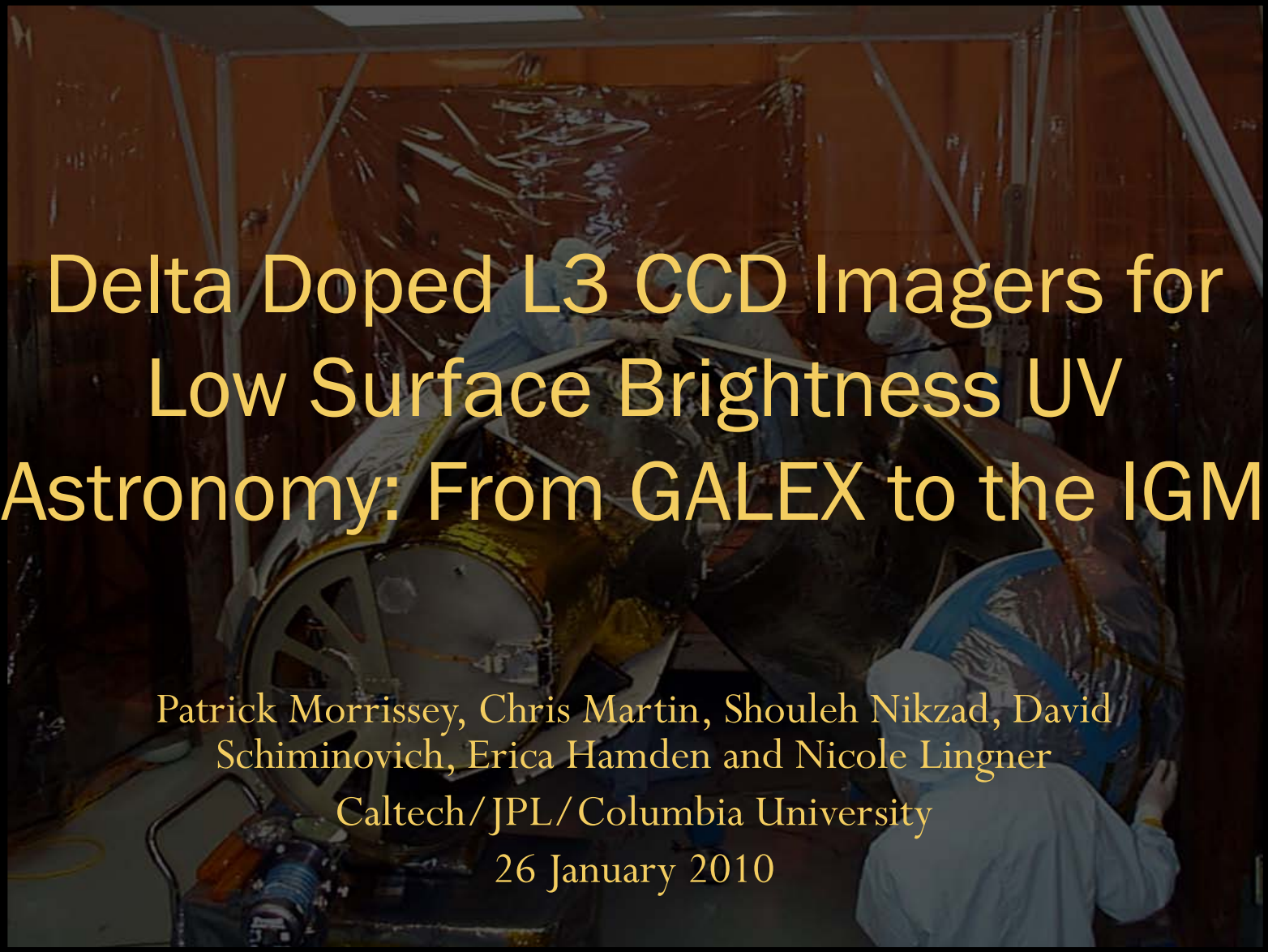


Delta Doped L3 CCD Imagers for Low Surface Brightness UV Astronomy: From GALEX to the IGM

Patrick Morrissey, Chris Martin, Shouleh Nikzad, David Schiminovich, Erica Hamden and Nicole Lingner

