Interim Presentation

Random Telegraph Signals In CCDs & Active Pixel Sensors

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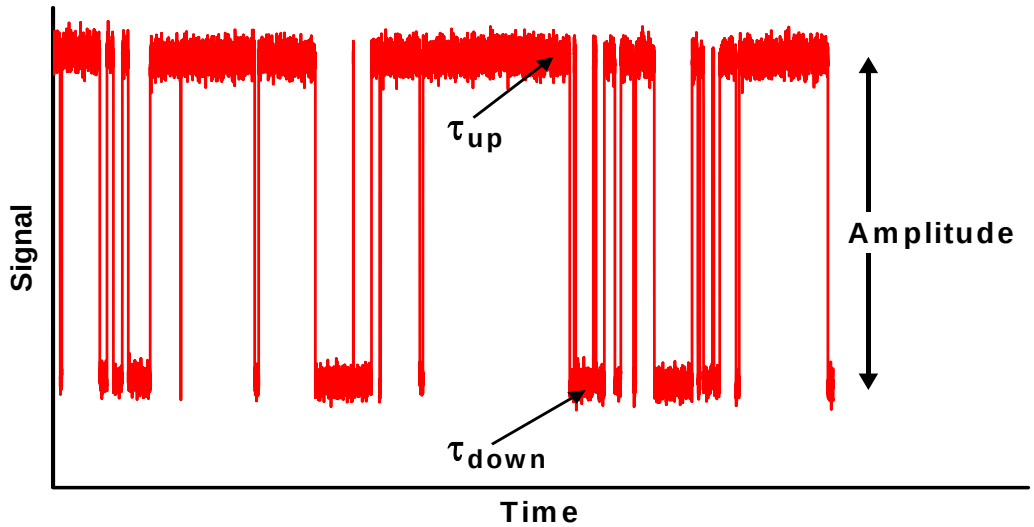
Introduction

- **Random telegraph signals (RTS) are seen in many electronic components**
  - **Occur when a defect can exist in two (or) more metastable states and switches between them at random time intervals**

