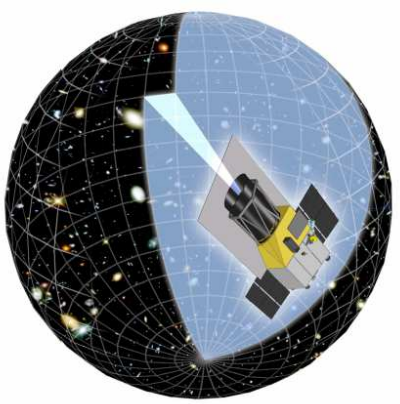
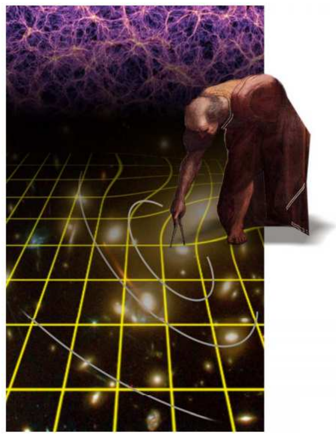
e2v centre for electronic imaging

Assessment of proton radiation-induced charge transfer inefficiency in the CCD204 detector for the Euclid dark energy mission



J. P. D. Gow, N. J. Murray, A. Holland, D. J. Hall,
M. Cropper, D. Burt, G. Hopkinson, L. Duvet

16th September 2011



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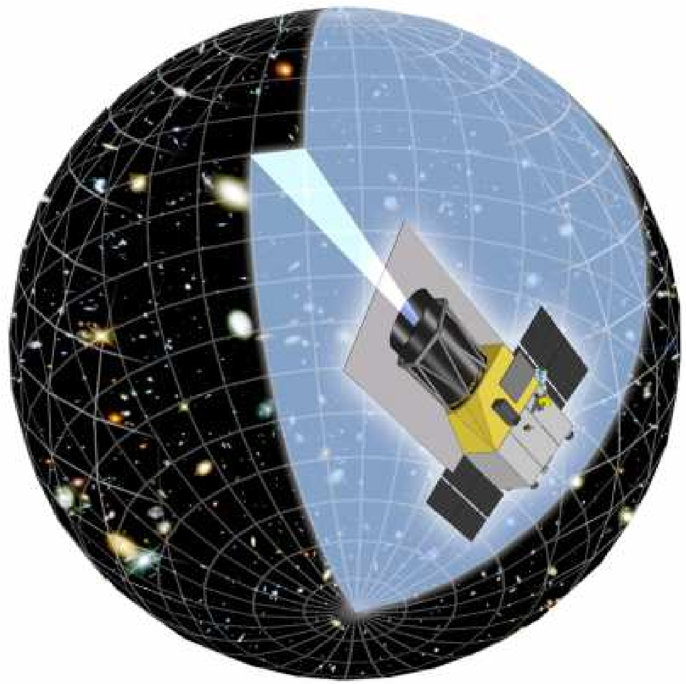
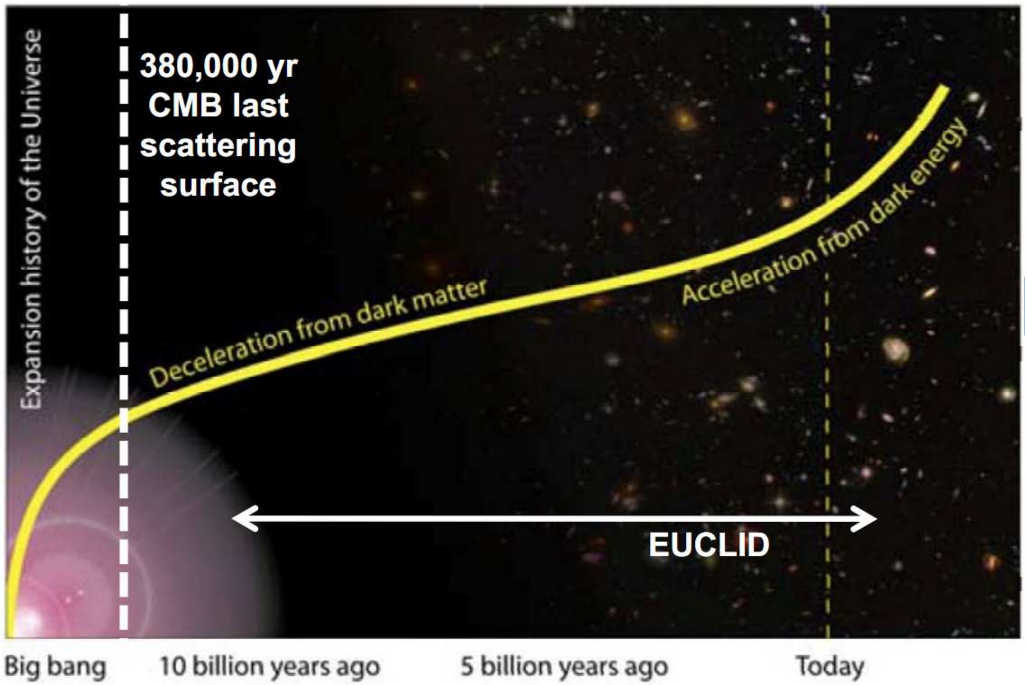
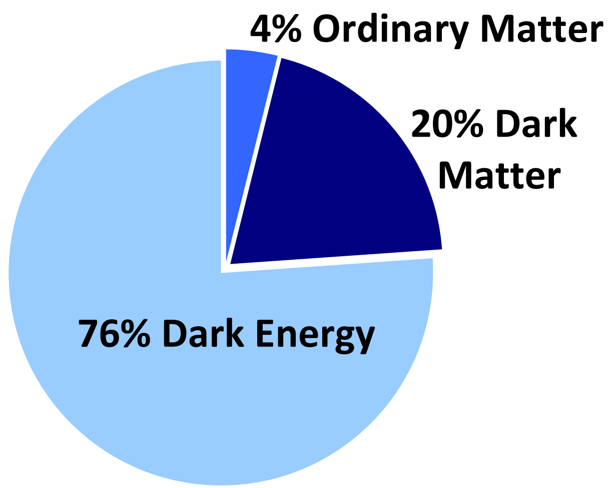


Euclid: Science Objectives

- Euclid's primary Science Objectives
  - The nature of dark energy
  - The nature of dark matter
  - The initial conditions
  - Modifications to gravity
- Secondary Science Objectives
- Legacy science
  - The detection of extrasolar planets via microlensing



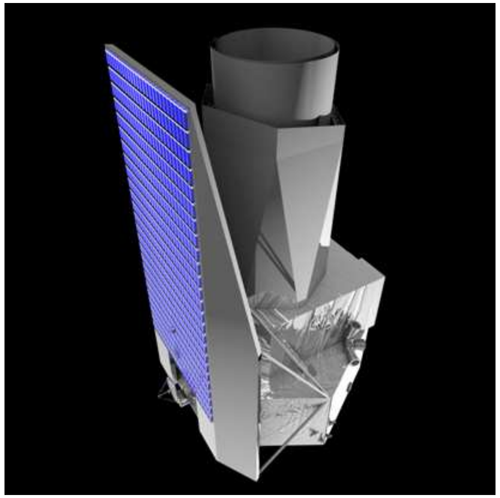
Credit: Euclid Assessment Study Report



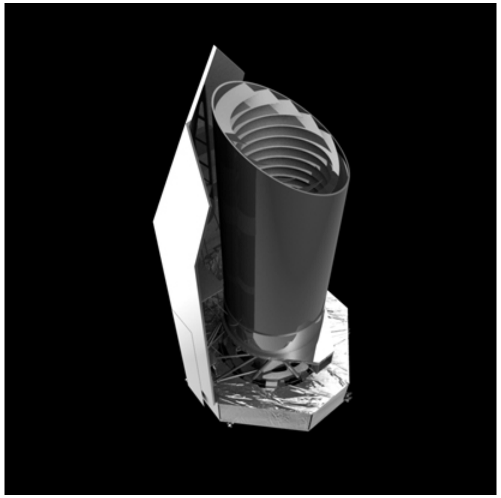
Euclid: The Mission

- Euclid is one of three medium class missions belonging to the cosmic vision plan for launch in 2017-2018
- Two missions will be selected during the final down-selection in October 2011
- Euclid will spend 5 years at L2, this could be increased, where it will study the geometry and nature of the dark Universe through the combination of several techniques of investigation, including
  - Weak Gravitational Lensing
  - Baryonic Oscillations
- The payload consists of a single telescope and two instruments, the UK led visible imager (VIS) for which this work has been undertaken and a near-IR photo-spectrometer

Spacecraft concepts



EADS Astrium



Thales Alenia Space

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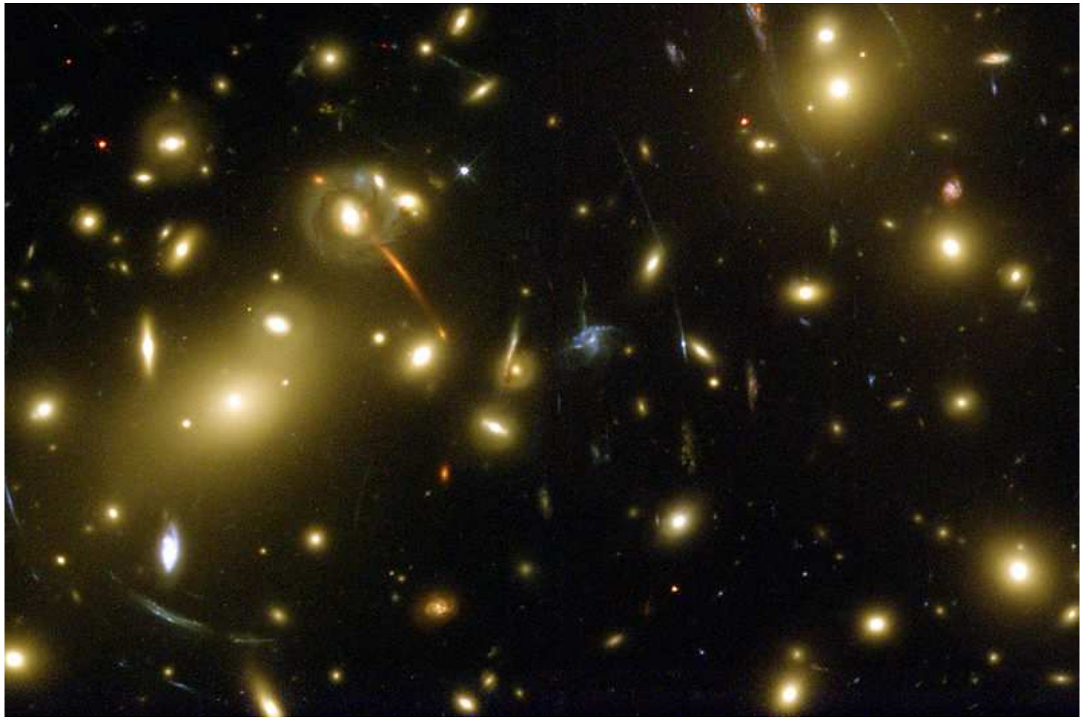
Euclid: The Mission

- Weak Lensing
  - Measures the change in ellipticity of galaxies to a few percent
  - Requires the use of multiple galaxies to calculate the amount and distribution of intervening matter



Galaxy cluster Abell 2218 and its gravitational lenses,
captured by Hubble in 1999

