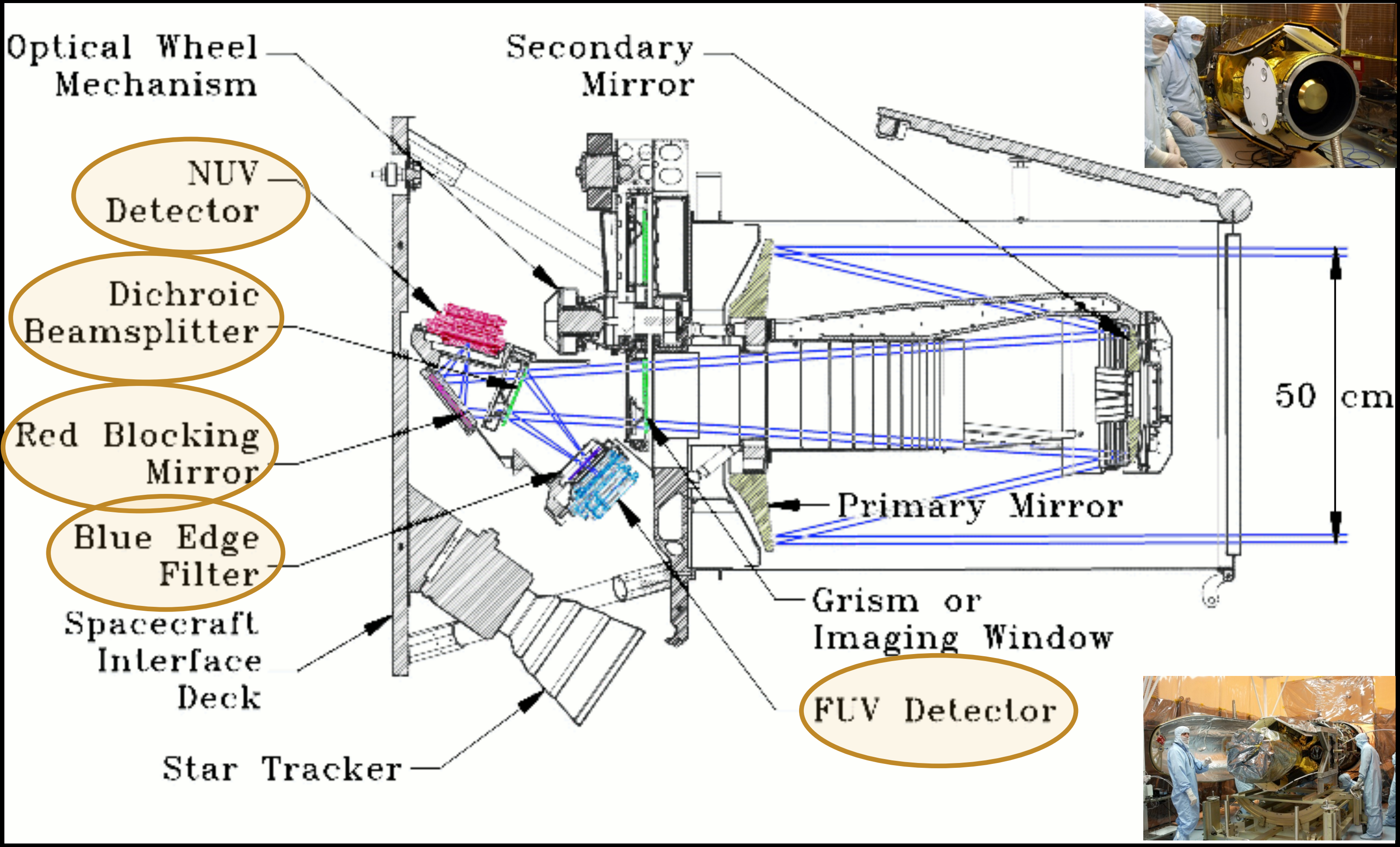
Patrick Morrissey, Chris Martin, Steve Kaye, Nicole Lingner (Caltech)
Shouleh Nikzad, Michael Hoenk, Blake Jacquot, Frank Greer (JPL)
David Schiminovich, Erica Hamden (Columbia)
Peter Pool (e2v)

KISS UV Instrumentation Workshop 2011

Overview

- Our group is operating the NASA Small Explorer GALEX, a UV all-sky survey mission now completing its eight year mission.
- Why the UV, why photon counting?
- What's next?
- Technologies for what's next.
- Results

GALEX UV Technologies



Why Photon Counting?

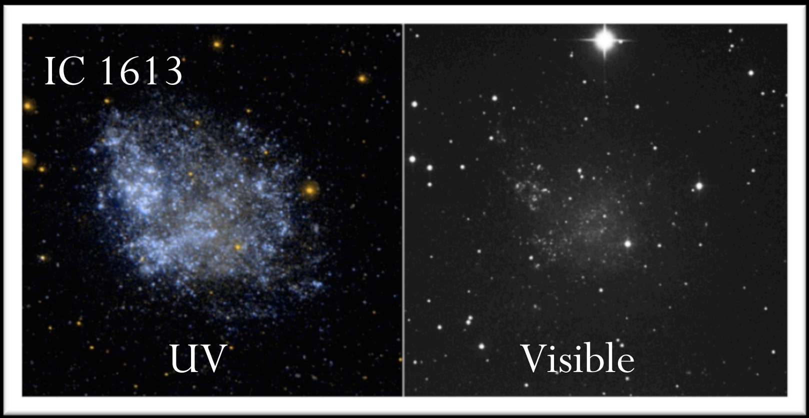
(why go to all this trouble?)