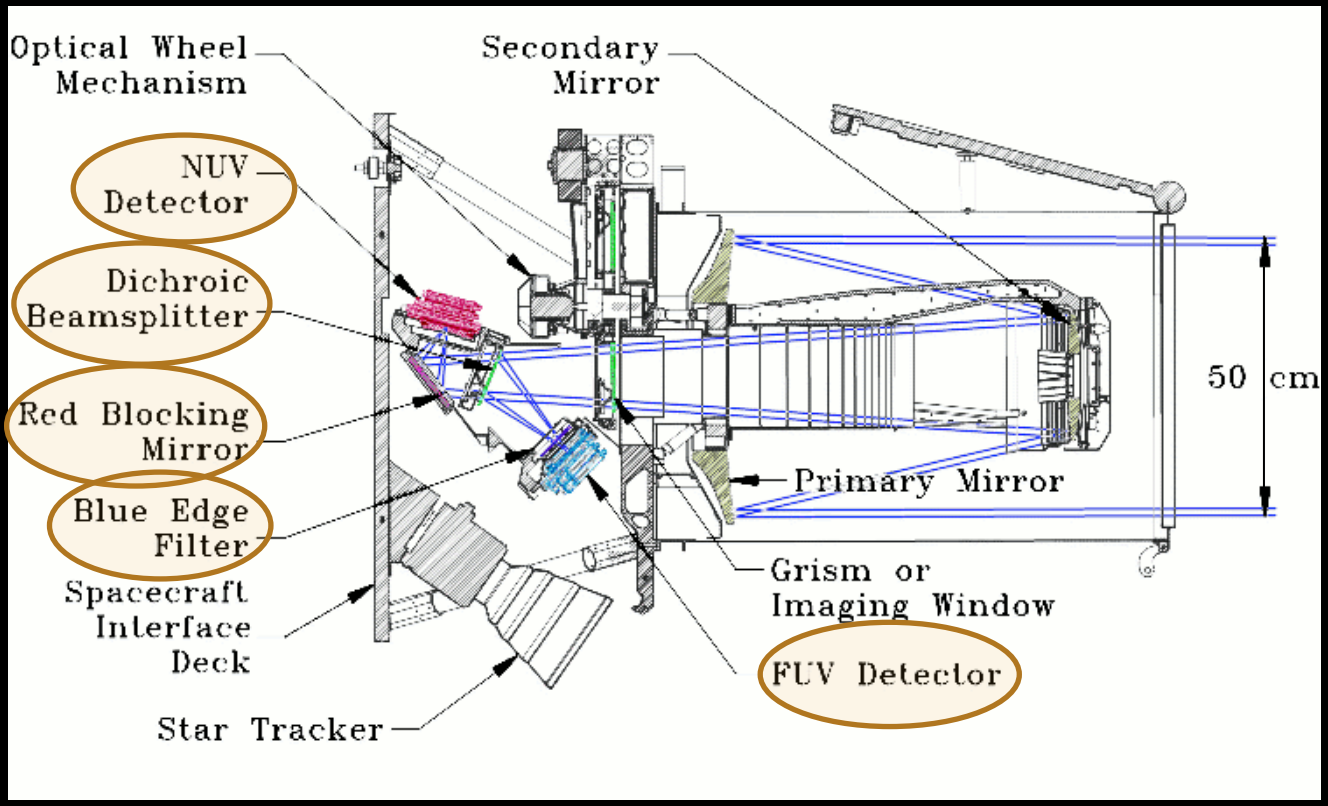
Caltech/JPL/Columbia University

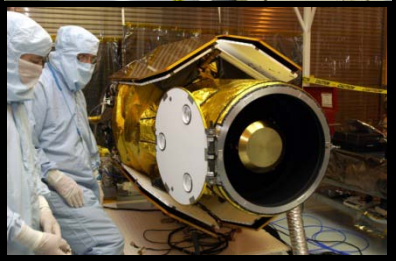
26 January 2010

Overview

- Our group is operating the NASA Small Explorer GALEX , a UV all-sky survey mission now in its seventh year.
- Discussion of GALEX technology
- Some GALEX results
- What's next?
- Technologies for what's next.