3D reconstruction of the dark
matter distribution

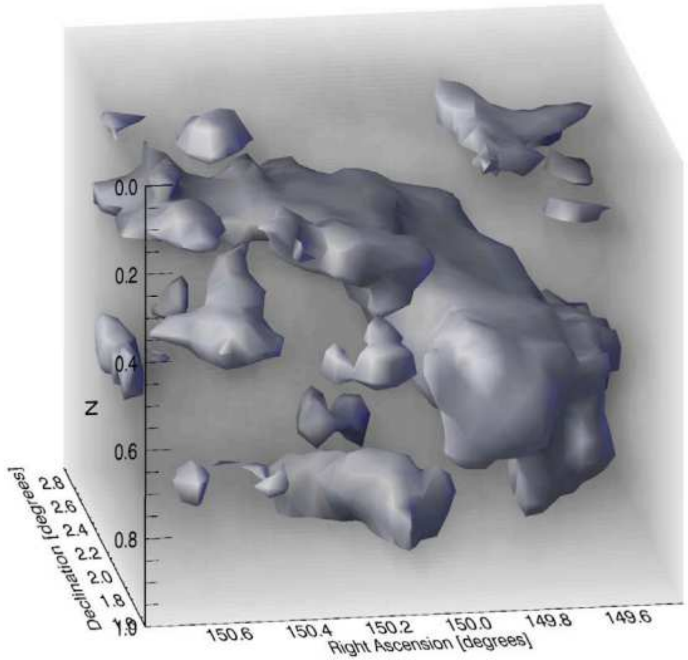
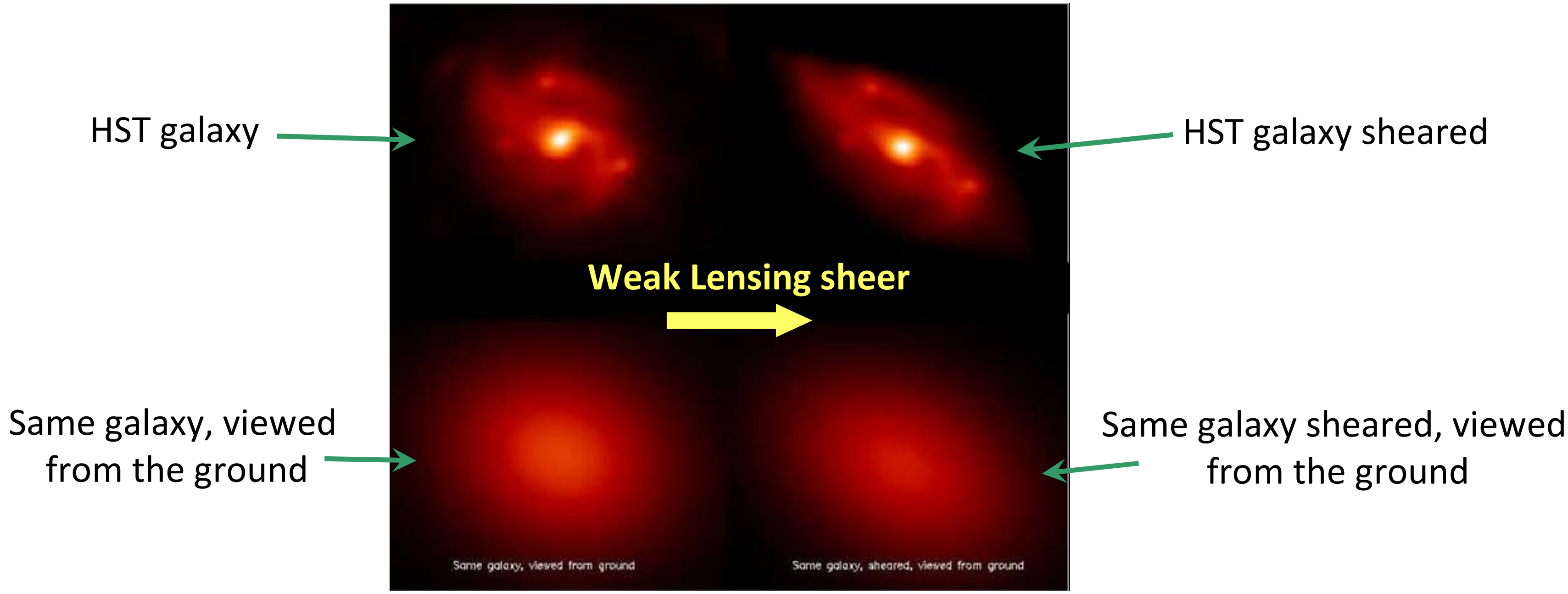


Image courtesy of Richard Massey,
R. Massey *et al., Dark matter maps reveal cosmic scaffolding, Nature 445 (2007)*

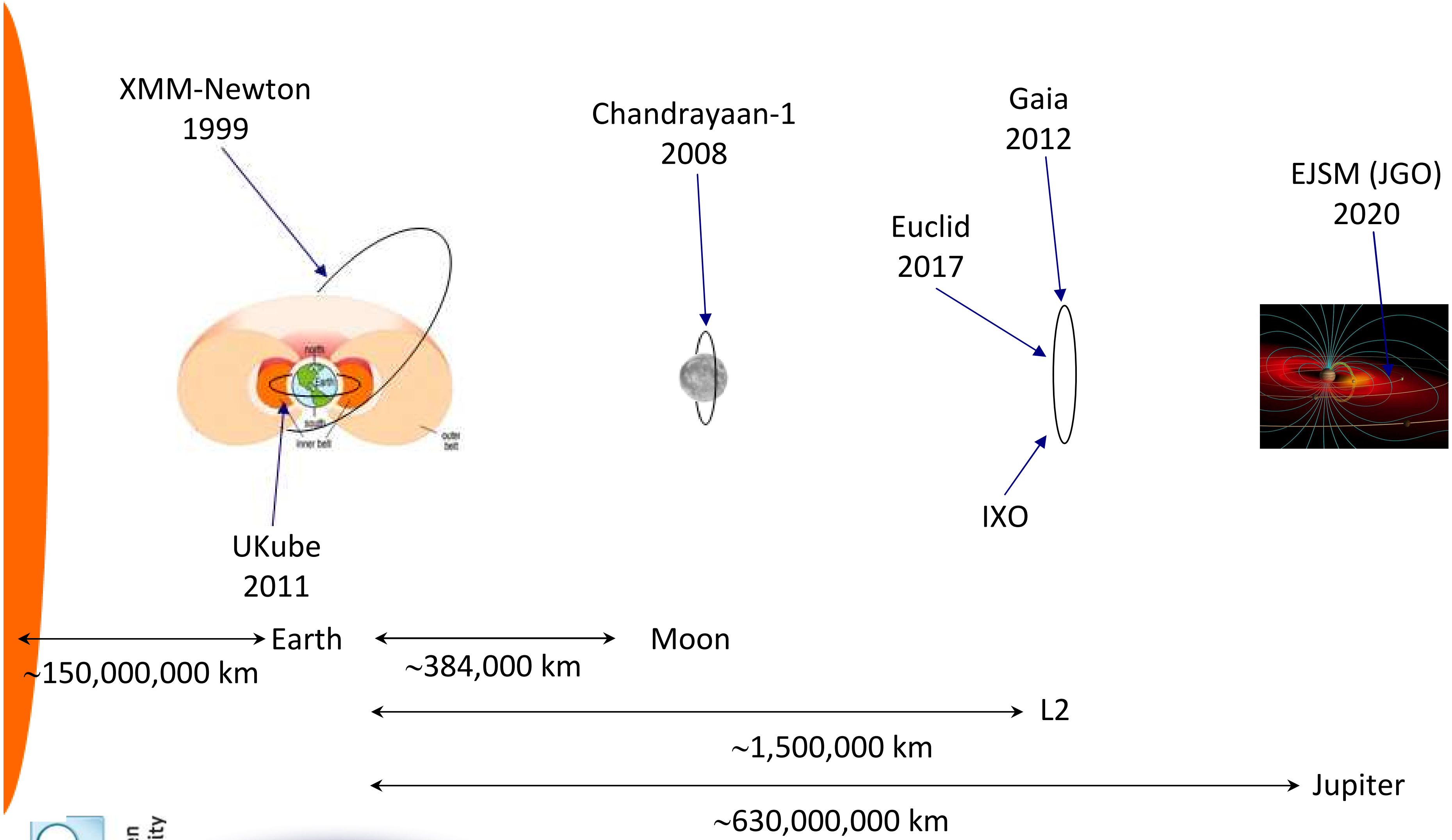
Euclid: The Advantages of Space

- Weak lensing measurements from ground based observatories are limited by atmospheric distortions
- Space based telescopes provide the precision photometry required to analyse background galaxies
  - Providing stable and smaller point spread functions (PSF)



- However, over the course of the five year mission it will be continually bombarded by radiation.

The Space Radiation Environment



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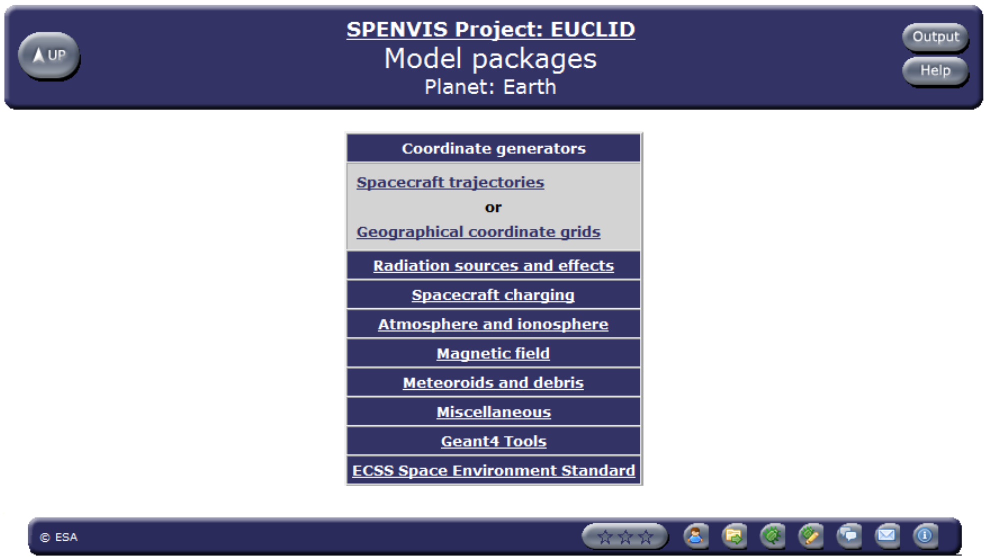
The Space Radiation Environment

- Shielding Assumptions
  - π steradians, as viewed from the CCDs, will have very limited shielding effect (~ 5 mm Al)
  - 3 π steradians will be significantly shielded (> 20 mm Al)

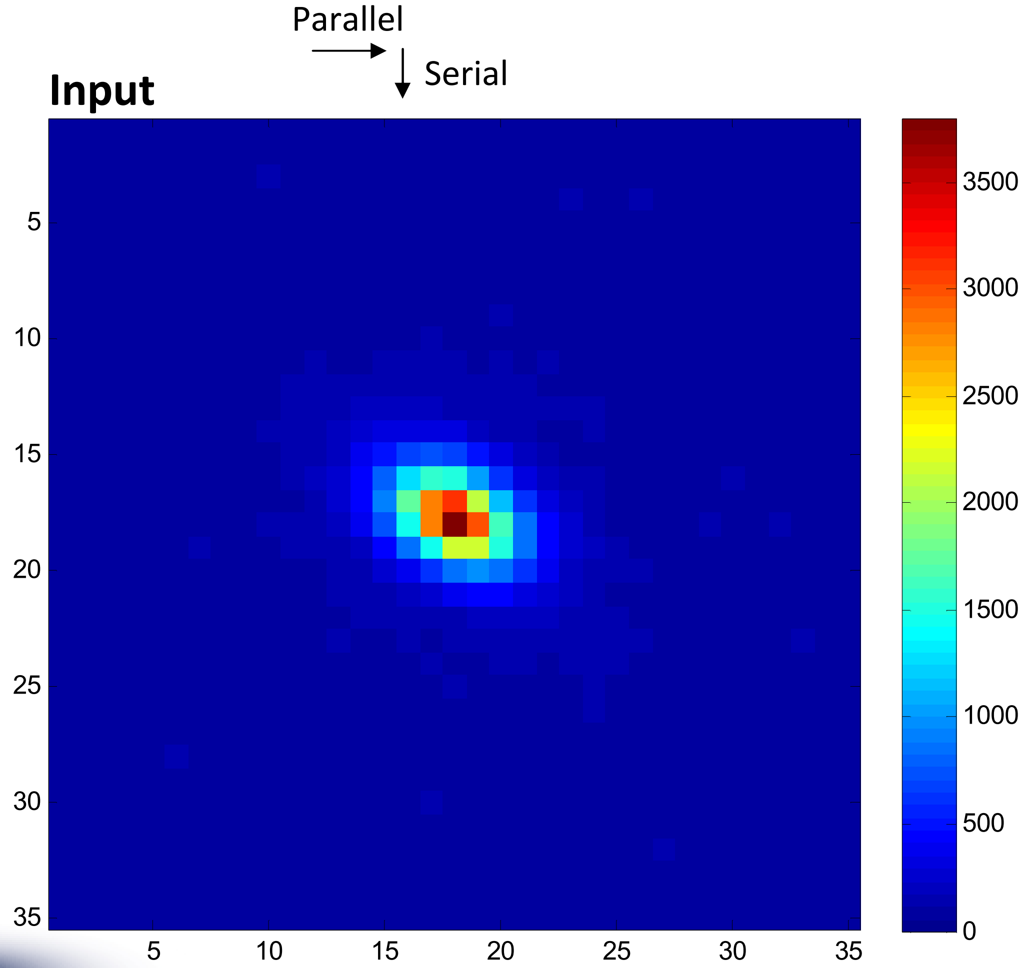
- Using ESA's SPace ENVironment Information System (SPENVIS) the worse case end of life proton fluence can be estimated
  - Orbital geometry
  - Mission start
  - Mission duration
  - Based on shielding