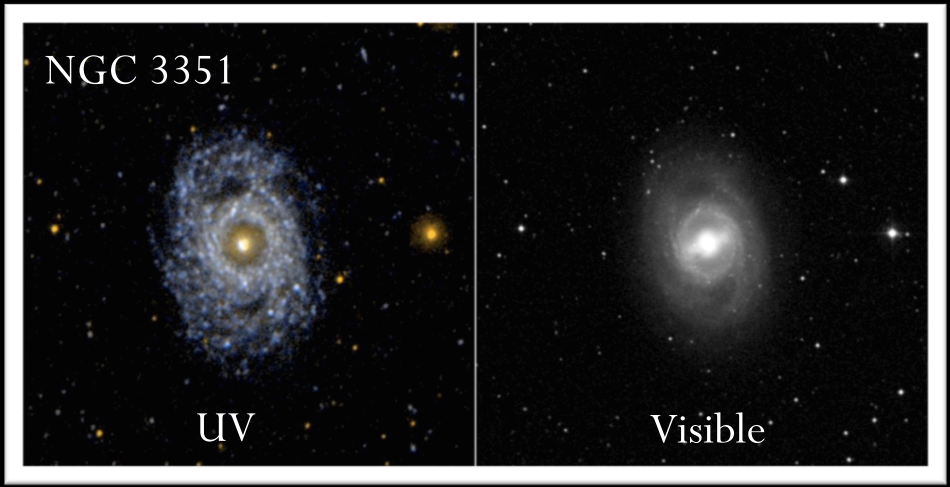
- GALEX FUV~2000 cps (1.25 deg FOV)
  - About ½ is "background"
  - 500 phot/s/cm^2/sr/A
  - In a pixel (~1"), this translates to only

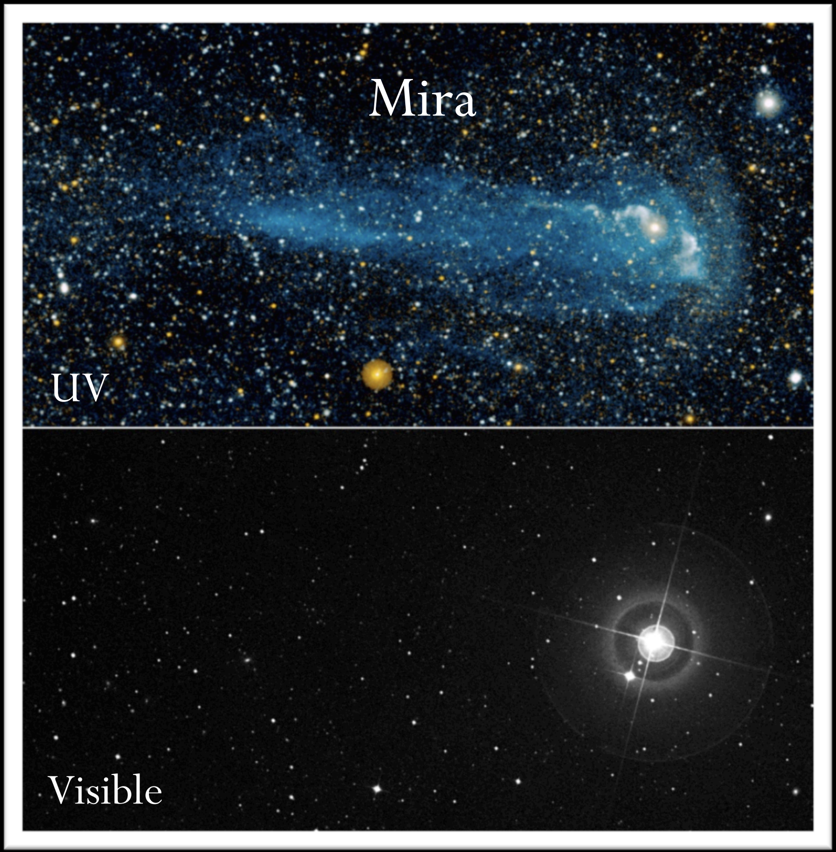
    ~1e-8 phot-s^{-1}-cm^{-2}-A^{-1}
  - Even broad band, that's ~1e-4 c-s^{-1}-pixel^{-1}
  - Reasonable exposures would be completely dominated by conventional CCD read noise at the 1 e^{-} level!

Dark UV Sky Enables Faint Detections

(it was worth the effort)

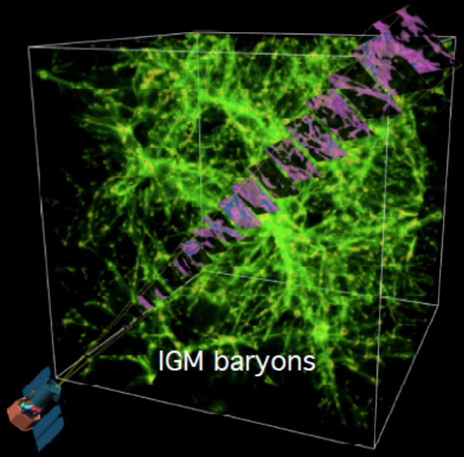






Follow-on Mission Goals

- Comparable instrument size and weight
- Order-of-magnitude sensitivity improvement
  – Raise QE
  – Lower noise
  – Decrease sky background even more
    - Spectroscopy
      – IGM
      – All the things GALEX looks at, but in narrow bands for improved S/N
        - QE requires AR-coated, delta doped silicon
        - Noise requires L3 technology



L3 Technology From e2v

(we can use a CCD after all)

2001

***The LLLCCD : Low Light Imaging without the need for an intensifier**

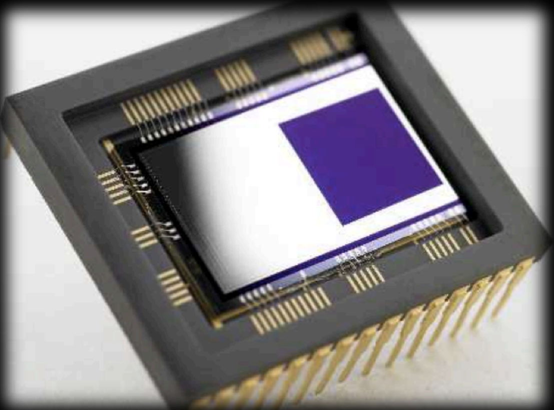
Paul Jerram , Peter Pool, Ray Bell, David Burt, Steve Bowring, Simon Spencer, Mike Hazelwood, Ian Moody, Neil Catlett, Philip Heyes