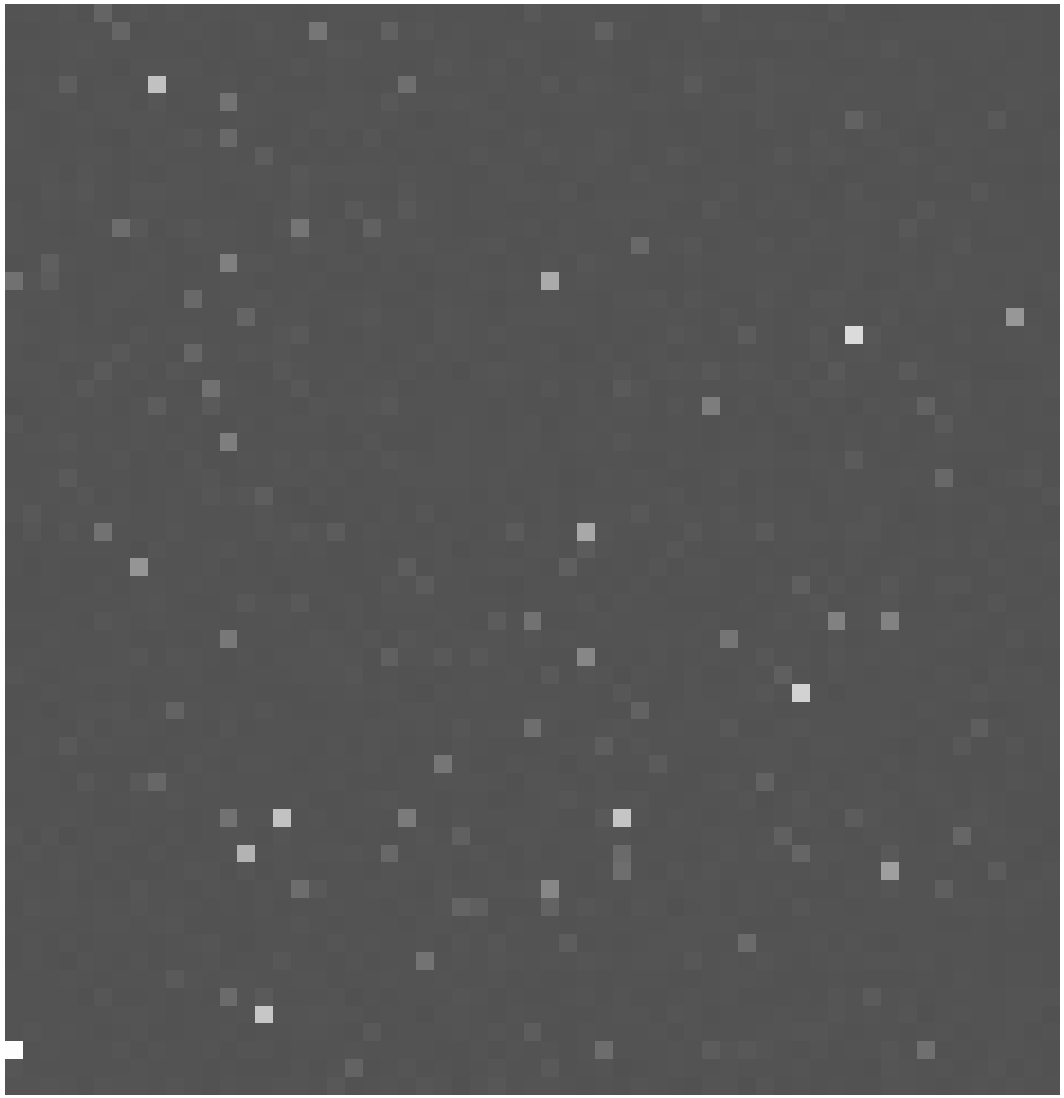


- **Can occur in MOSFETS (conductance fluctuations), memories (leakage current), IR detectors (dark current)**
- ***and dark current in proton irradiated CCD and APS imagers***

Motivation

- RTS is important because we need to minimise the cooling requirements for detectors (to save power).
  - Trend to use smaller CMOS cameras for many applications
- Running at higher temperature means higher dark current
- RTS effects make dark current correction difficult
  - Difficulties with subtraction of dark images
  - Ideally, need a model to predict RTS effects
- Can see RTS effects in some missions, e.g GOMOS (ENVISAT)
- Effect discovered in 1992. Some early studies (limited device types and limited number of pixels), since then only 'casual' investigations (exception is Fillfactory study on STAR250)
- RTS data collection & analysis is very time consuming
  - *Need a dedicated study*
  - *Need to be aware of 'selection effects': studies can be limited by time resolution, time duration and by readout noise*
    - *So worth 're-visiting' earlier work*

Typical Image



Approach (1)

- **To study RTS effects for low enough proton fluence**
  - Chance of more than one defect in a pixel is low
  - Variety of devices and temperature range +20°C to below 0°C
- **Existing devices (already irradiated), 512 x 512 pixel**
  - *Atmel TH7890M CCD*
  - *Fillfactory STAR250 CMOS active pixel sensor*
    - Dosimetry somewhat uncertain in some cases and (at least for CCD)
    - Proton fluence rather high for CCD (APS has small area photodiodes so RTS occurrence probability is low and a higher proton fluence can be tolerated)
  - *Data analysed for temperature behaviour of RTS & presented here*
  - Also have e2v CCD57-10 devices, but only as back-up
- **New devices (purchased but not yet irradiated):**
  - e2v CCD57-10 (3 off)
  - Fillfactory STAR1000 (2 off)