- The Emission Solar Proton model was used to provide a worse case (assuming 5 years at solar maximum) end of life **10 MeV equivalent fluence of 6.0×10^{9} protons.cm^{-2}**
- A launch date of 2018 gives an end of life 10 MeV equivalent fluence of 1.5×10^{9} protons.cm^{-2}

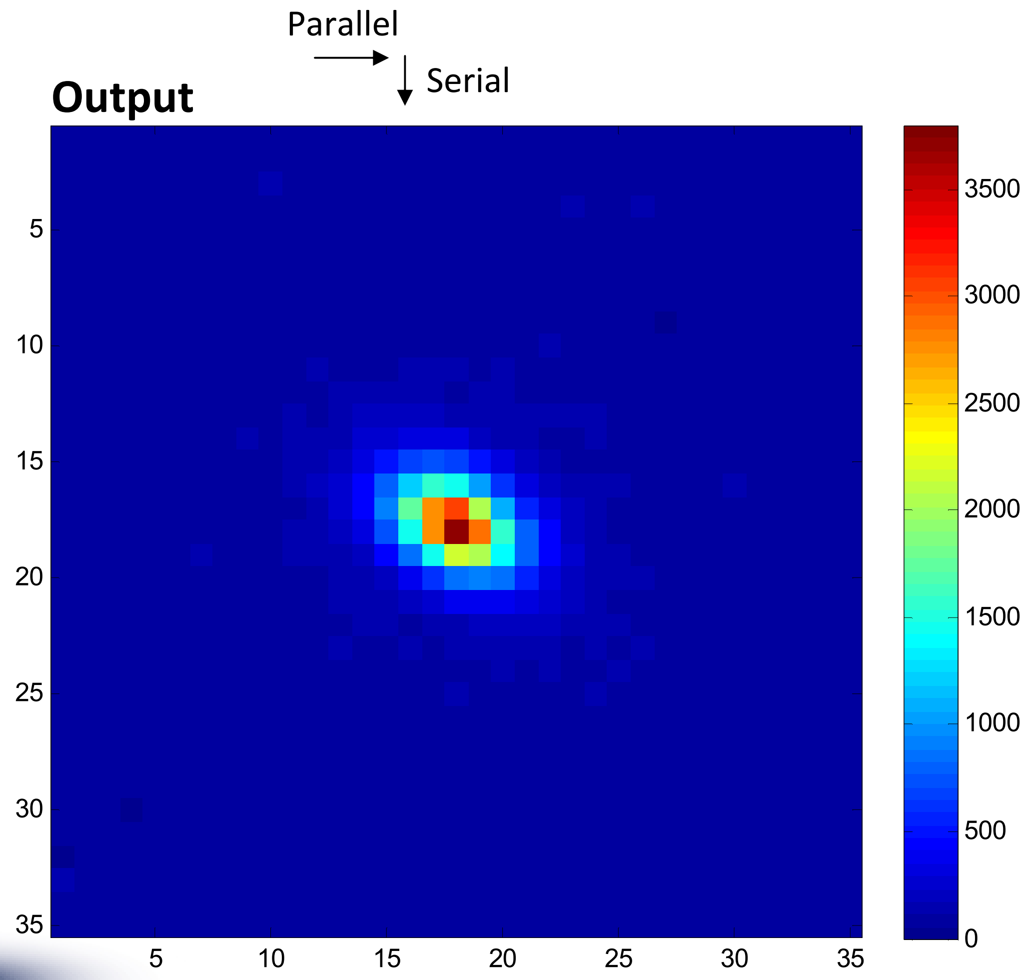
Radiation damage effects

- Sample point spread function provided by CEA for input into the groups Monte Carlo charge transfer model



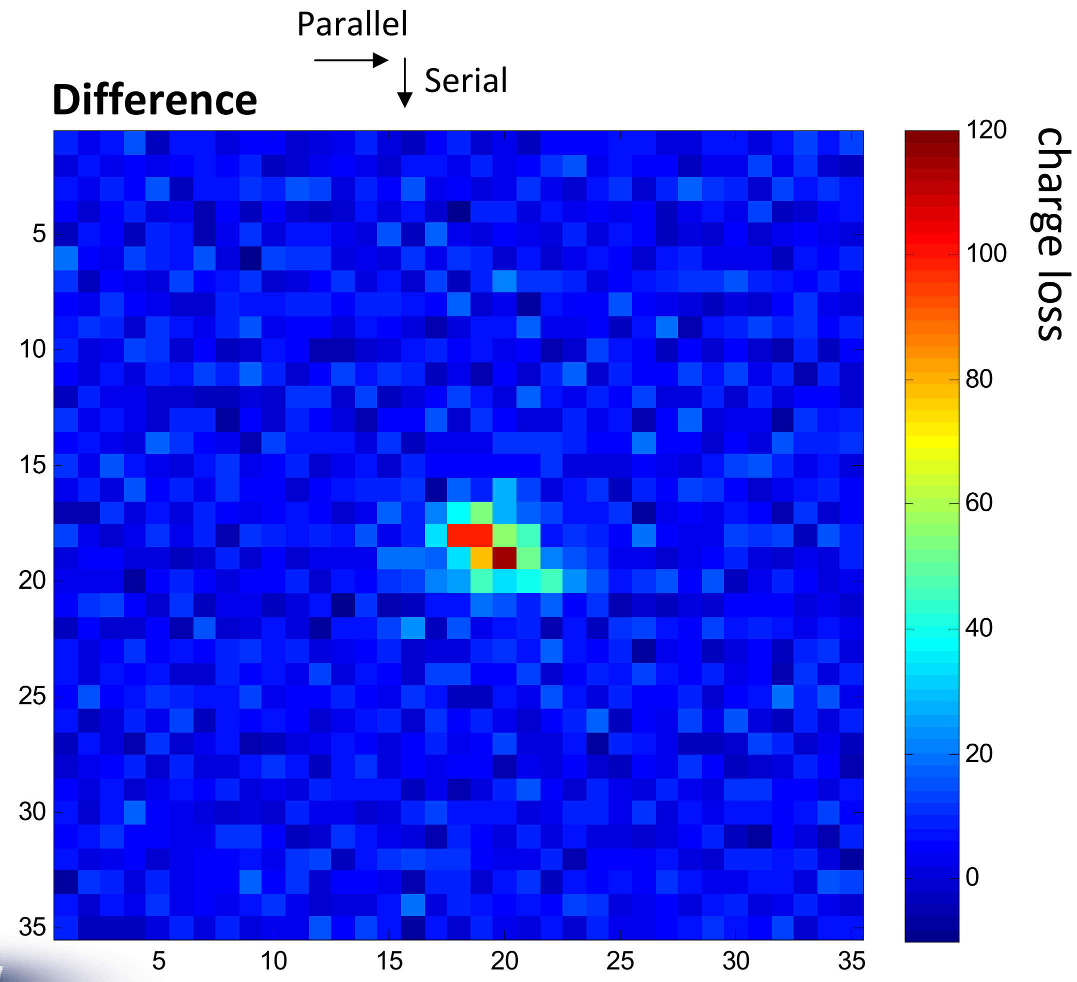
Radiation damage effects

- Resulting point spread function after processing to account for radiation induced charge transfer inefficiency (CTI)



Radiation damage effects

- Image showing the difference between the input and output



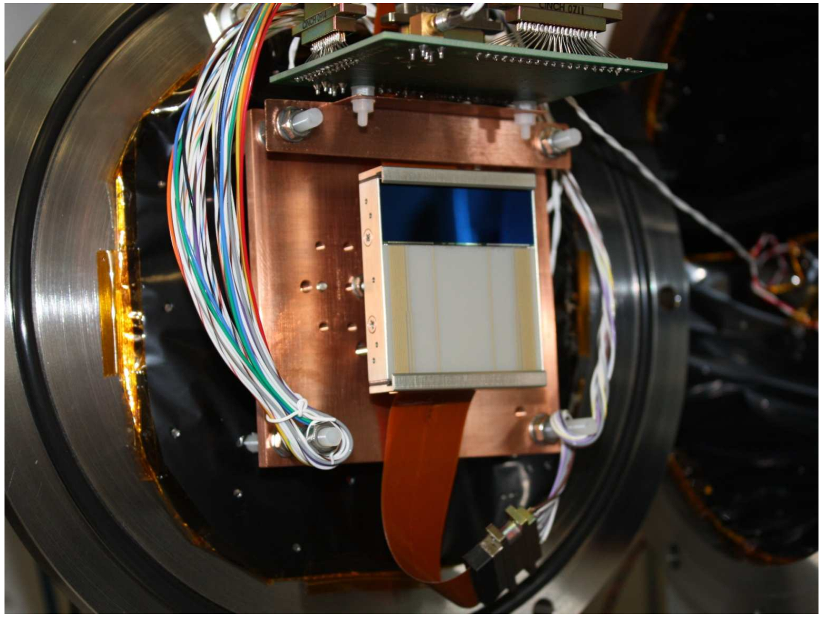
Aims on an assessment into the proton radiation damage

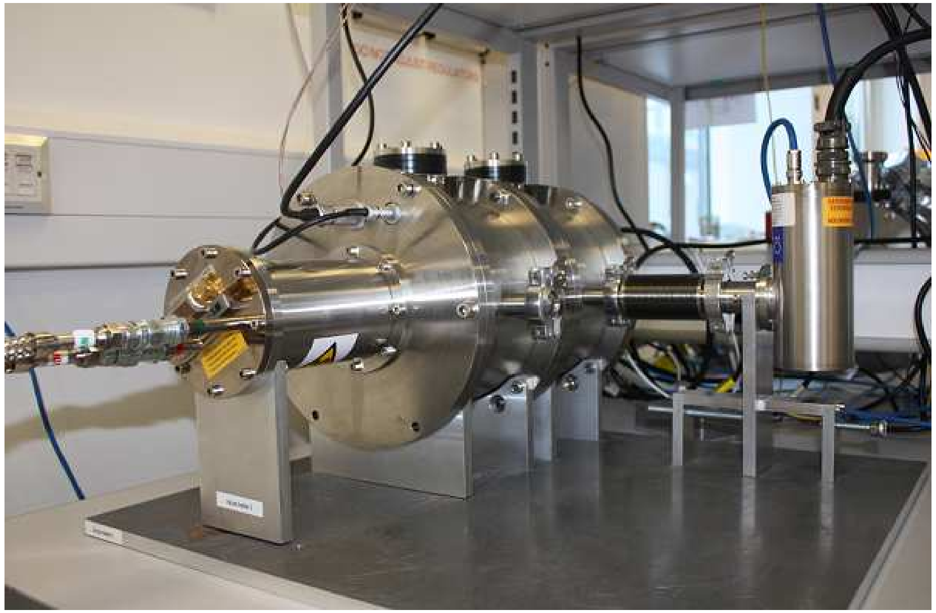
"It is beneficial that the effects of radiation-induced charge transfer inefficiency in the Euclid CCDs over the course of the 5 year mission at L2 are understood"

- To provide experimental data to be used for charge transfer model verification,
  - Simple analyticl model
  - Monte Carlo model
- To asses the impact of radiation damage on Euclid CCD performance
  - Dark current and bright defects
  - Charge transfer inefficiency under similar Euclid operating conditions
    - Effect of temperature
    - Effect of optical background
    - Effect of charge injection

Experimental Arrangement

- e2v technologies plc. CCD204
  - Two output nodes
  - Image area of 4096(H) × 1064(V)
  - 12 μm pixels
- Vacuum test facility
  - CryoTiger® refrigeration system
  - An X-ray tube was used to fluoresce a manganese target held at 45° to the incident X-ray beam to provide a known energy for calibration and X-ray CTI measurements.