Marconi Applied Technologies, Chelmsford, Essex, UK

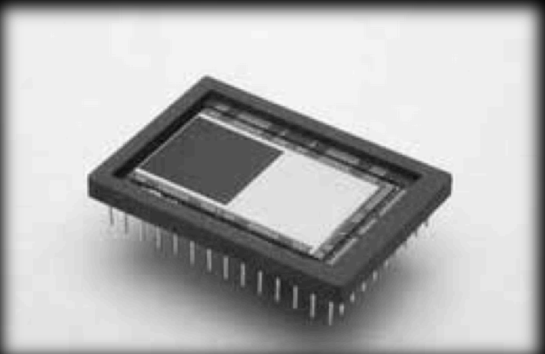
now e2v

ABSTRACT

A new CCD sensor technology has been developed by Marconi Applied Technologies (Chelmsford, UK) which effectively reduces read-out noise to less than one electron rms[1,2,3]. A single Low Light Level CCD (LLLCCD) can operate over a wide range of read-out rates from TV to slow-scan and give superior performance to that available from either intensified or slow-scan CCD sensors.



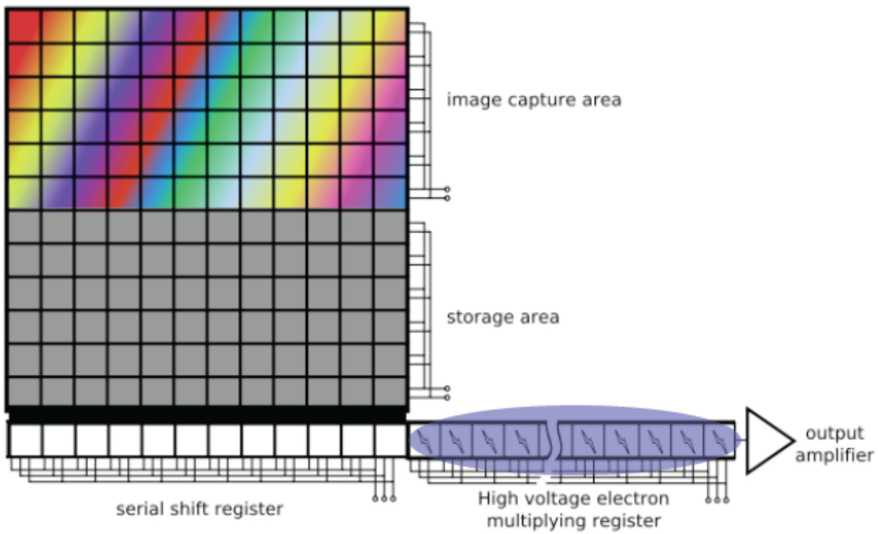
CCD97: 0.5k x 1k format
8.2 x 16.4 mm

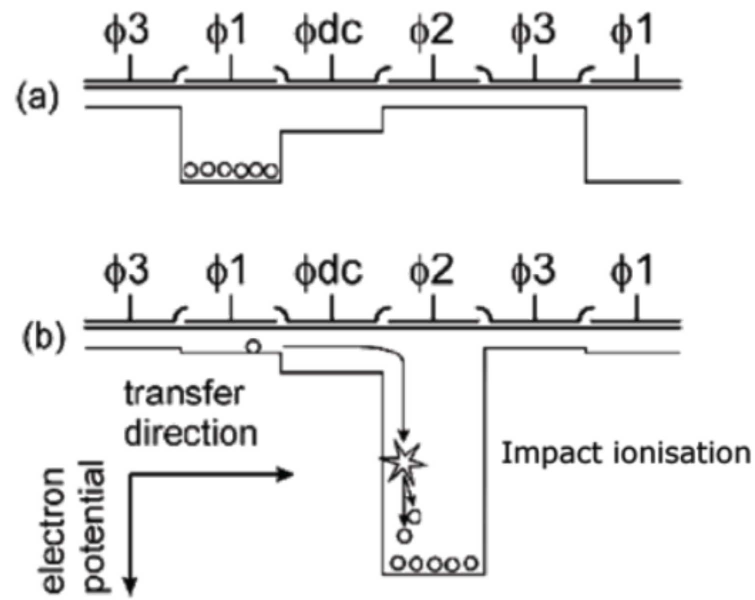


CCD201: 1k x 2k format
13.3x26.6 mm

In principle this technology is scalable to any CCD format!

L3 CCD Concept





$$\overline{G} = (1+p)^n$$

$$\sigma_{eff} = \frac{\sigma_{real}}{\overline{G}}$$

Delta Doping

1992
Applied
Physics
Letters

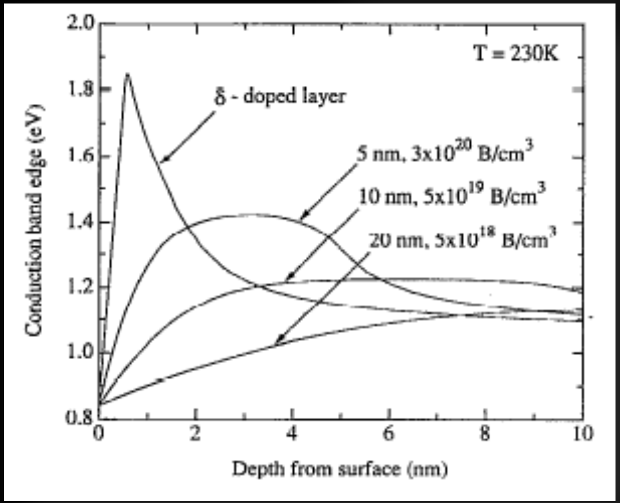
Growth of a delta-doped silicon layer by molecular beam epitaxy on a charge-coupled device for reflection-limited ultraviolet quantum efficiency

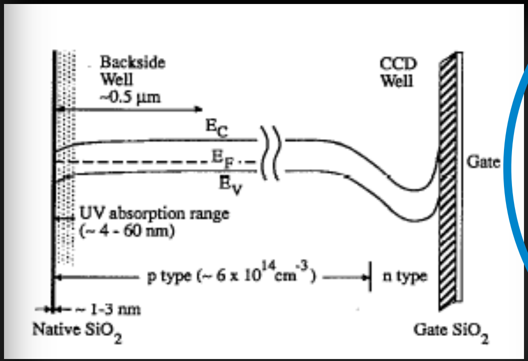
Michael E. Hoenk, Paula J. Grunthaner, Frank J. Grunthaner, and R. W. Terhune
Center for Space Microelectronics Technology, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109-8099