  } Irradiate at PSI & Harwell

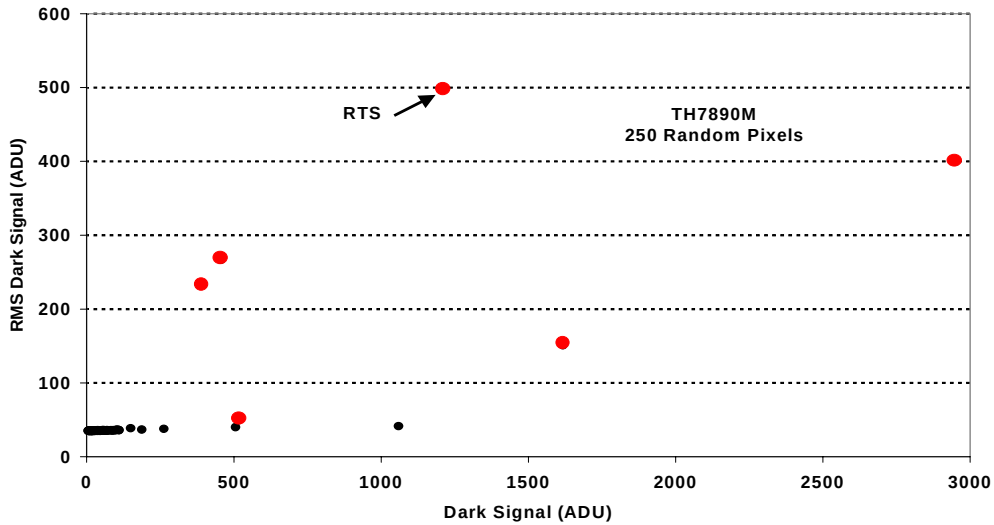
Approach (2)

- **Another APS of interest is the HAS sensor from Fillfactory.**

- **Irradiation of Gaia 1966 x 4500 pixel CCD at ~ -100°C**
  - **So far have done proton irradiations at room temperature**
  - **Are defects (particularly CTE traps and dark current defects) different when created at -100°C ?**
    - ***e.g. annealing / metastable behaviour***
  - **Have spare device**
  - **Modifications to cryostat made**
  - **New alpha source purchased**

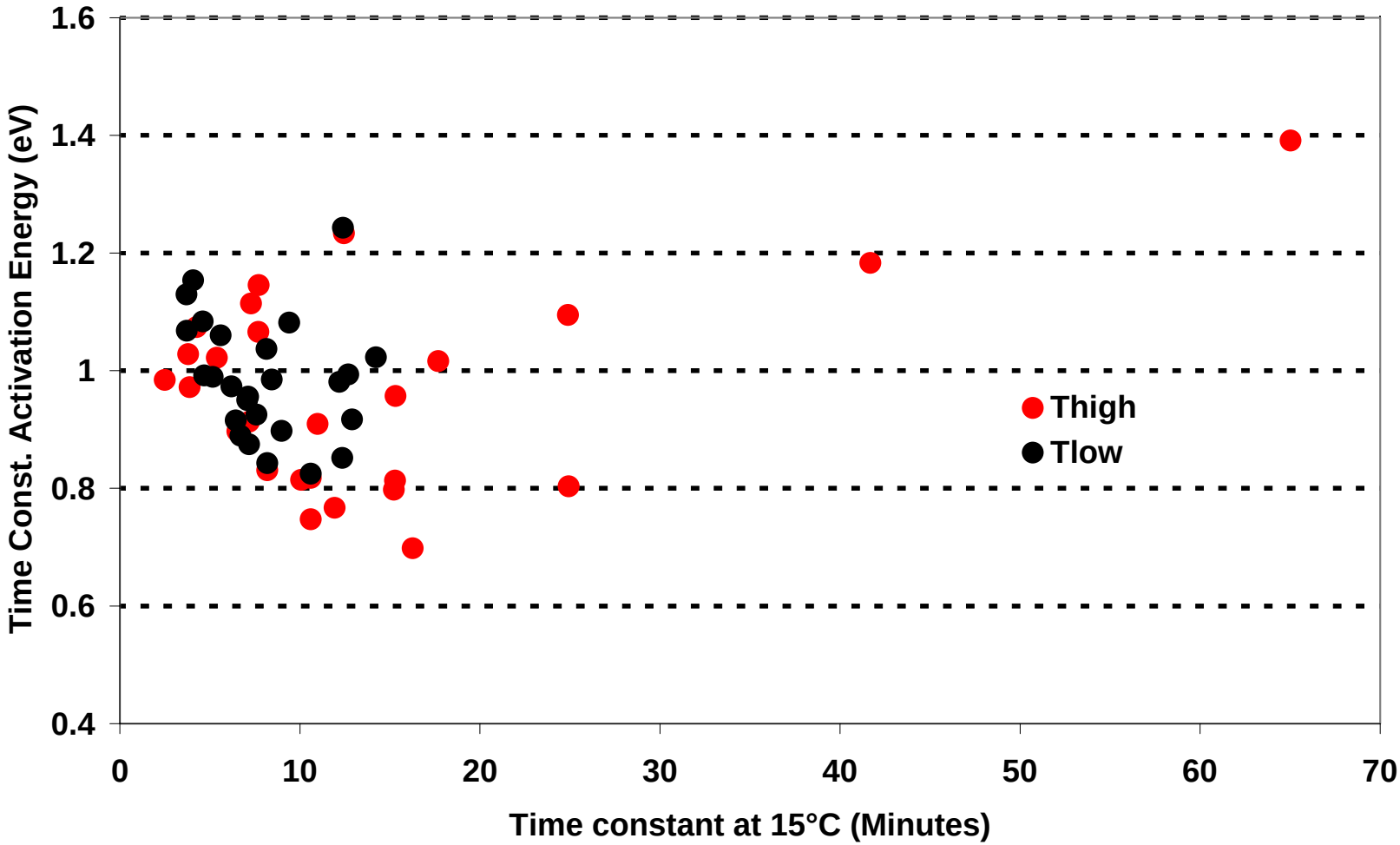
Results TH7890M (1)