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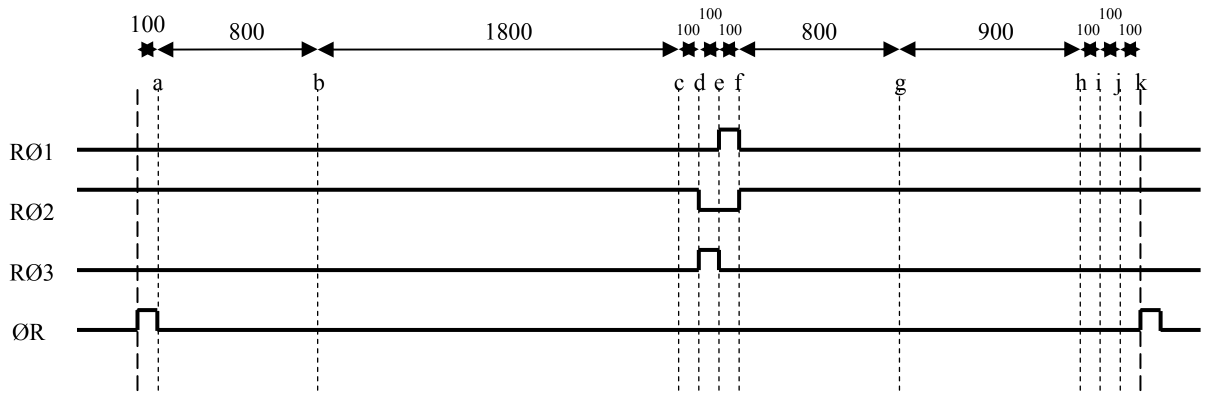
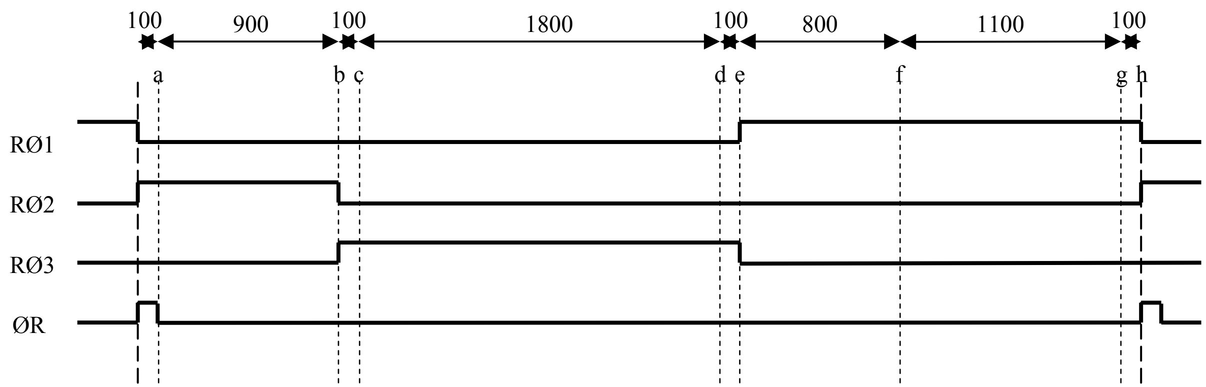
Experimental Technique

- Data collection performed using,
  - 500s integration time
  - CCD readout at 200 kHz, providing a parallel line dwell time of ~10 ms
  - CTI measurements were made using Mn-Kα X-ray events
  - Video mode clocking (a brief comparison was made using burst mode clocking)

Burst mode clocking

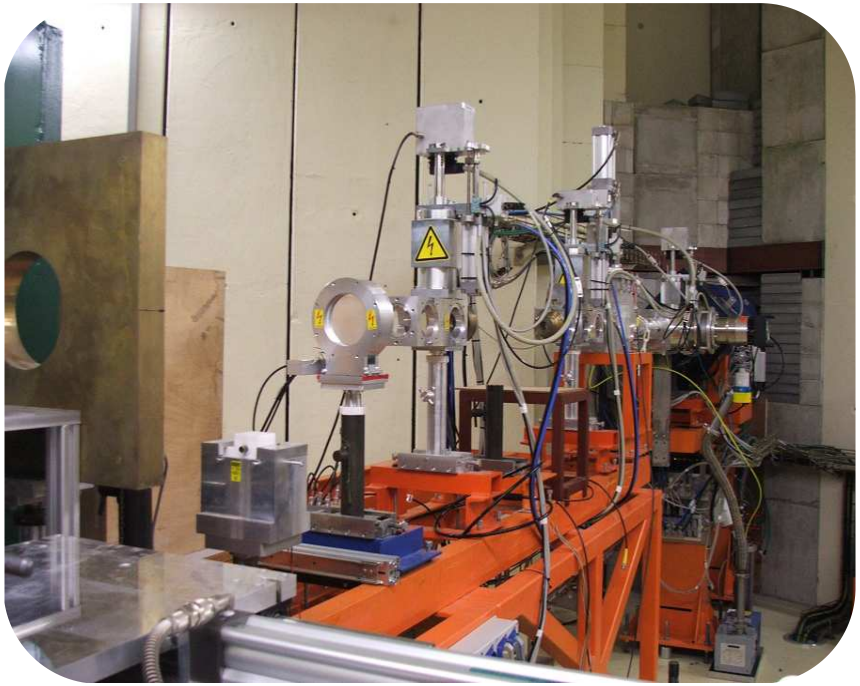


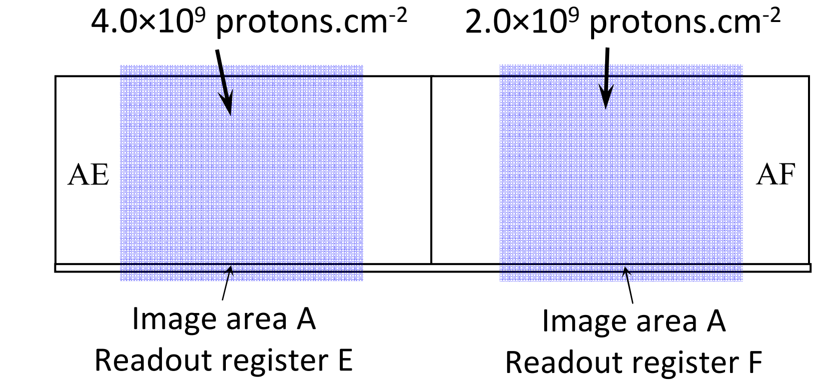
Video mode clocking

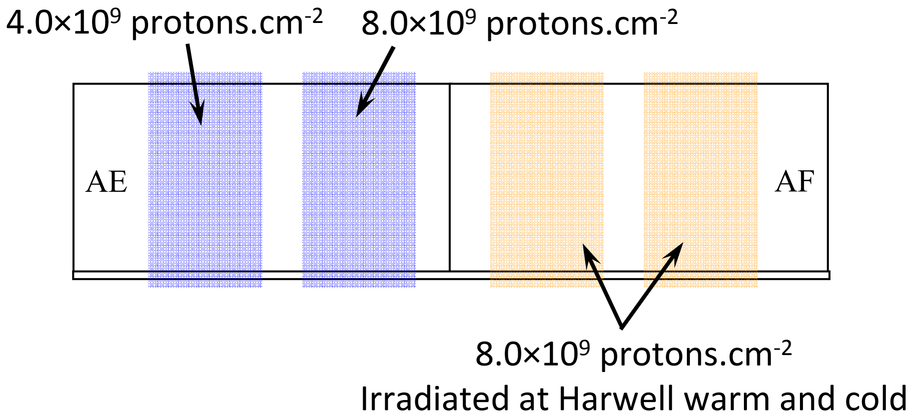


CCD proton irradiation

- Two CCDs irradiated at the Accelerateur Groningen-ORsay (AGOR) cyclotron at the Kernfysisch Versneller Instituut (KVI) in Holland
  - Irradiation performed using 50 MeV protons