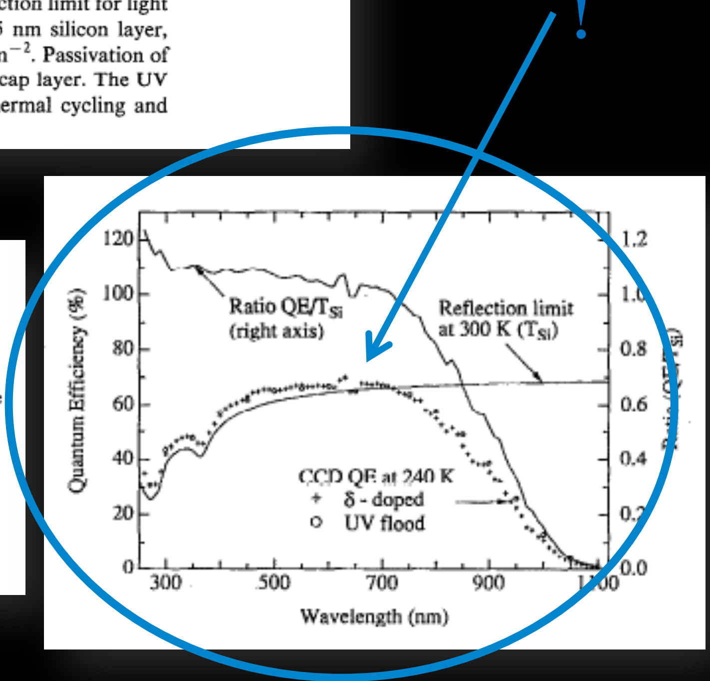
Masoud Fattahi and Hsin-Fu Tseng
EG&G Reticon, 345 Potrero Avenue, Sunnyvale, California 94086

(Received 28 April 1992; accepted for publication 30 June 1992)

We have used low-temperature silicon molecular beam epitaxy to grow a δ-doped silicon layer on a fully processed charge-coupled device (CCD). The measured quantum efficiency of the δ-doped backside-thinned EG&G Reticon CCD is in agreement with the reflection limit for light incident on the back surface in the spectral range of 260–600 nm. The 2.5 nm silicon layer, grown at 450 °C, contained a boron δ-layer with surface density $\sim 2\times 10^{14}$ cm^{-2}. Passivation of the surface was done by steam oxidation of a nominally undoped 1.5 nm Si cap layer. The UV quantum efficiency was found to be uniform and stable with respect to thermal cycling and illumination conditions.

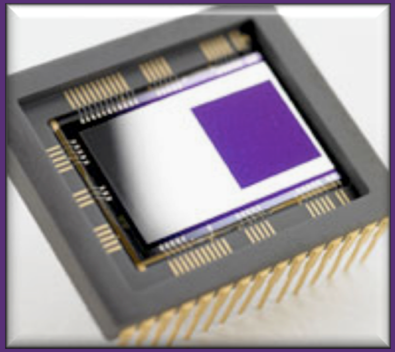




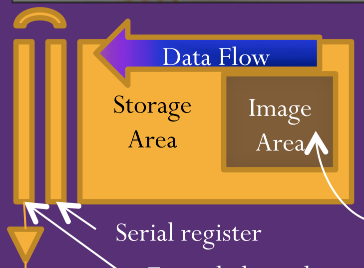


Delta-Doped L3 Detectors Improve UV Detector Performance by an Order of Magnitude

e2v L3 Technology

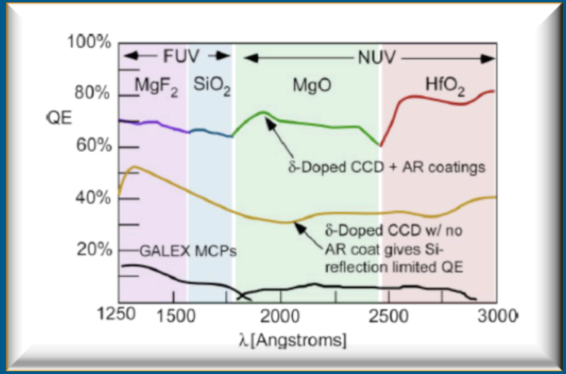


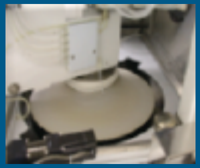
- New technology from e2v enables high QE CCD imaging and **zero read noise** photon counting.
- A **Low Light Level (L3) extended serial register** operating at elevated voltage (~50V) amplifies signals well above the level of the read noise.