- ~ 5 x 10^8 10 MeV p/cm^2
- count number of RTS pixels in 4 blocks of 250 pixels
  - = 37 ± 6 ➡ occurrence probability of (2.4 ± 4) x 10^{-5} /p/pixel
  - Very close to previous quoted value (for CCD02) of 1.6 x 10^{-5} /p/pixel



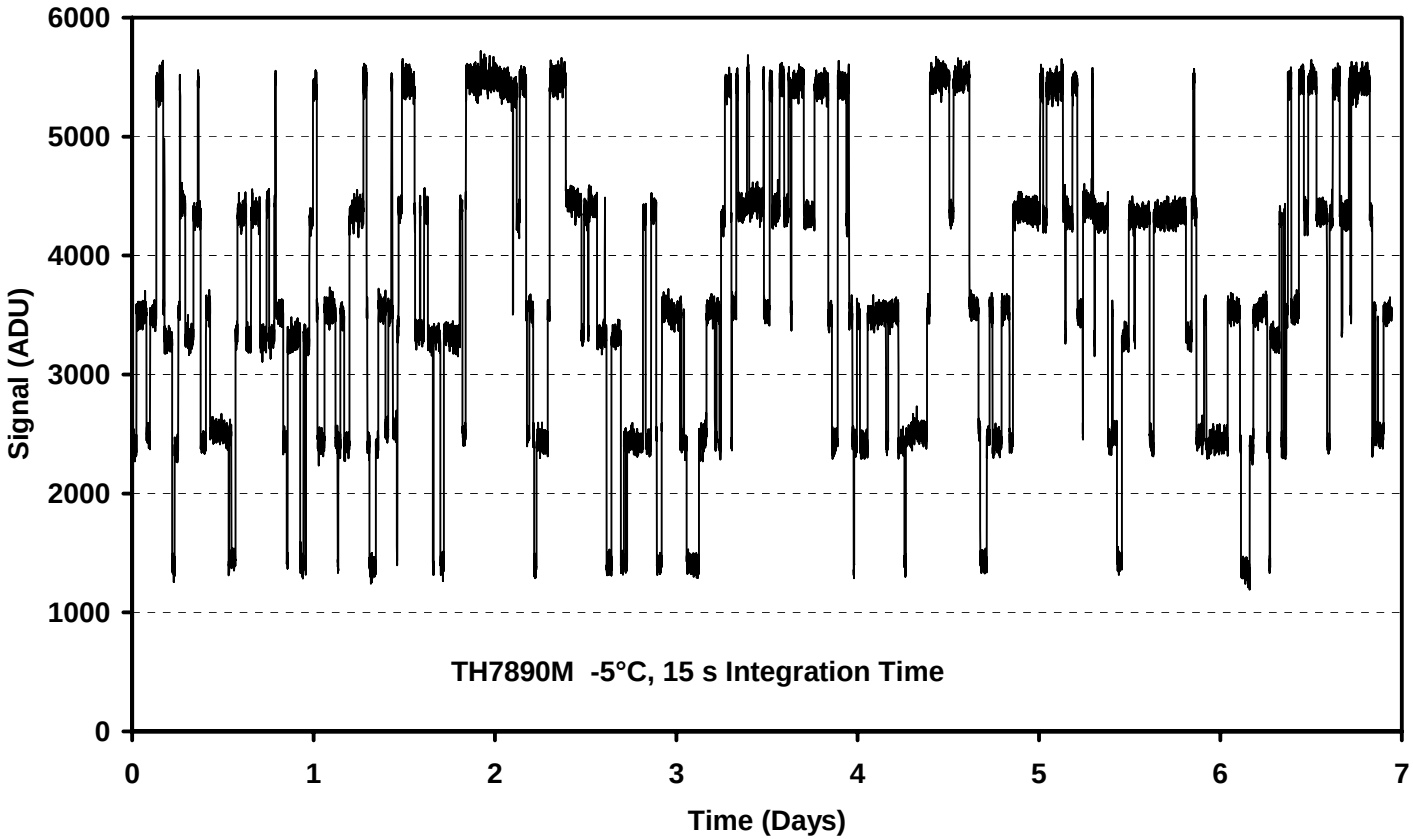
- About half pixels are ‘classic’ two level RTS and half are multi-level
- Analyse ‘classic’ pixels for amplitude and time constants
  - Typically need 20 000 samples to give about 50 transitions
  - Adjust integration time to improve SNR, can require 3-4 day runs at 0°C

