Trap Pumping for Euclid
Identifying radiation induced traps in-orbit

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Euclid

- ESA M2 mission
  - ‘Mapping the Dark Universe’
  - Dark Matter and Dark Energy
  - Two instruments (VIS and NIR)

- VIS instrument (weak lensing)
  - Measure shapes of galaxies of large part of the sky down to $R \sim 24.5$
  - Use these data to infer Dark Matter distribution
  - Large focal plane
    - 36 CCDs (4k x 4k)
    - Over half billion pixels
    - 0.01 arcsec pixel scale
    - 0.5 deg$^2$ Field of View
Radiation damage

- High energetic particles from the Sun can damage the silicon lattice in the CCD
  - Creates defects
- These defects (or traps) can capture electrons and release them later in time
  - Leads to smearing of the data
- For Euclid radiation damage over 6 year mission will be major issue
  - High level of correction is needed
  - Requires improved knowledge of trap species and parameters
- Trap pumping method can identify and characterise single defects (or traps)
- Trap pumping will be used in-orbit for Euclid

Before Correction

From: Massey et al. (2010)
Trap pumping theory

- Trap pumping works by clocking charge back and forth between phases

- If the phase time \( (t_{ph}) \) resonates with the emission time constant \( (\tau_e) \) of the trap
  - Charge will be effectively shuffled from one pixel to the other
- Repeating this cycle a number of times \( (N) \) will result in a dipole for each trap
Trap pumping theory

- The intensity of the dipoles is given by

\[ I = NP_c \left[ \exp \left( \frac{-t_{ph}}{\tau_e} \right) - \exp \left( \frac{-2t_{ph}}{\tau_e} \right) \right] \]  
(Eq. 1)

- Different \( t_{ph} \) values will give different dipole intensities for each trap
- Fitting Eq. 1 to the intensity curve will give \( \tau_e \) and capture probability \( P_c \)
Simulating trap positions

- Dipole intensities also depend on position of the trap in the pixel, signal size, clocking scheme, pixel geometry, etc.
- All these parameters can be simulated using the CEI CCD Charge Transfer Model (C3TM) developed for simulating CTI effects in CCDs (Skottfelt et al. 2017)
- Simulating 3 phase device with standard clocking scheme
  - Single trap under $\Phi_3$
  - Single trap under $\Phi_2$
  - Single trap under $\Phi_1$
- Direction and shape of dipole can thus give subpixel information
- Simulating all subpixel positions to get map of dipoles for traps across the pixel
- Comes in handy in more complex situations
Sub-pixel clocking scheme

- Euclid CCD273 device has 4 phases and alternative clocking scheme thus needed
- Number of possible clocking schemes simulated and tested in lab
- Sub-pixel pumping scheme (1-2-3-2-1) chosen because of its simplicity
- Small part of pixel probed, but low risk of dipoles cancelling
- Direction of dipole can give sub-pixel and sub-phase positions
Trap pumping analysis

- CCD273 devices tested at OU as part of irradiation campaign for Euclid
- This shows data from pre-irradiated devices (1600 e⁻)
- 3 peaks
- $\tau_e$ scales with temperature
Trap species

- Plotting the peaks found at the three different temperatures
- $\tau_e$ peaks matches defects from Phosphorus and Boron (used as dopants) mixed with Carbon and Oxygen impurities
  - $\text{C}_i\text{P}_s (0.23, 0.26 \text{ eV})$
  - $\text{B}_i\text{O}_i (0.24 - 0.27 \text{ eV})$
  (Pichler, 2004)
- Results similar to the p-channel study
  (Talk by Ben Dryer)
Electrode widths

- Lab test show that when pumping 2-3-4-3-2 almost no traps are detected
- Possible explanation for this is that electrode widths are slightly skewed
- Simulation of TP with different widths for $\Phi_1$ and $\Phi_3$ gives similar effect
- Infer knowledge about the electrode widths

$\Phi_1 = 4.5 \, \mu m$  $\Phi_2 = 2 \, \mu m$  $\Phi_3 = 3.5 \, \mu m$  $\Phi_4 = 2 \, \mu m$

**Lab data**

- Scheme 1-2-3-2-1
  - 4004 traps

- Scheme 2-3-4-3-2
  - 26 traps

**Simulated data**

- Scheme 1-2-3-2-1
  - $\Phi_1 = 4 \, \mu m$, $\Phi_3 = 4 \, \mu m$

- Scheme 2-3-4-3-2
  - $\Phi_1 = 4.5 \, \mu m$, $\Phi_3 = 3.5 \, \mu m$

- Scheme 1-2-3-2-1
  - 2006 traps

- Scheme 2-3-4-3-2
  - 1156 traps

- Scheme 1-2-3-2-1
  - 2253 traps

- Scheme 2-3-4-3-2
  - 169 traps
Summary

- Weak lensing experiment on Euclid mission requires high resolution imaging
- Radiation damage degrades the data and therefore needs to be corrected for
- Trap pumping method can identify and characterise single traps in silicon lattice
  - Will be used by Euclid in orbit
- Trap pumping scheme chosen for Euclid
  - Gives subpixel and even sub-phase positional information
  - Reveals defects from dopants and impurities (pre-irradiated devices)
- Information about electrode width can be inferred from the by comparing lab and simulated trap pumping data
The conference BBQ this evening will still take place, but it will be moved indoor if the weather does not improve.