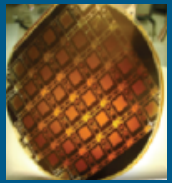
L3 functional diagram

JPL Delta Doping





Wafer Polish

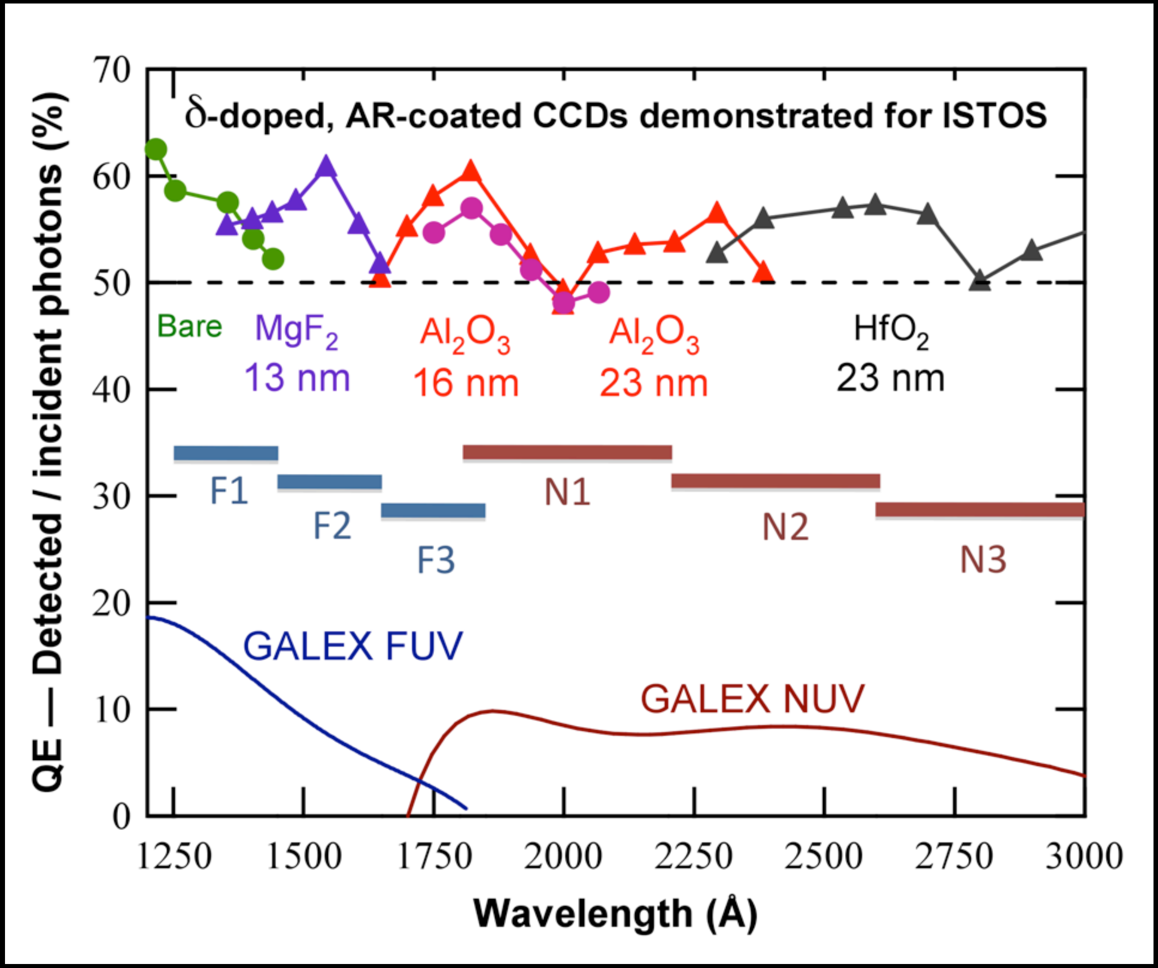


Wafer Thinning

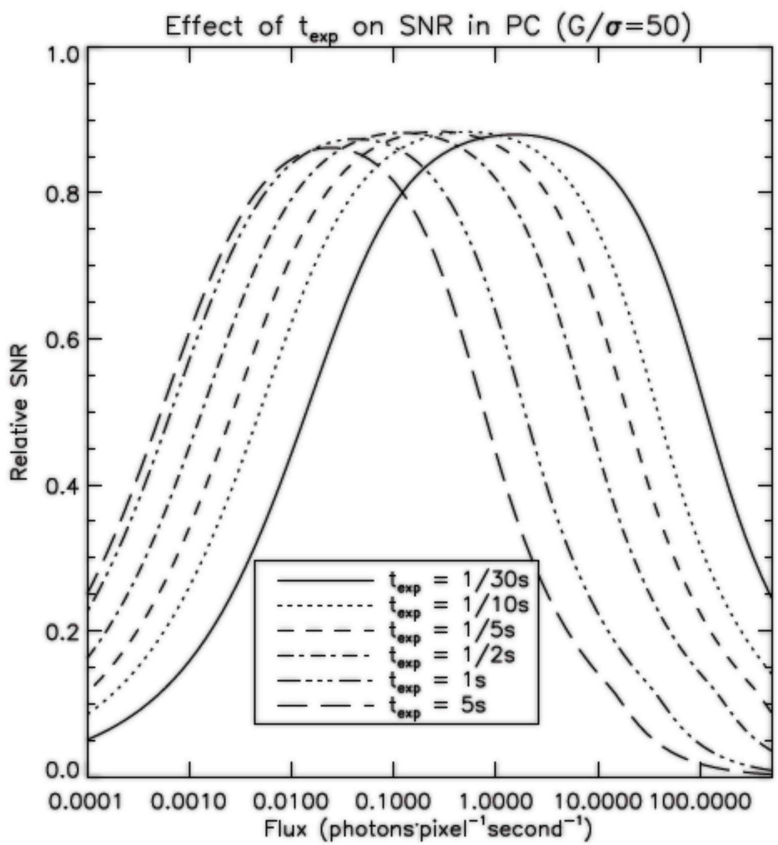
MBE/Delta Doping

- JPL **Delta Doping** technology sensitizes L3 CCDs to the ultraviolet.
- A **10X** improvement in performance is possible over existing MCP detectors.