Results TH7890M (2)



- Average amplitude activation energy ~ 0.53 eV

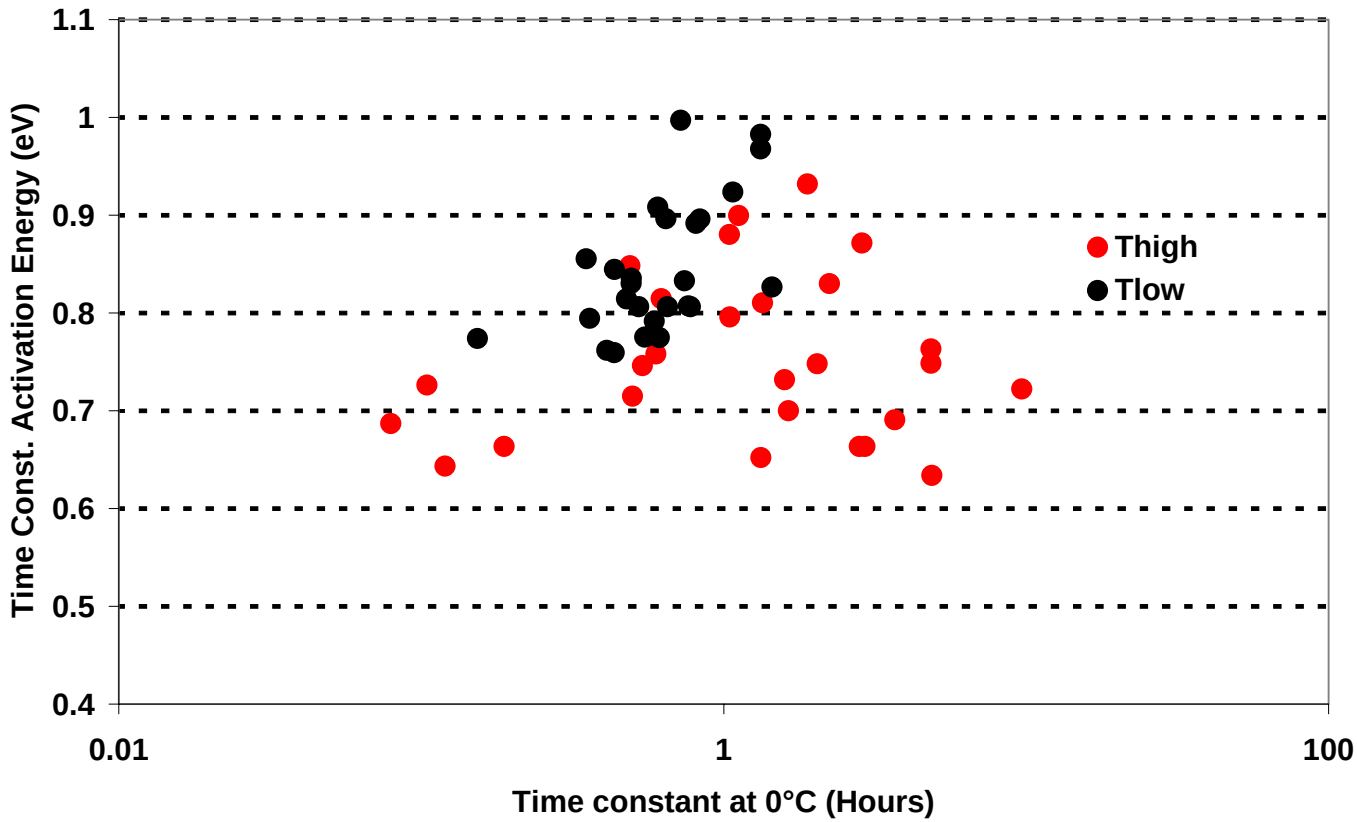
Multi-level Behaviour



- Too many multi-level pixels compared with low occurrence probability
  - Effect of clustering ? (but mostly point defects at 10 MeV)
  - Are individual defects multi-level ? (effect of electric field ?)