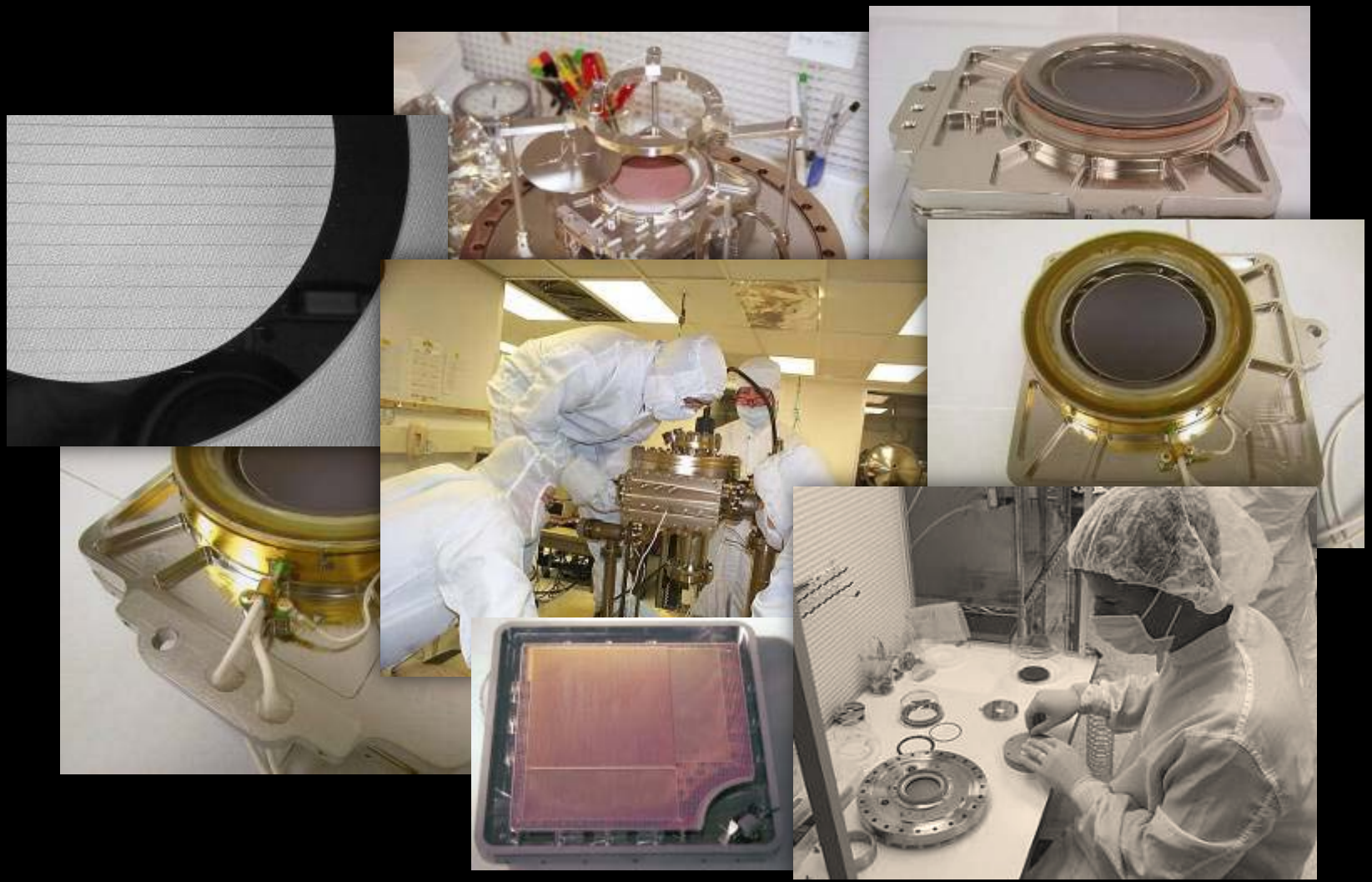
GALEX



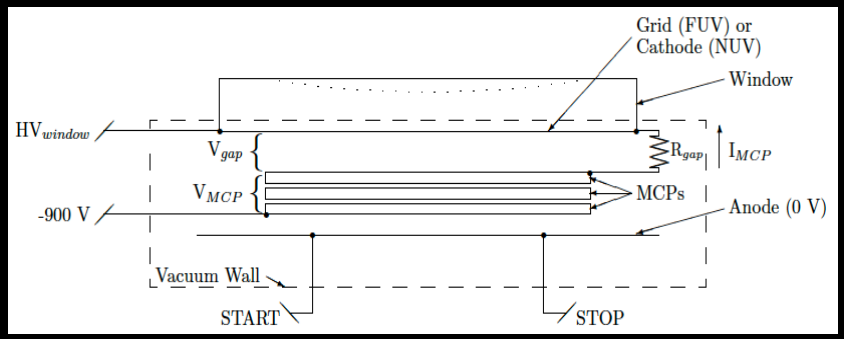


Designed and built by Caltech, JPL, UC Berkeley, the Orbital Sciences Corporation, Centre National d'Etudes Spatiales of France and the Korean Ministry of Science and Technology.