δ Doping Achieves Excellent QE



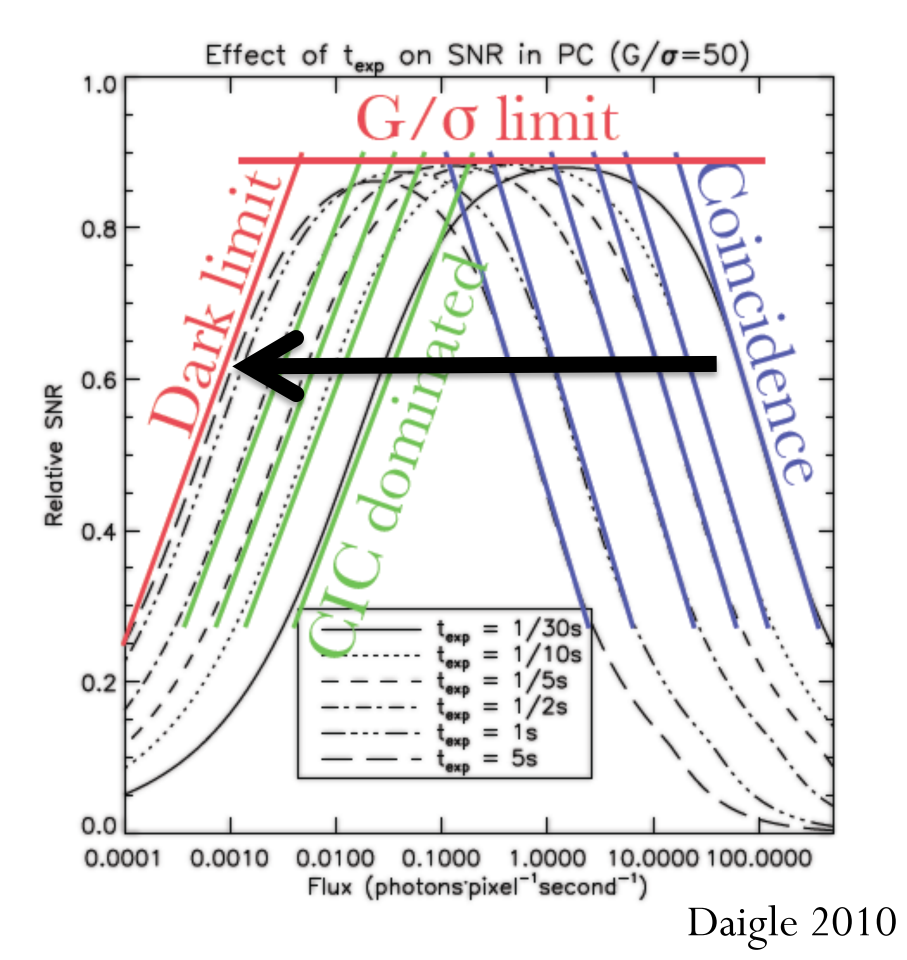
L3 CCD Noise Limits



Daigle 2010

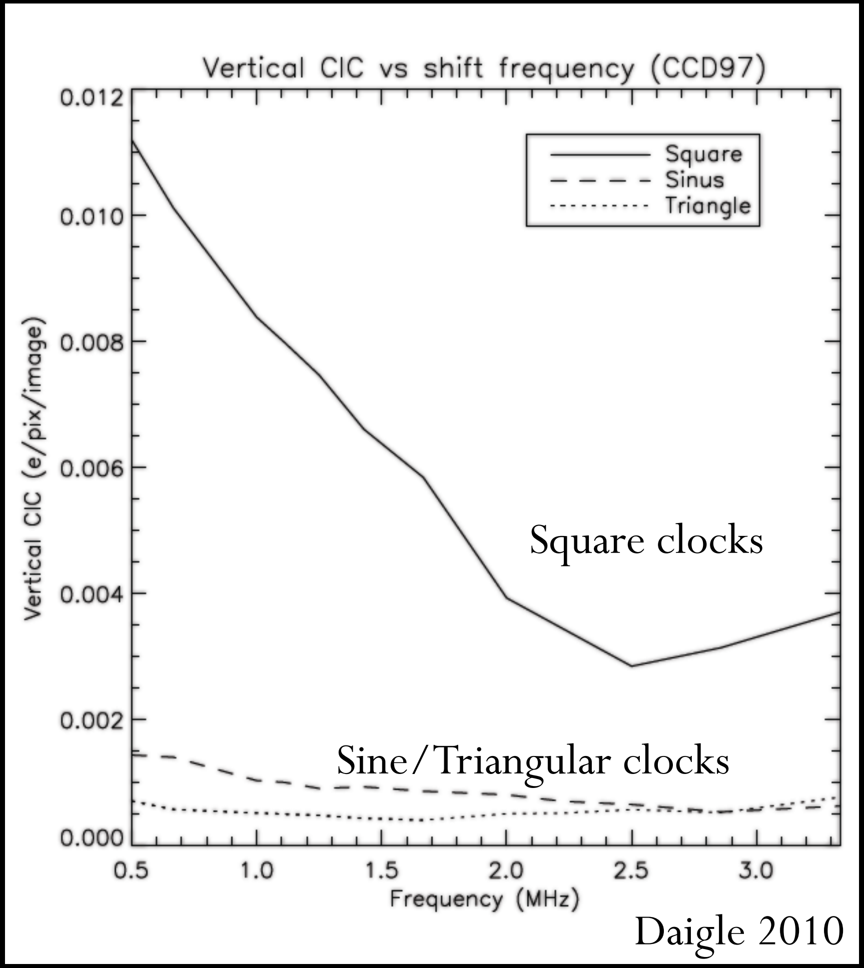
- Fundamental noise sources at the faint end and saturation at the bright end limit all photon counting detectors.
- Parameters can be optimized for the flux regime of interest.

L3 CCD Noise Limits



- Cold operation allows extremely low flux detection.
- Long integrations have an equivalent effect.

Clock Shaping Reduces CIC



Dark Current

(QE is only part of the story…)