STAR250 Results (1)

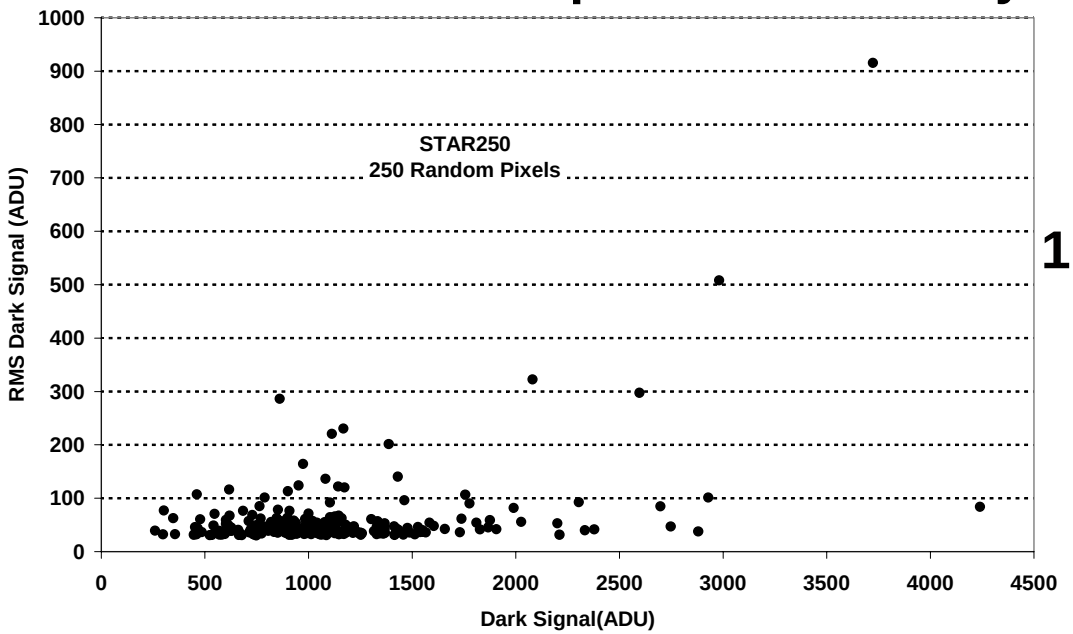
- Vpix = 0.35 V to prevent lag and reduce spike amplitude



- Average amplitude activation energy ~ 0.53 eV
- Time constant of 1 hour at 0°C equivalent to = 10 min at 15°C
- Contrasts with Fillfactory result ~ 0.6 eV