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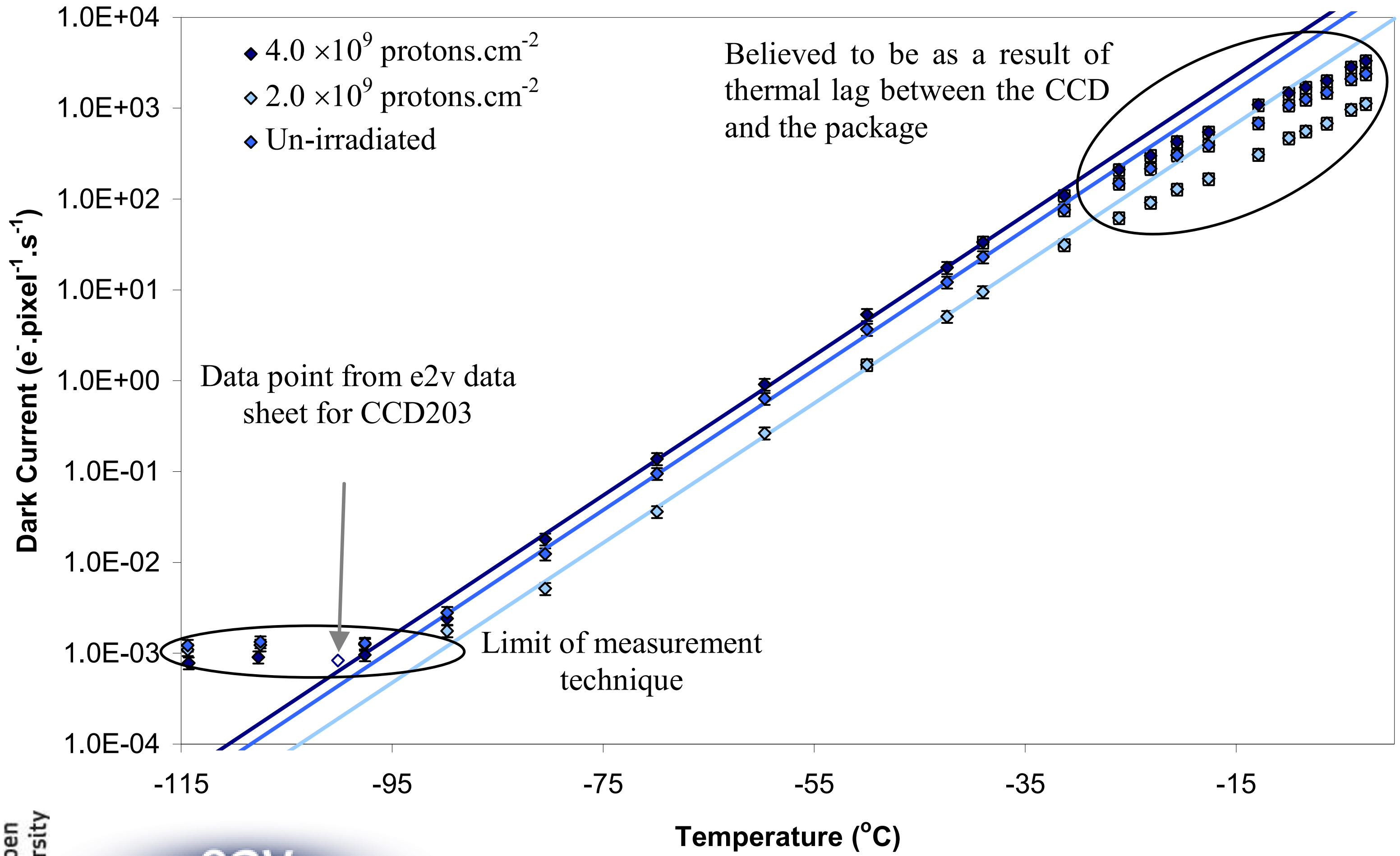
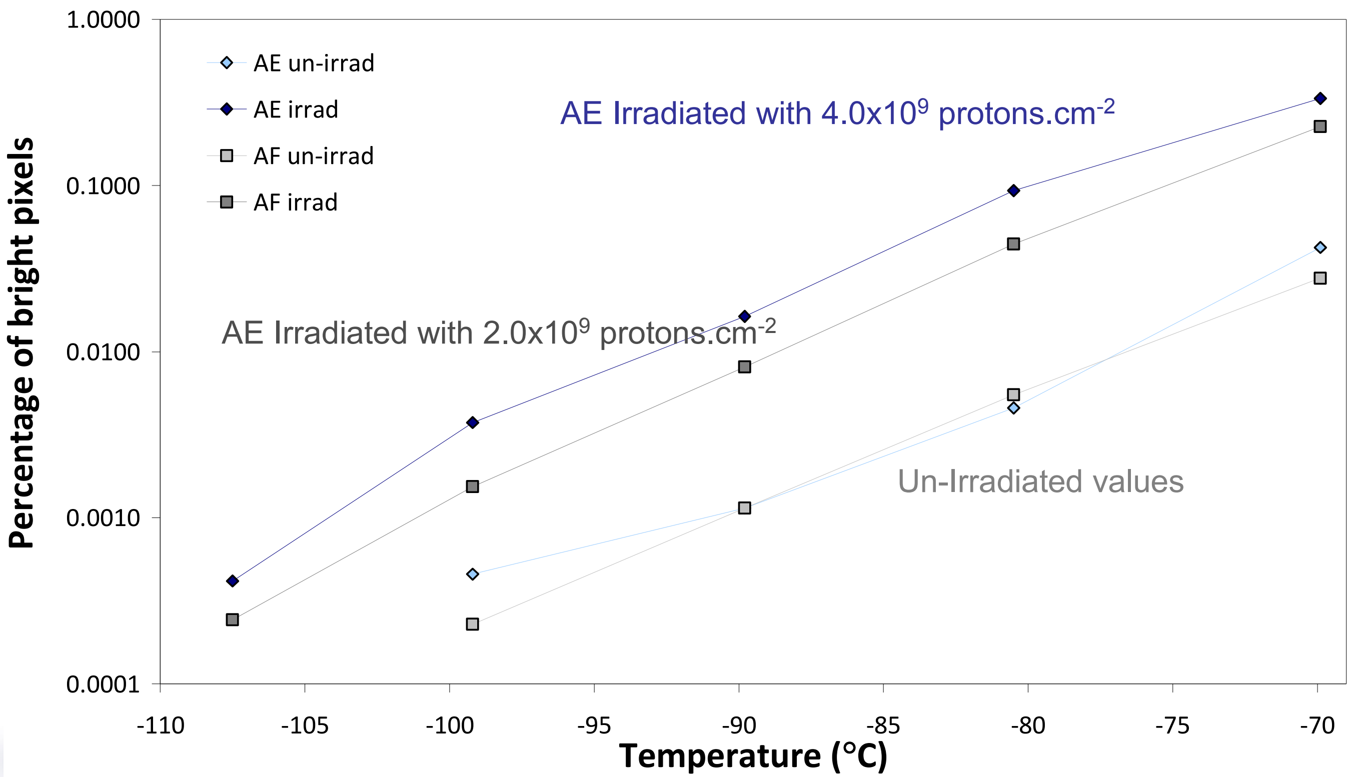
Results: Dark Current

- Dark Current measured as a function of temperature, indicating dark current will be negligible at Euclid operating temperatures



Results: Cosmetic Quality

- The number of bright and dark defects and their locations were recorded as a function of temperature between -114 °C and -70 °C.
- A bright and dark defect was defined as any pixel exhibiting charge levels > 5σ after a 500 seconds integration time, where σ is the r.m.s. noise in the image, above or below the mean background respectively.
- One dark column was identified starting in row number 368 of column 373



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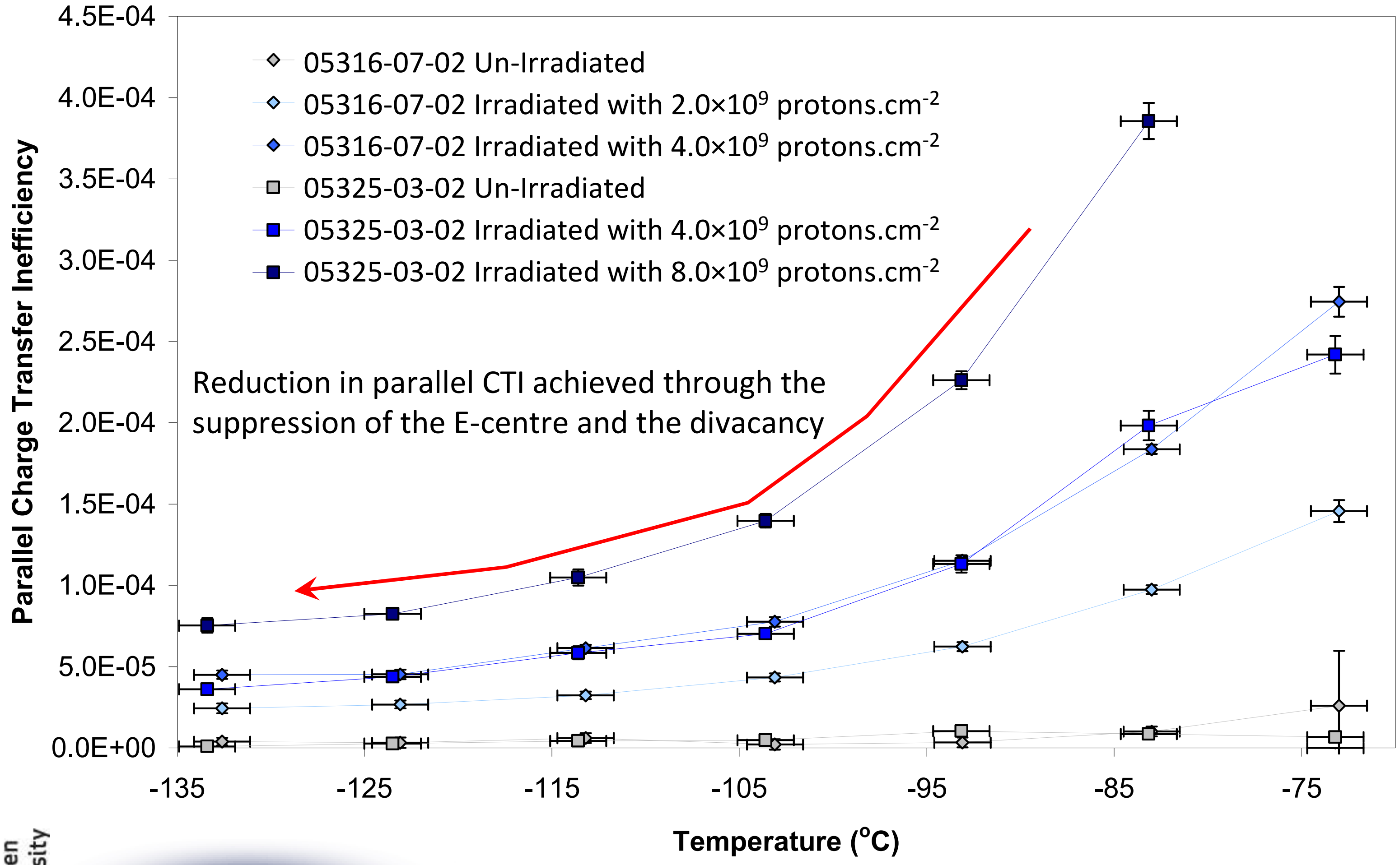
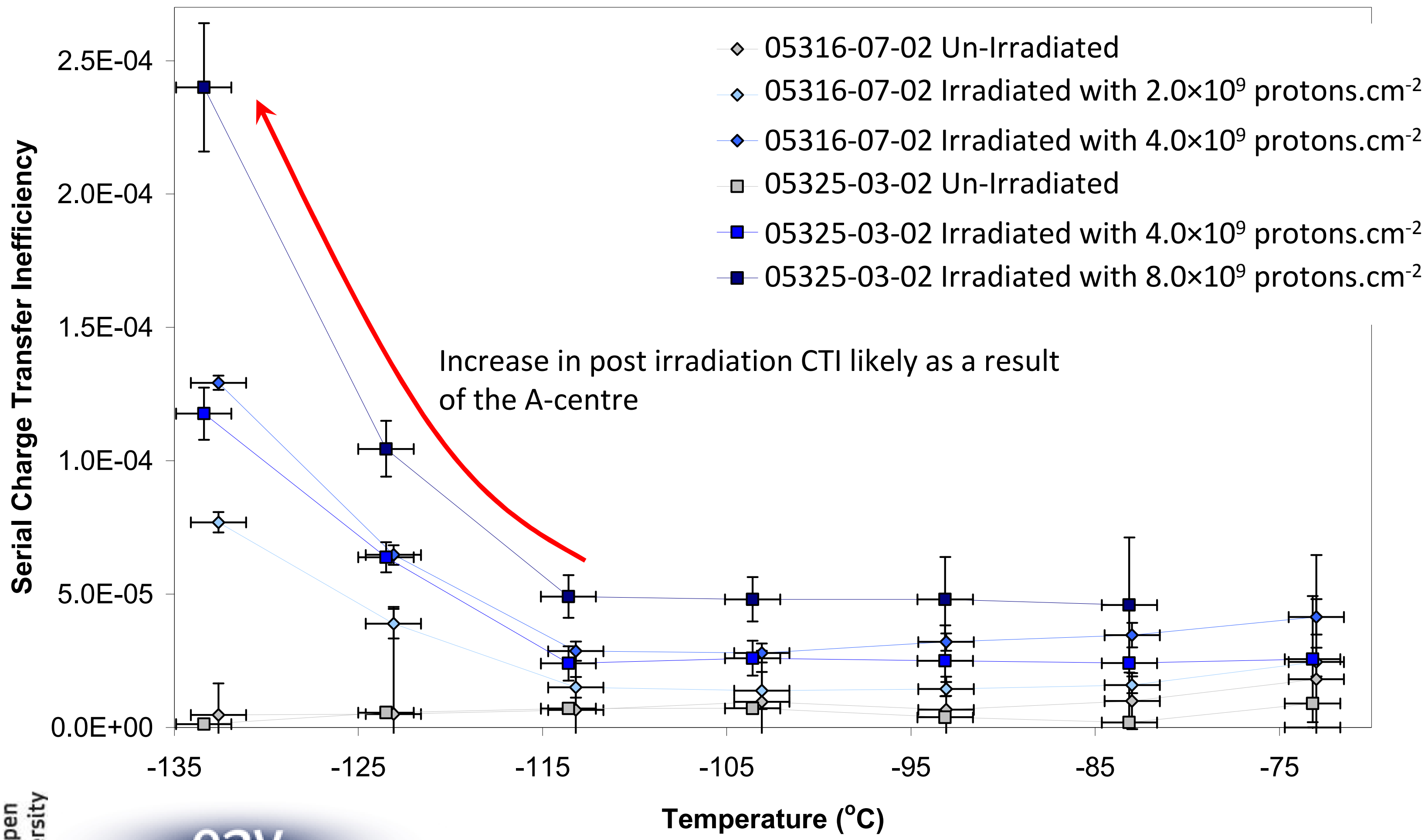
Results: CTI as a function of Temperature