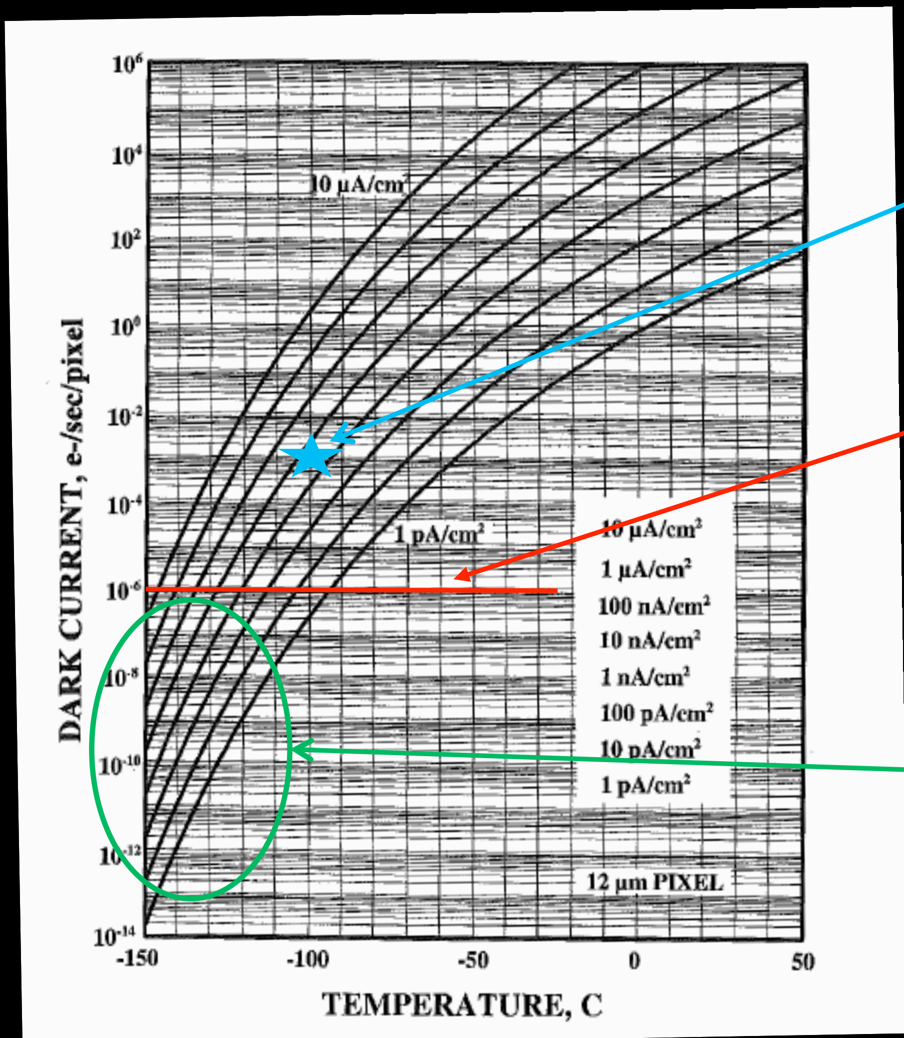


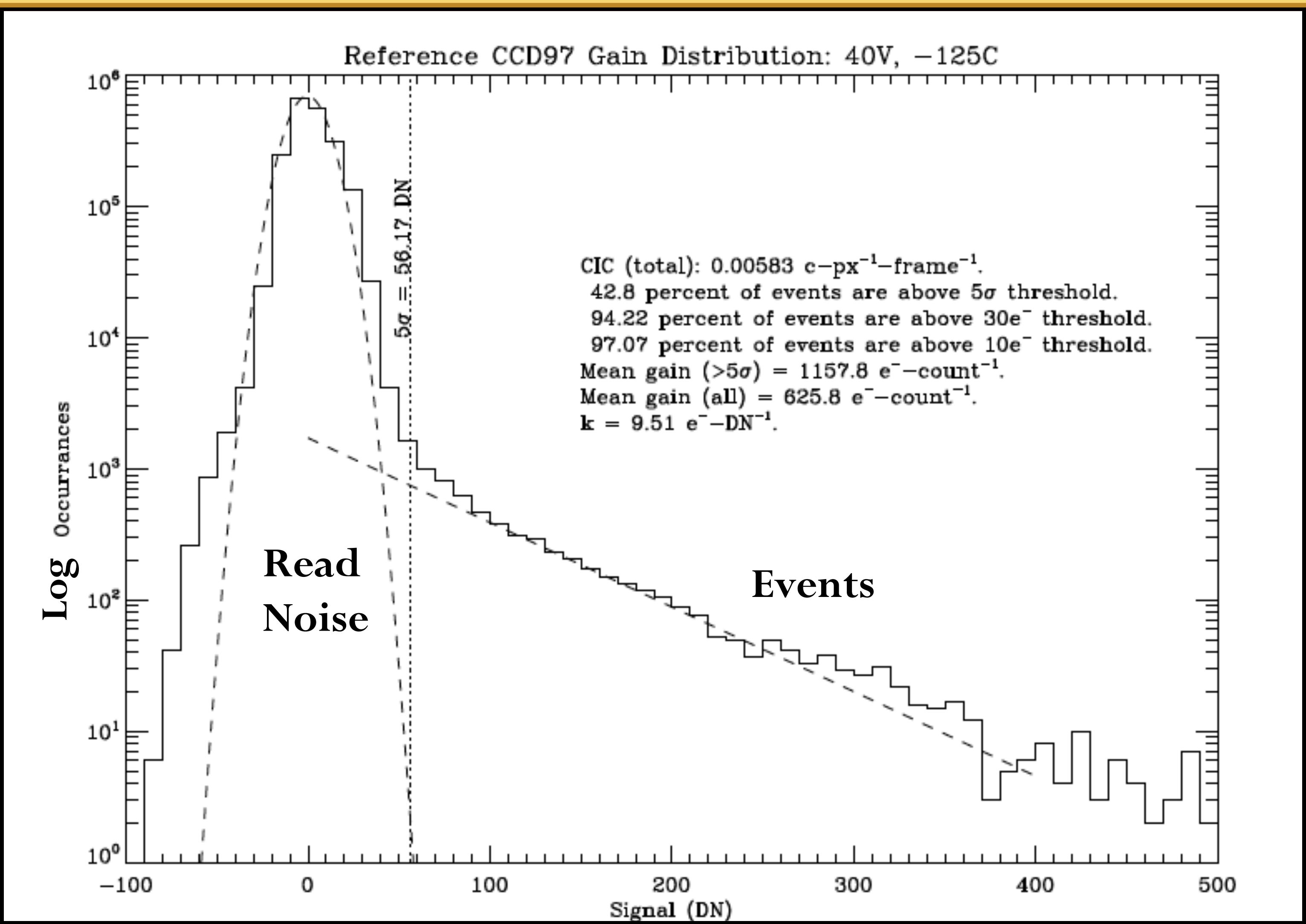
Figure 7.6 Image taken while CCD was submerged in liquid nitrogen.

e2v non-inverted, back-illuminated CCD (CWI measured)