Sealed Tube Development

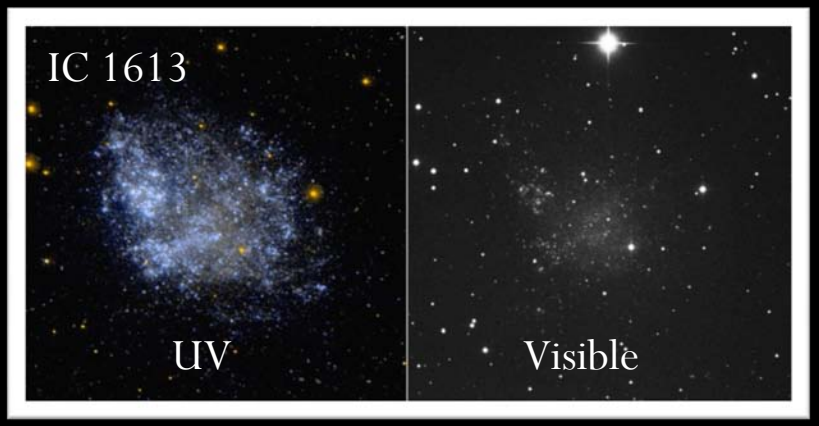


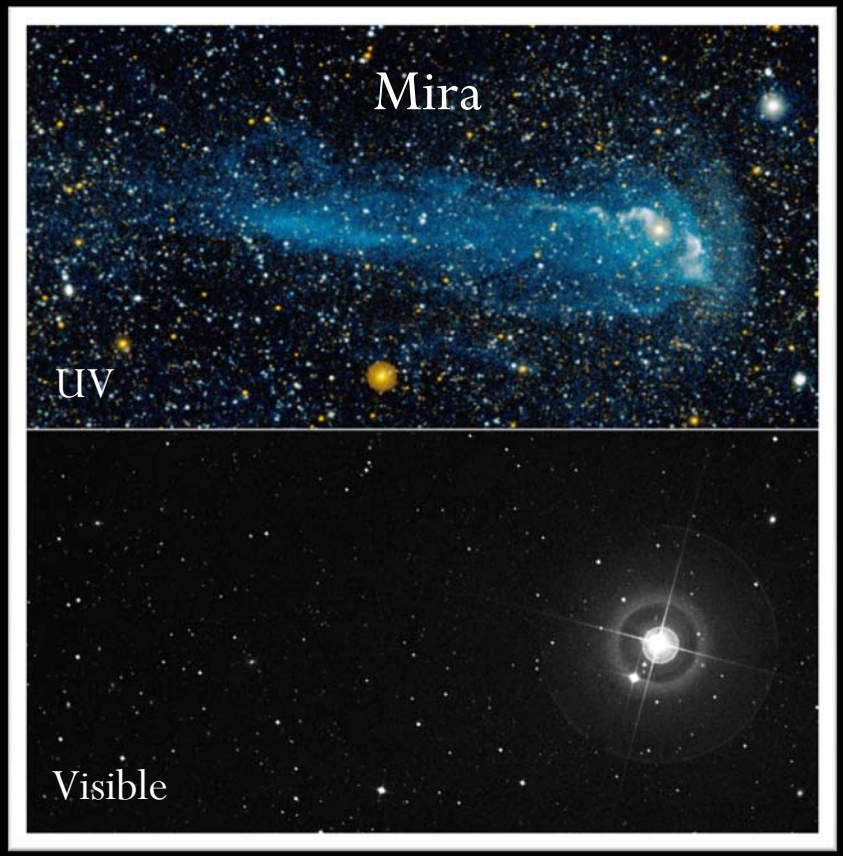
GALEX Detector Overview

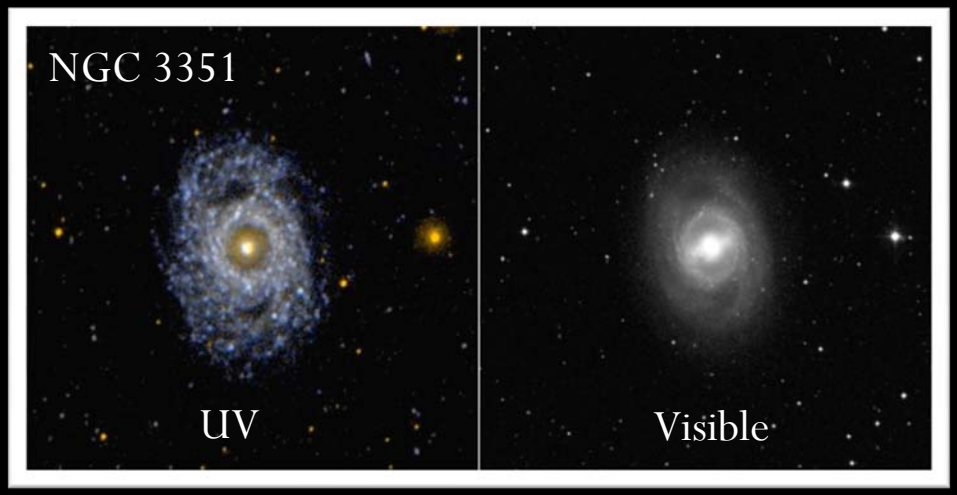


- GALEX detectors are sealed tubes with a stack of three microchannel plates and an anode readout.
- The tubes operates at 5200-6200V.
- Each tube is a work of art with its own interesting features.