- Parallel CTI as a function of temperature



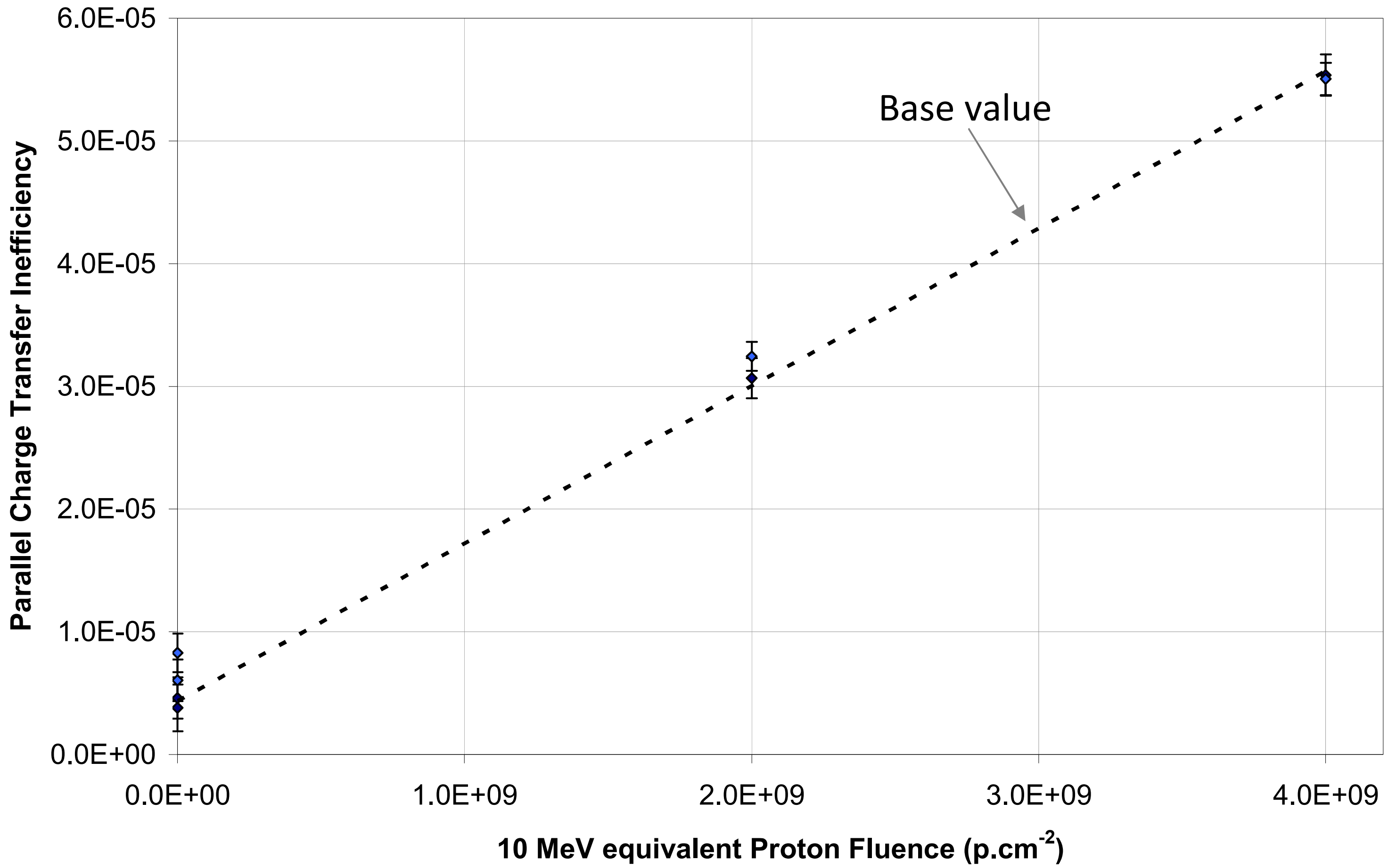
Results: CTI as a function of Temperature

- Serial CTI as a function of temperature



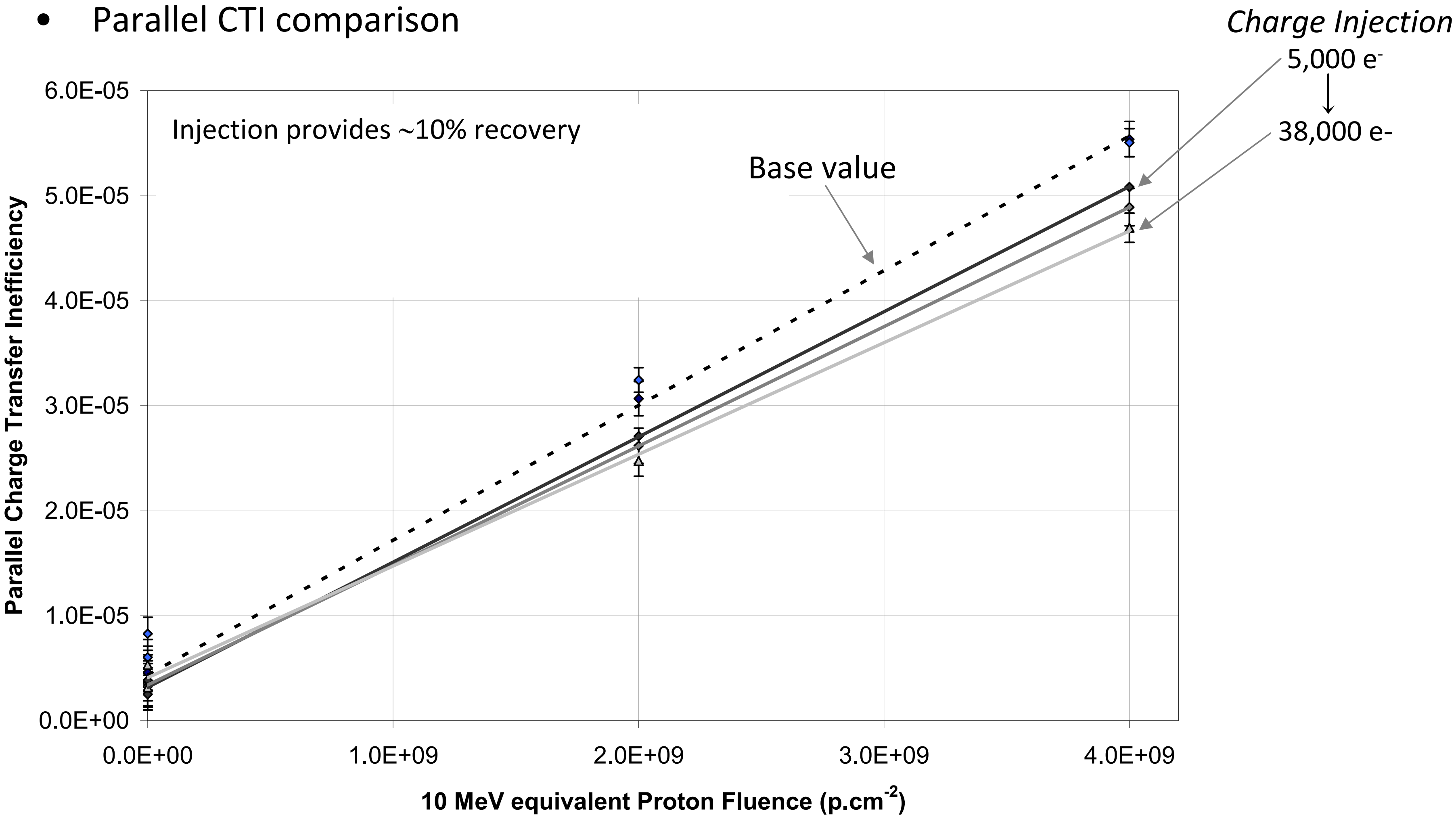
Results: Parallel CTI at -113 °C (160 K)

- Parallel CTI comparison



Results: Parallel CTI at -113 °C (160 K)

- Parallel CTI comparison



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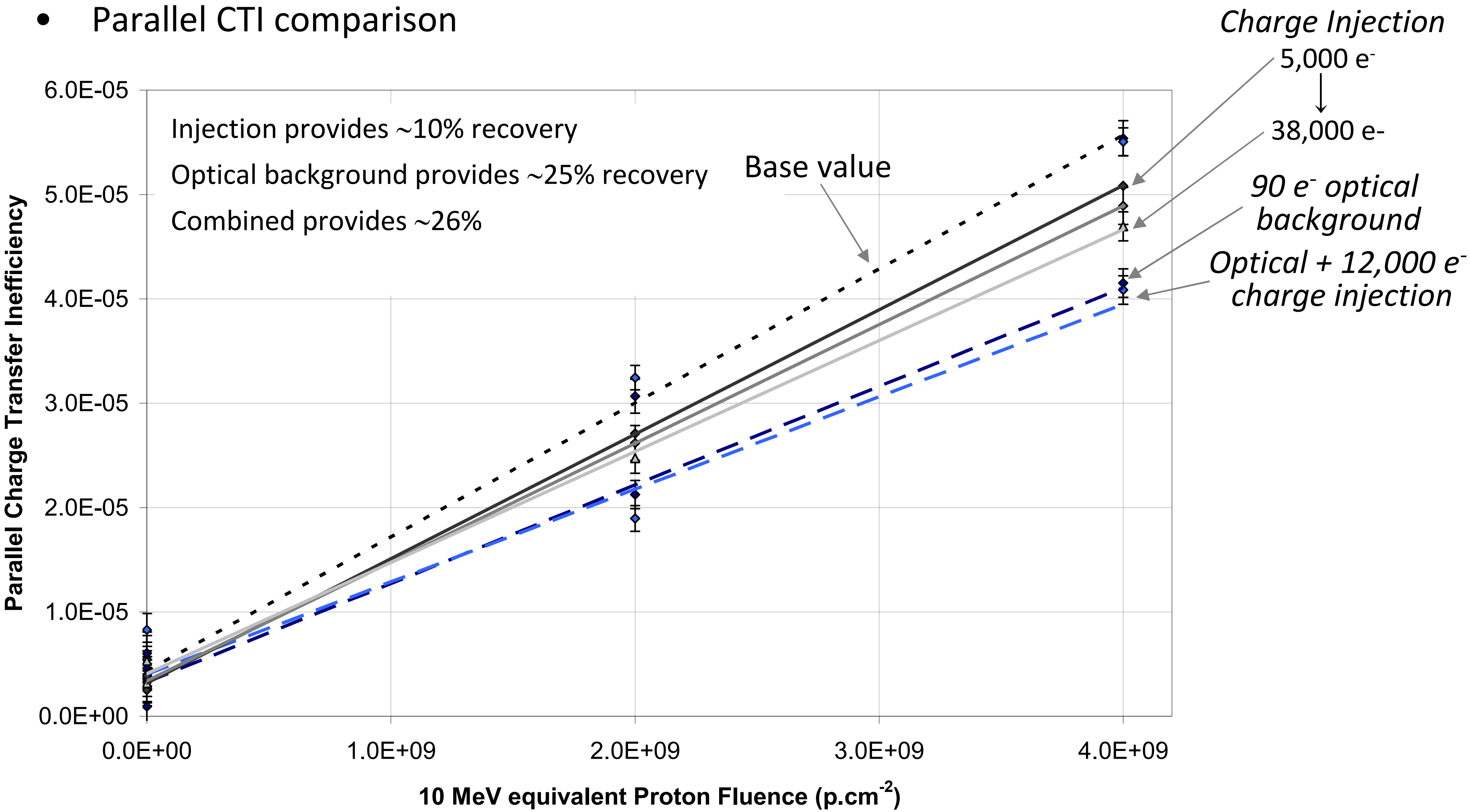
Results: Parallel CTI at -113 °C (160 K)