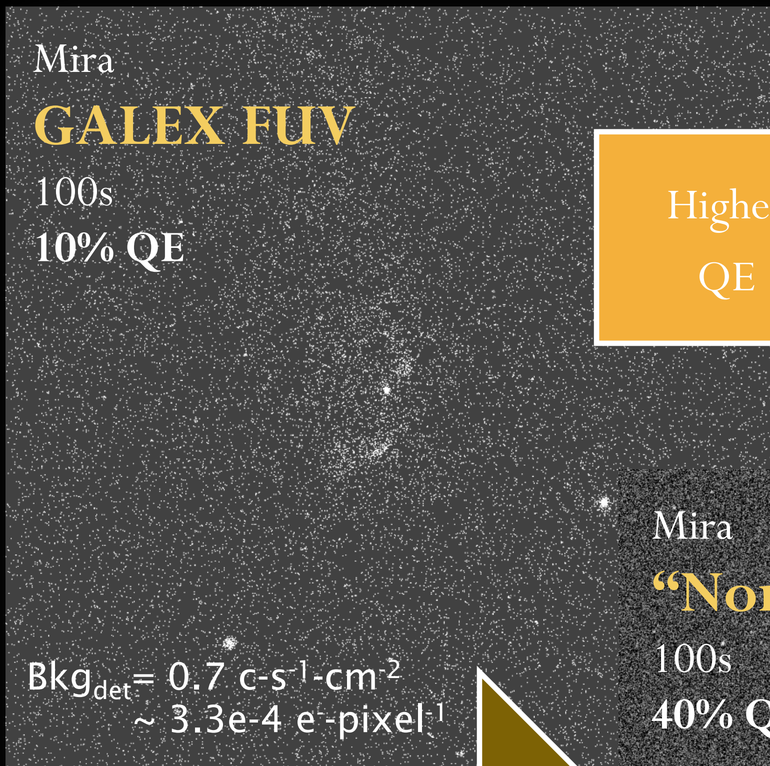
CsI photocathode as-measured GALEX FUV ~ 0.7 c-s^{-1}-cm^{-2}

There is plenty of parameter space available to drive the silicon dark below typical photocathode values. This parameter space can also be used to maintain the low dark rate as the device ages.

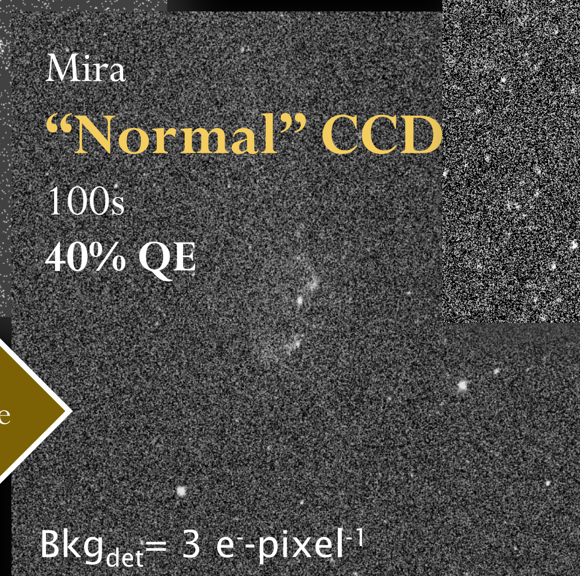
L3 CCD Noise, Slow Scan



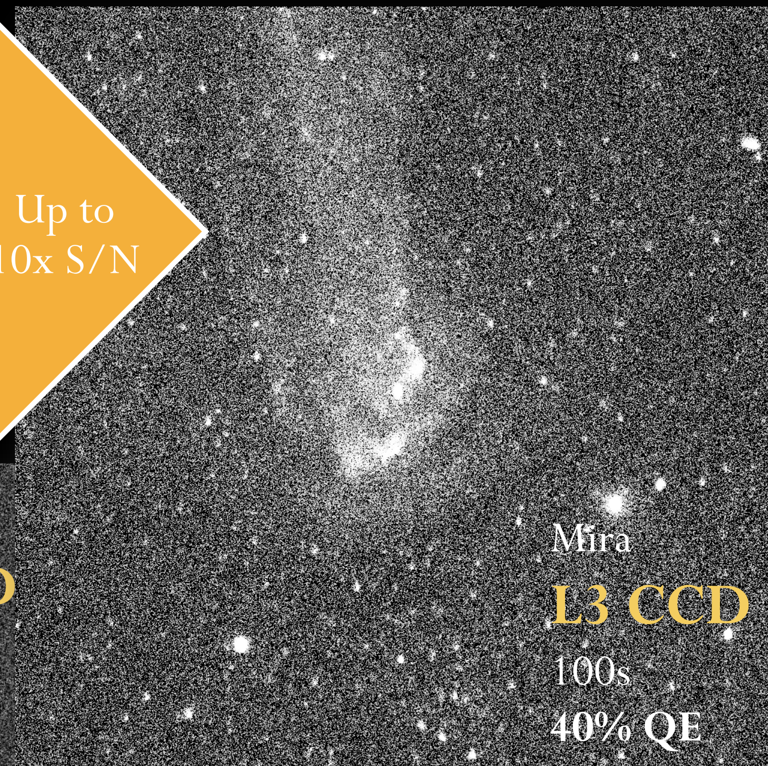
MCP vs CCD vs L3CCD



Higher QE | Lower Noise | Up to 10x S/N



Higher QE | Higher Noise | No improvement



L3 CCD Simulation has 4x S/N of GALEX 100s AIS.

L3 CCD vs MCP

	MCP	Delta-doped, L3 CCD
QE	10-25%	>40%
Noise limit 1800s	0.7 $c\text{-}s^{-1}\text{-}cm^{-2}$ (dark) ~0.006 $c\text{-}pixel^{-1}$	0.001 $e^{-}\text{-}pixel^{-1}\text{-}frame^{-1}$ (CIC) ~0.001 $e^{-}\text{-}pixel^{-1}$
HV	5-20 kV	50V
Thermal	Ambient	-100 to -150C
Radiation	Rad-hard	Shield, cool, split image
Red leak	Excellent	Spectroscopy
Contamination	Relatively immune	Regular warm cycle (HST)
Large format array	Difficult	Easy
Curvature	Difficult	Yes

The L3 CCD can provide a S/N improvement of over an **order-of-magnitude** for faint sources.