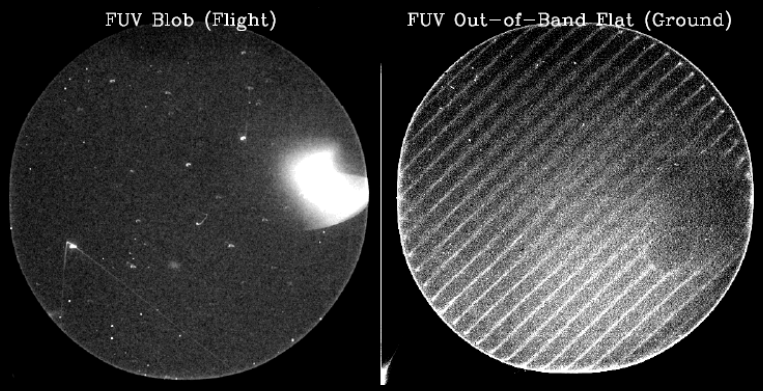
Dark UV Sky Enables Faint Detections



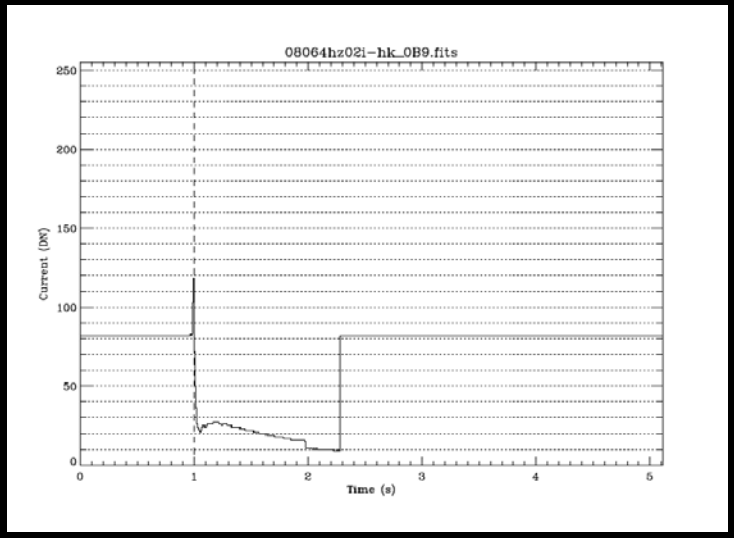


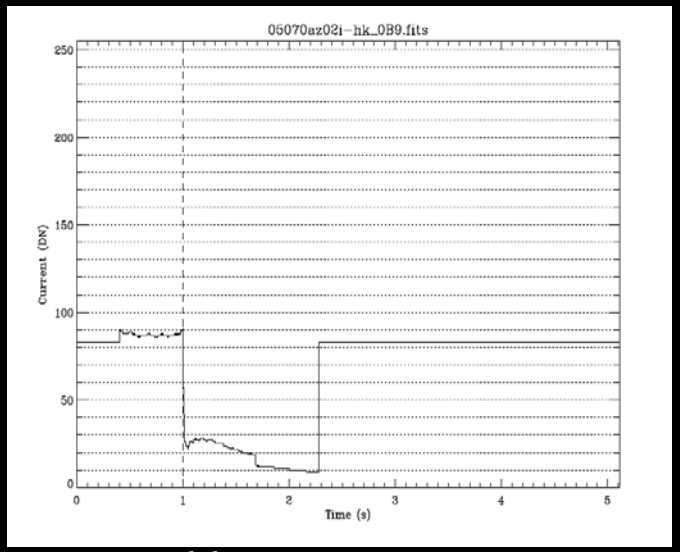


MCPs Are Not Perfect



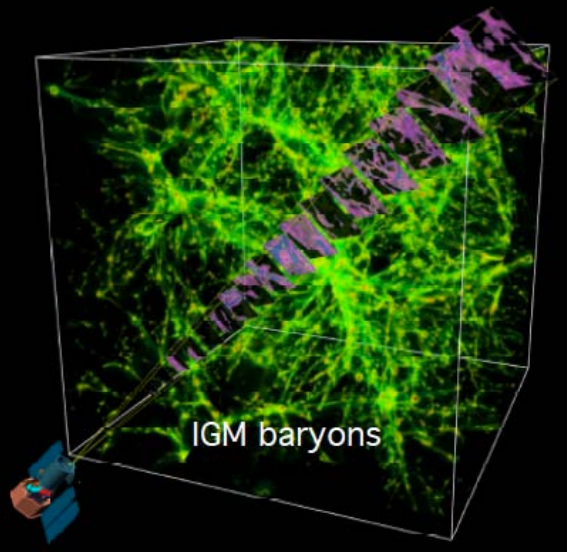
- HV can be problematic
- QE could be improved

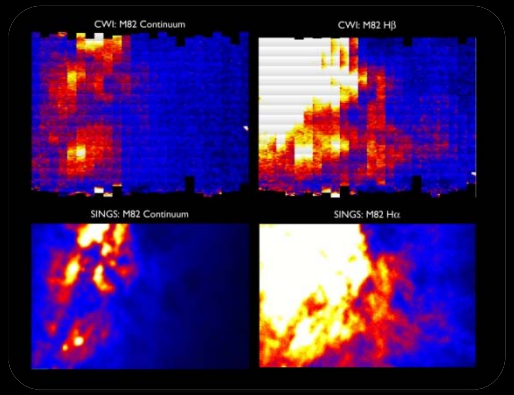




Follow-on Mission Goals

- 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





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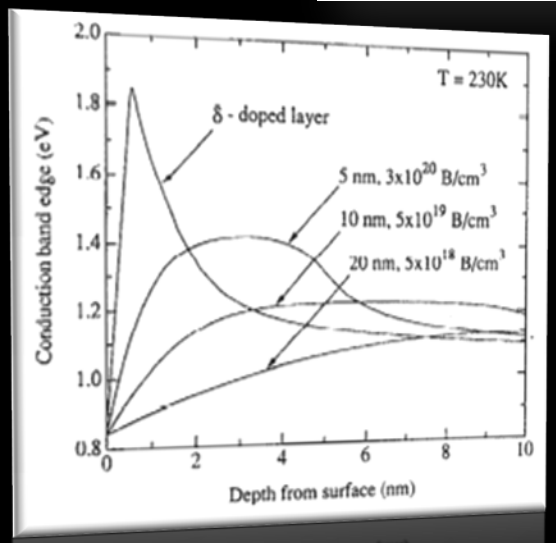
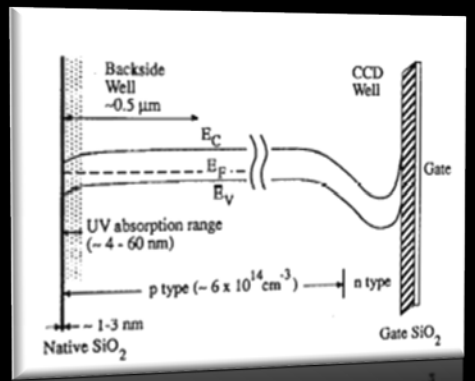
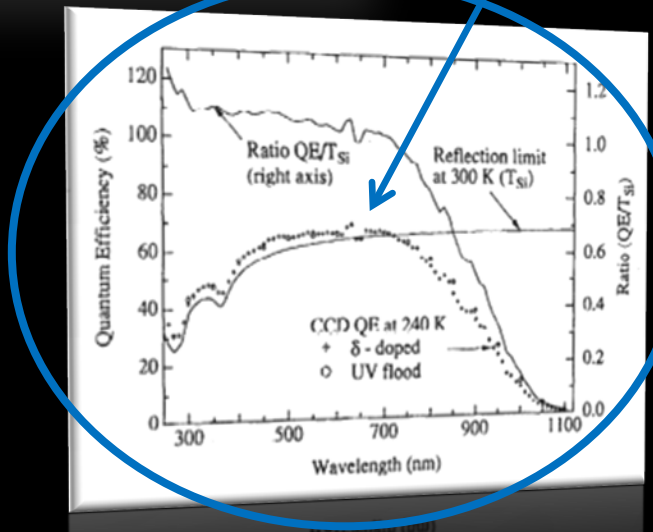
(Received 28 April 1992; accepted for publication 30 June 1992)