- Parallel CTI comparison



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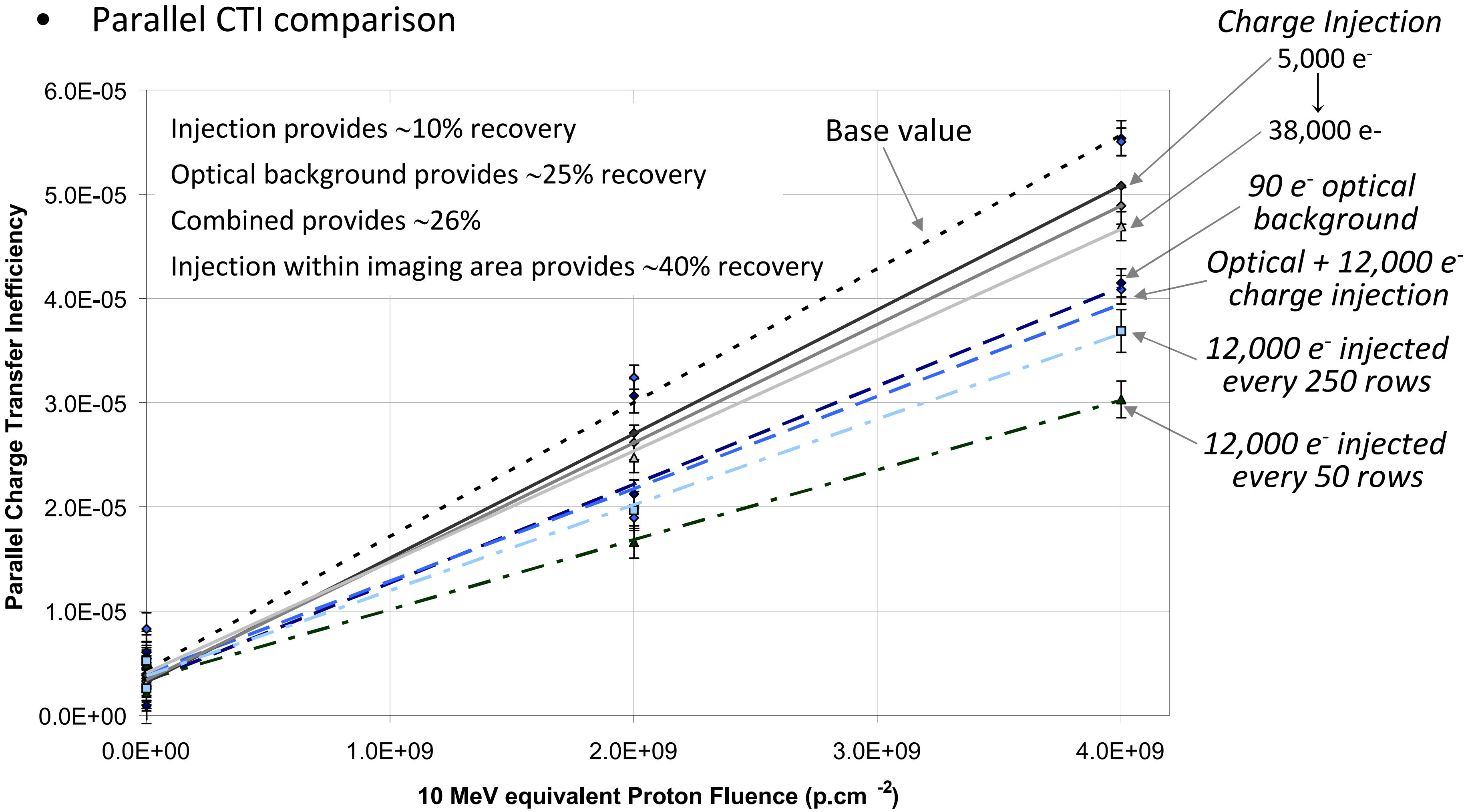
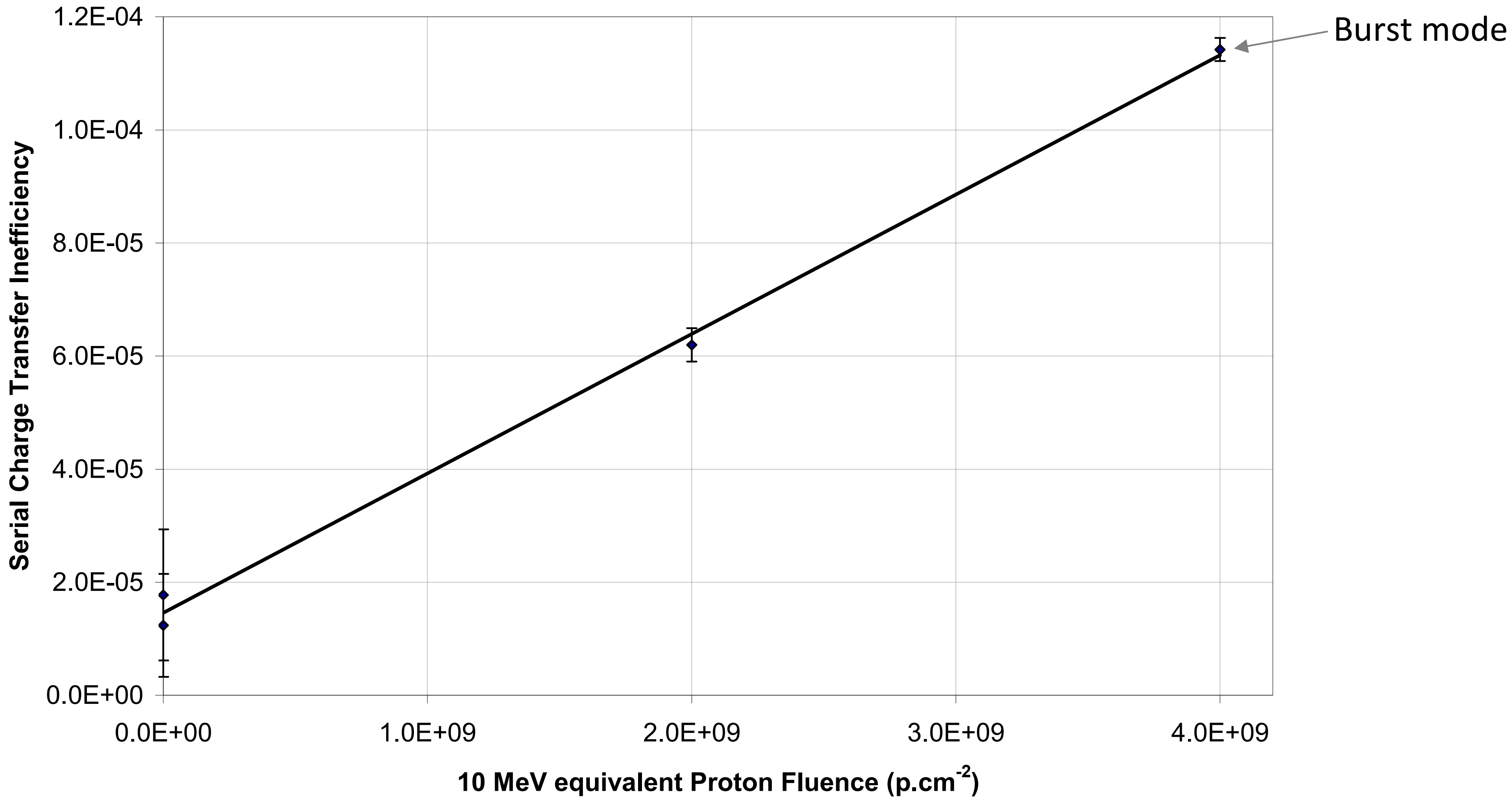
Results: Parallel CTI at -113 °C (160 K)

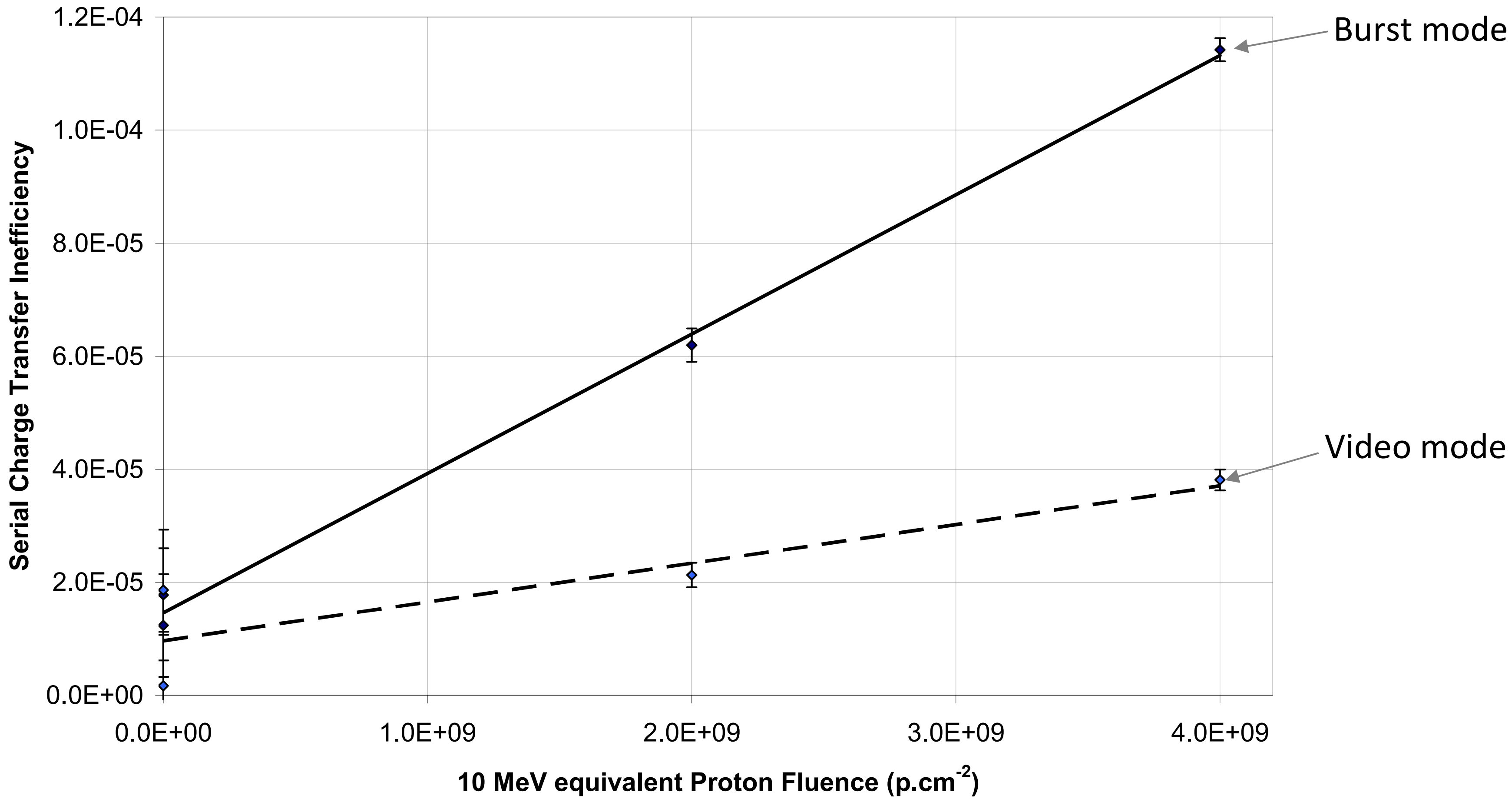
- Parallel CTI comparison



Results: Serial CTI at -113 °C (160 K)



Results: Serial CTI at -113 °C (160 K)



Results: Serial CTI at -113 °C (160 K)