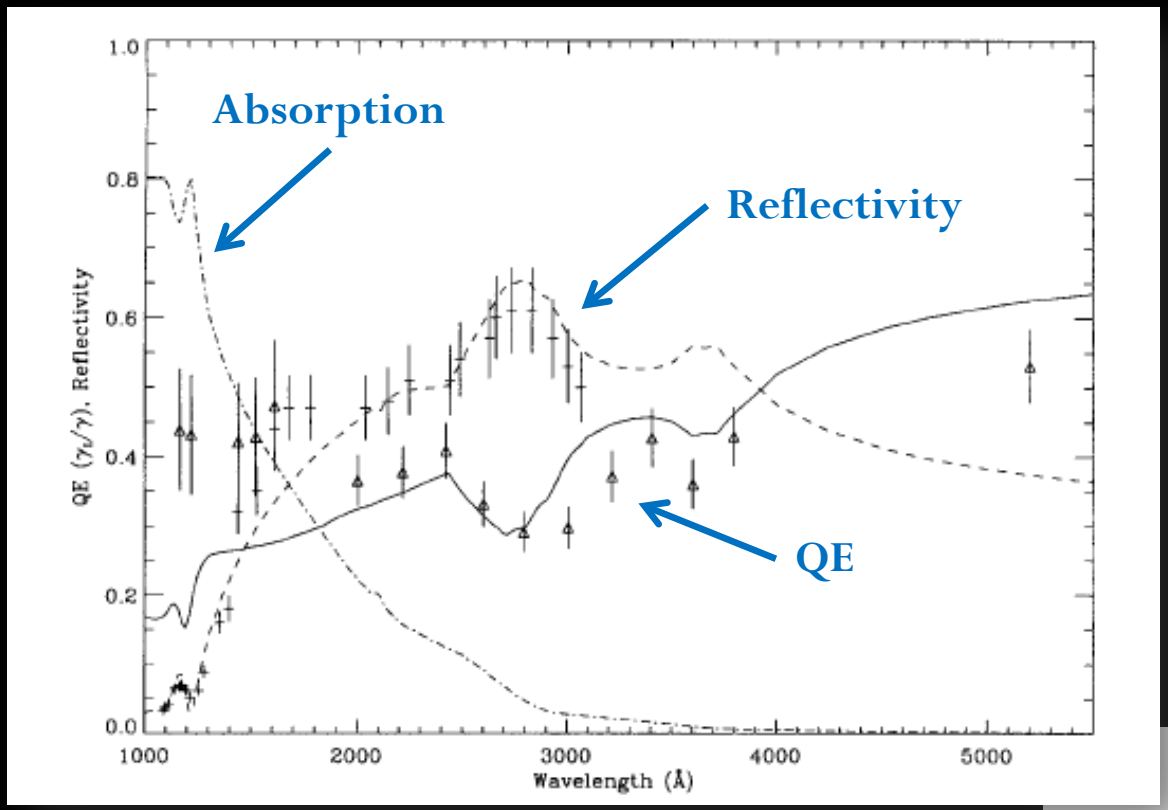
We have used low-temperature silicon molecular beam epitaxy to grow a δ-doped silicon layer on a fully processed charge-coupled device (CCD). The measured quantum efficiency of the δ-doped backside-thinned EG&G Reticon CCD is in agreement with the reflection limit for light incident on the back surface 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 $\sim 2\times10^{14}$ 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.