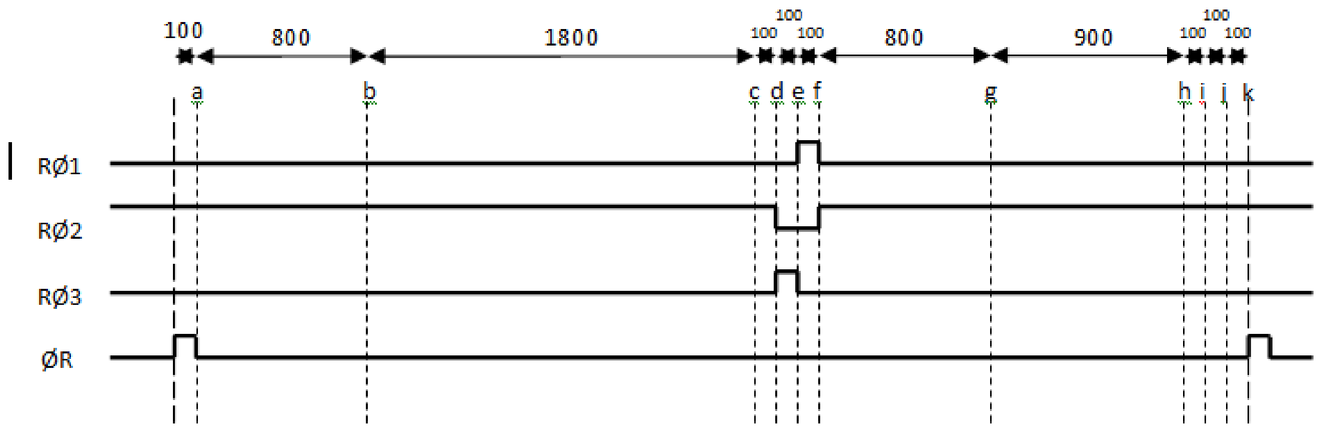


Figure 4: Clocking scheme used for burst mode operation (time in ns)

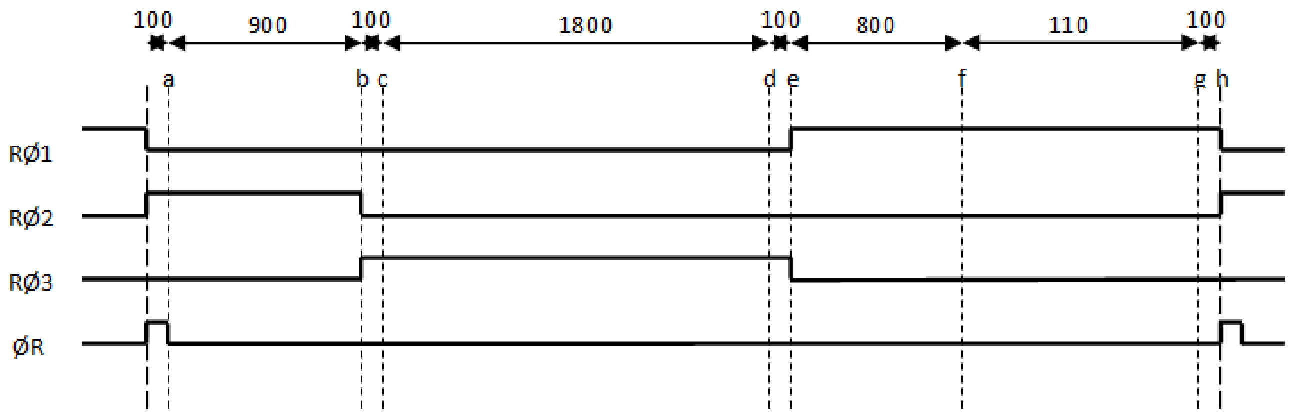


Figure 5: Clocking scheme used for video mode operation (time in ns)

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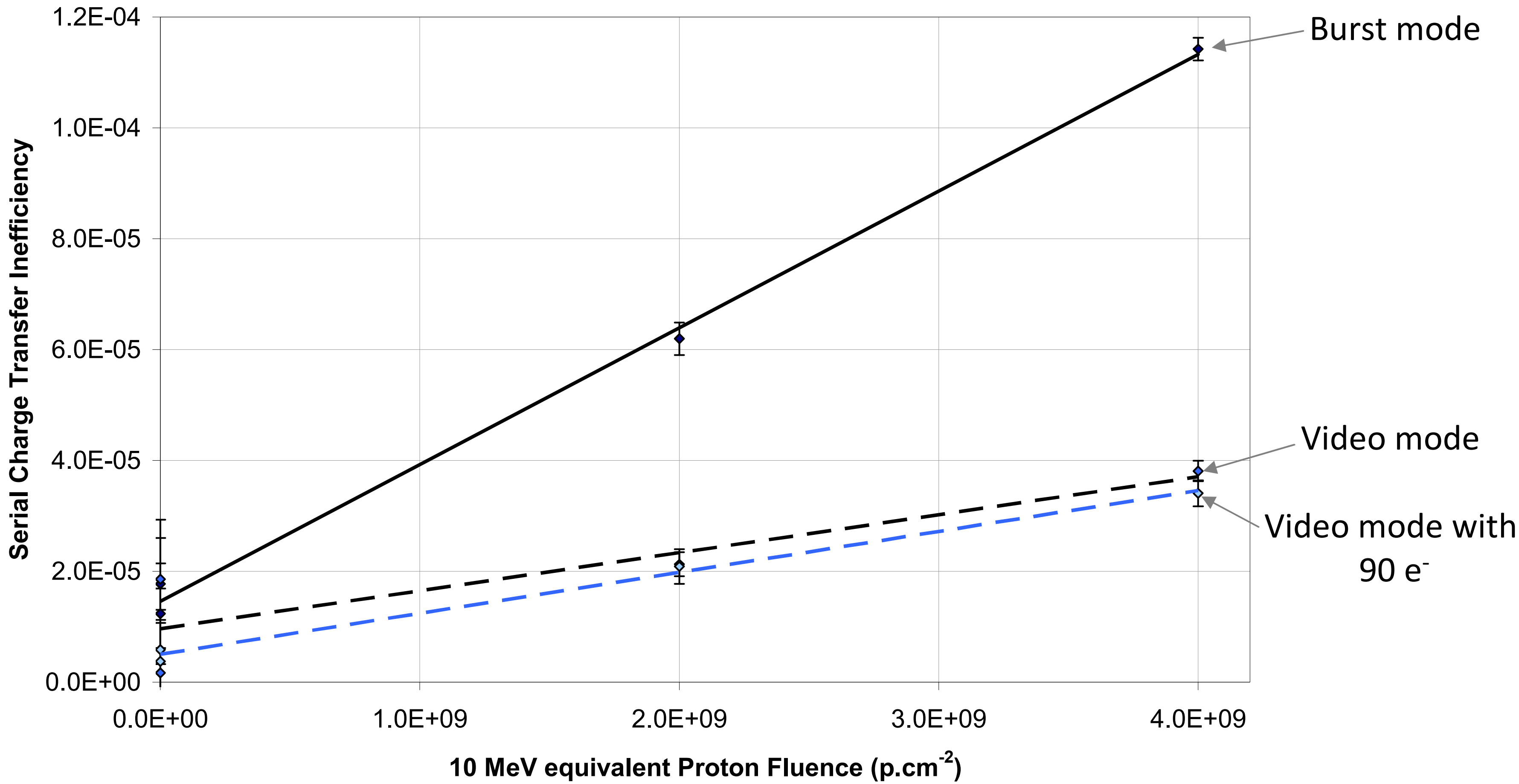
Results: Serial CTI at -113 °C (160 K)



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Conclusions

- Experimental data used for charge transfer model verification which will be developed further within the cei
- Operating temperature recommendation made of around -113 °C (160 K)
  - Current nominal operating temperature is between 150 K to 165 K
- Dark current and radiation induced noise increase should not be a problem for Euclid at its nominal operational temperature
- No bright pixels identified at -113 °C (160 K)
  - Bright defects from cold irradiation to be investigated
- Charge Transfer Inefficiency
  - Performance evaluation has provided a high level of confidence in the CCD and CTI models can recover galaxy shapes to the required accuracy
  - Charge injection within the imaging area allows for the possibility of mission extension
  - Further optimisation of the serial clocking scheme has led to improvements in serial CTI
- A custom CCD has been designed, designated the CCD273, based on this work and discussions between e2v technologies plc. and the Euclid consortium.

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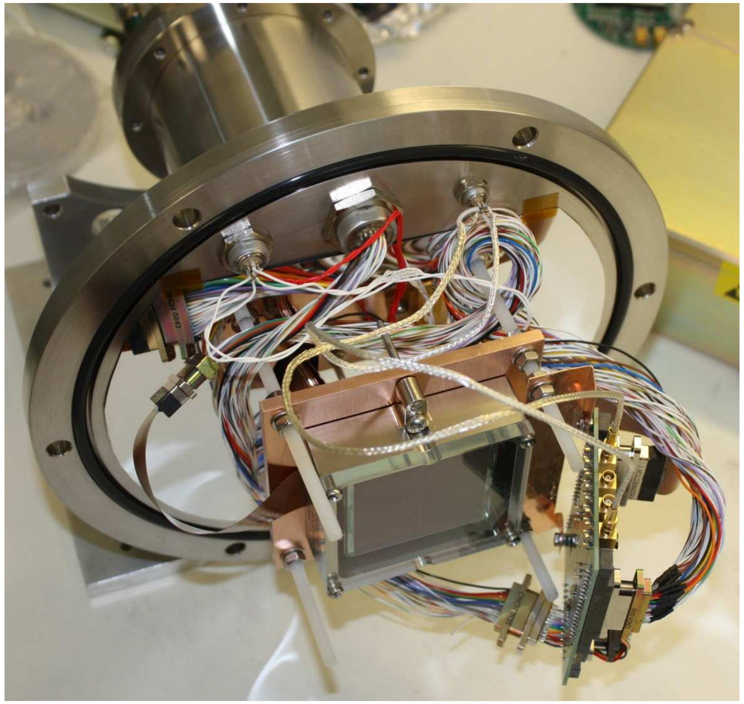
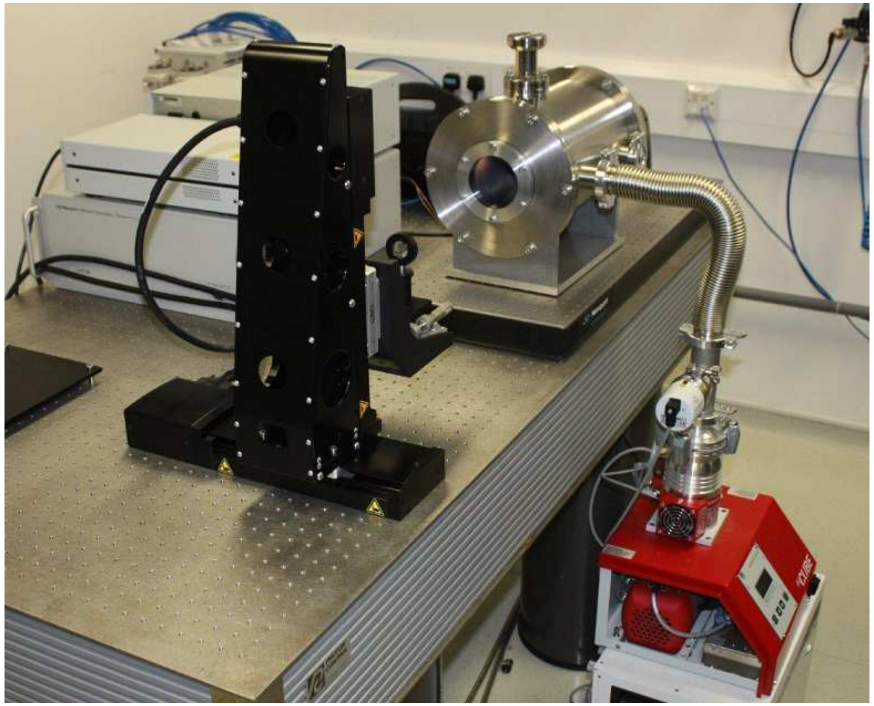
Ongoing and Future Work

- Compare the performance of the CCD273 to that of the CCD204, focussing on the effect on serial CTI
- Development of an optical test bench for Euclid CCD testing
- To investigate the post proton irradiation performance of a p-type buried channel CCD204, fabricated using the same mask set as the n-channel devices.



CCD273 mounted and awaiting testing



Euclid optical test bench

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