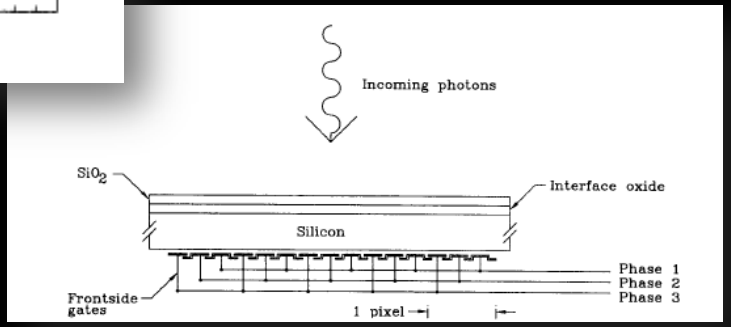




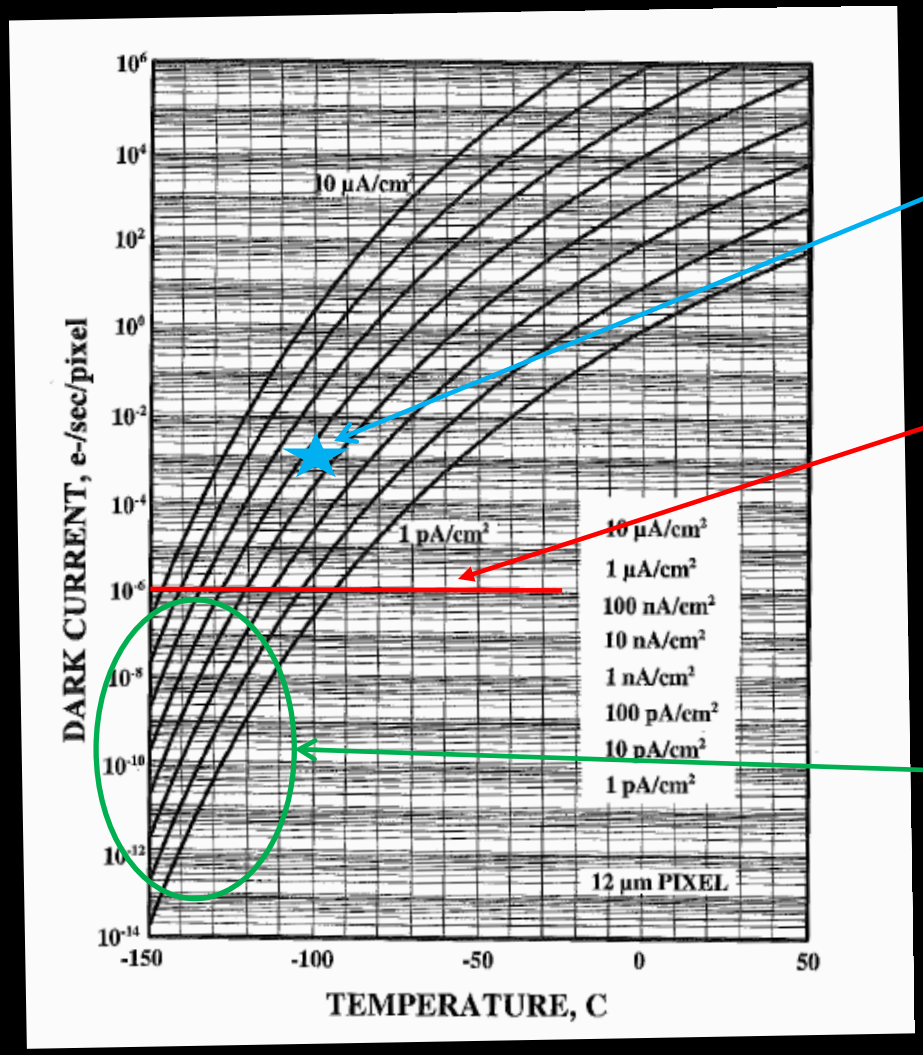
AR Coating Improve Performance



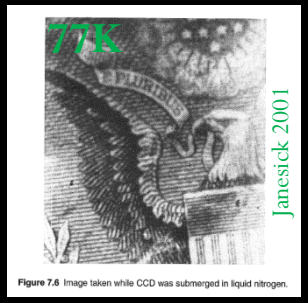
A bare, back-illuminated CCD can only be expected to achieve ~40% QE in the UV due to reflection and absorption losses. This is already pretty good, but we are working in parallel on AR coatings.



Dark Current



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



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

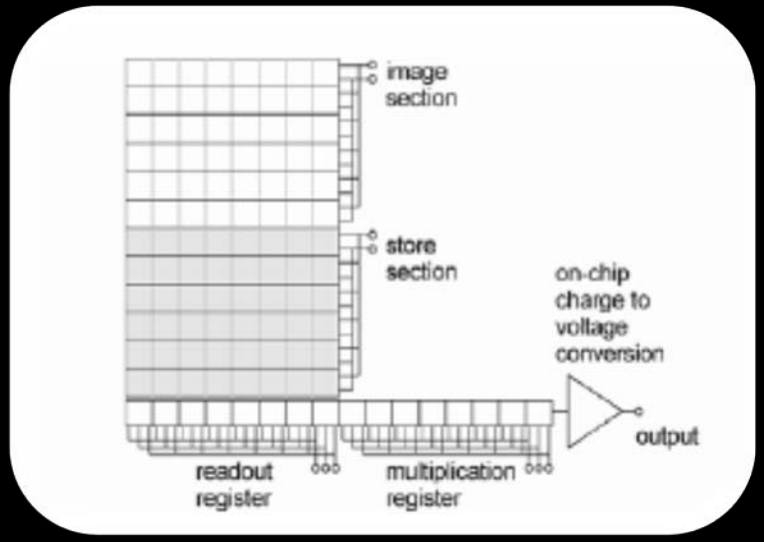
There is plenty of parameter space available to drive the silicon dark below typical photocathode values. This parameter space can also be used to maintain the low dark rate as the device ages.

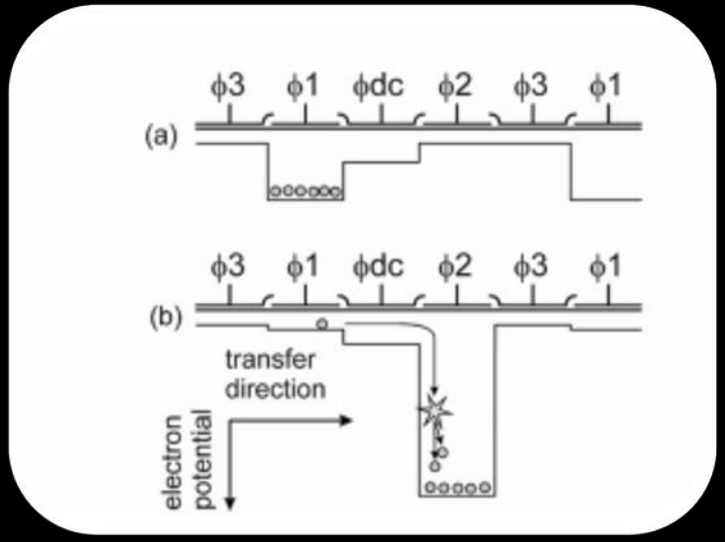
L3 Technology From **e2v**

Electron Multiplying CCDs

P.A.Jerram, P. J. Pool, D. J. Burt, R. T. Bell, M.S.Robbins
e2v technologies ltd, 106, Waterhouse Lane, Chelmsford, Essex, UK CM1 2QU

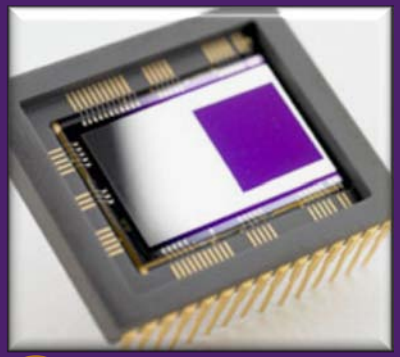
Electron multiplying CCD (EMCCD) technology has found important initial applications in low light surveillance and photon starved scientific instrumentation. This paper provides a description of the technology and discusses the attributes of the EMCCD which may make it useful for other detectors, particularly those which are photon starved



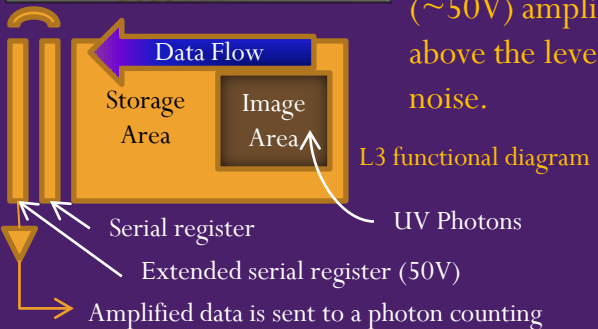


Delta-Doped L3 Detectors Improve UV Detector Performance by an Order of Magnitude

e2v L3 Technology

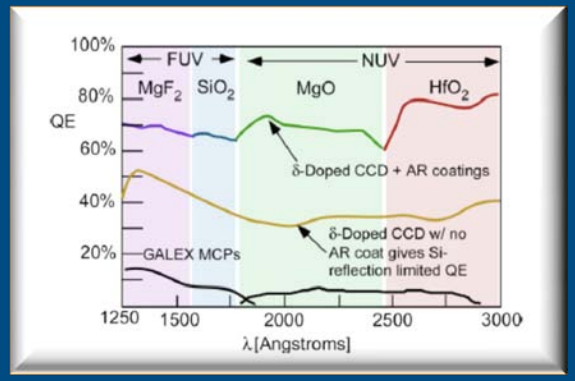


- New technology from e2v enables high QE CCD imaging and **zero read noise** photon counting.
- **A Low Light Level (L3) extended serial register** operating at elevated voltage (~50V) amplifies signals well above the level of the read noise.



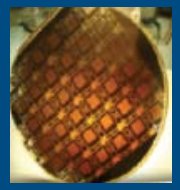
L3 functional diagram

JPL Delta Doping



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

Wafer Polish



Wafer Thinning

MBE/Delta Doping

Ours will be the *first ever* curved, mosaicable detector combining

- high UV QE,
- zero read noise,
- and NO high voltage.

MCP vs CCD vs L3CCD

Mira

GALEX FUV

100s

10% QE

Bkg_{det} = 0.7 c-s^{-1}-cm^{-2}
~ 3.3e-4 e$^-$-pixel^{-1}

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

Mira

"Normal" CCD

100s

40% QE

Higher QE | Higher Noise | No improvement

Bkg_{det} = 3 e$^-$-pixel^{-1}

Mira

L3 CCD

100s

40% QE

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

L3 CCD vs MCP

	MCP	Delta-doped, L3 CCD
QE	10%	>40%
Noise limit 1800s	0.7 c-s^{-1}-cm^{-2} (dark) ~0.006 c-pixel^{-1}	0.001 e^{-}-pixel^{-1}-frame^{-1} (CIC) ~0.001 e^{-}-pixel^{-1}
HV	5000V	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.

Short Term Goals

- We have obtained L3 CCD97 wafers from e2v
- Wafer processing has begun at MDL/JPL. We anticipate test devices in the next short while.
- Test system is being developed at CIT.
  - UV calibration
  - Optimized readout code
  - Leach controller with custom HV driver board from ROE (Derek Ives)
- e2v is interested in supplying a FUV-optimized device for comparison.