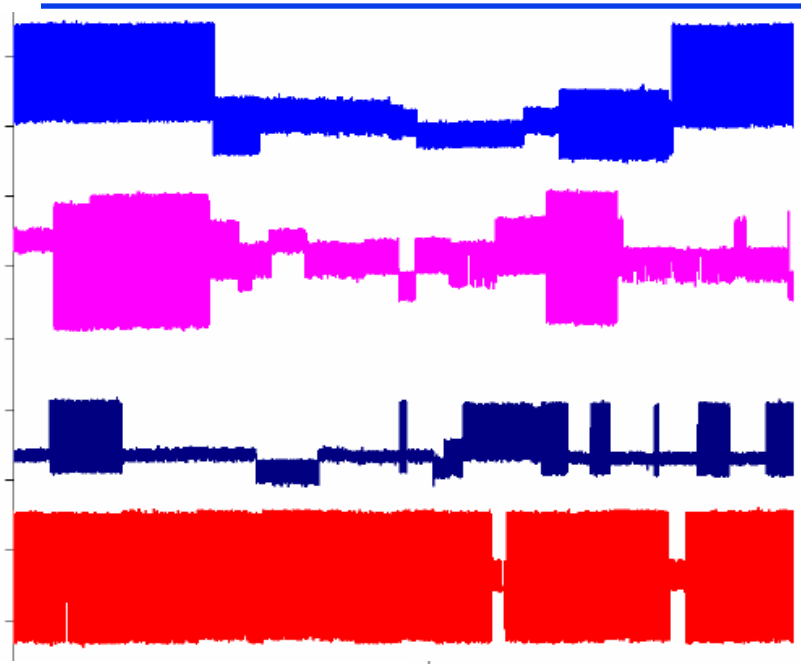
STAR250 Results (2)

- For 1.8 x 10^{11} 10 MeV p/cm^2 region ~ half pixels show RTS, but many have small amplitude.
- 10% have significant amplitude and of these ~ half are 2-level (the rest multi-level)
- For 1.8 x 10^{10} 10 MeV p/cm^2 region ~ 2/3 of brightest pixels show multi-level RTS – again, why so many multi-level RTS ?
- Analysis on 3 multi-level pixels shows amplitudes and time constants behave with temp. in a similar way to 2-level pixels



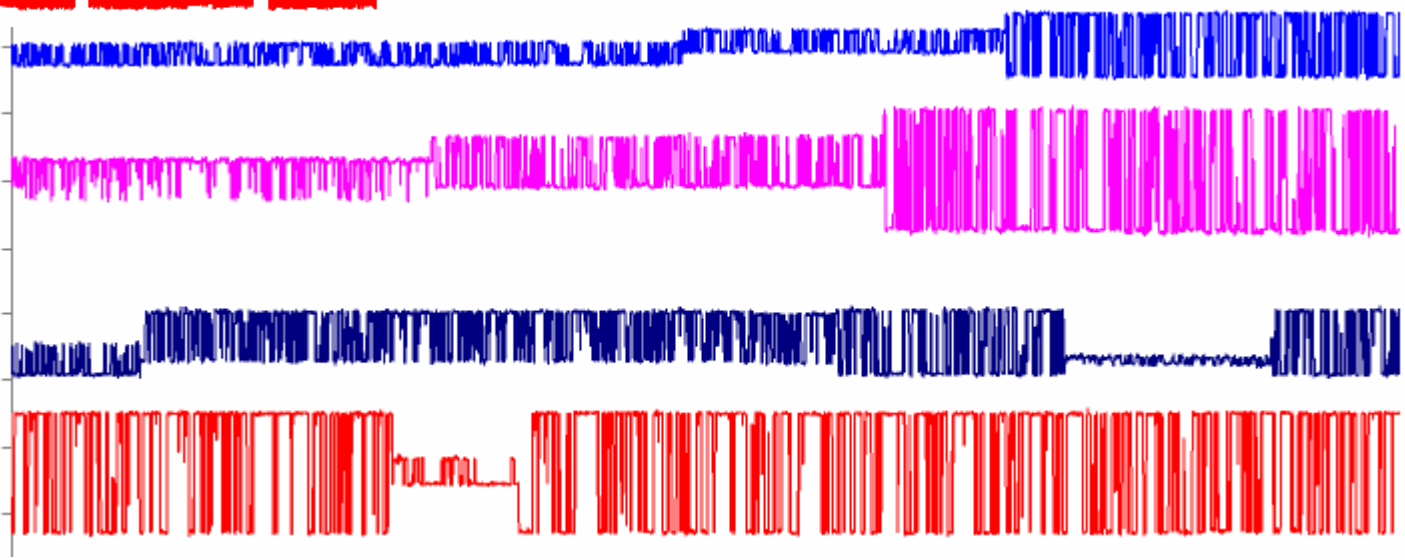
1.8 x 10^{11} 10 MeV p/cm^2

STAR250 Results (3)

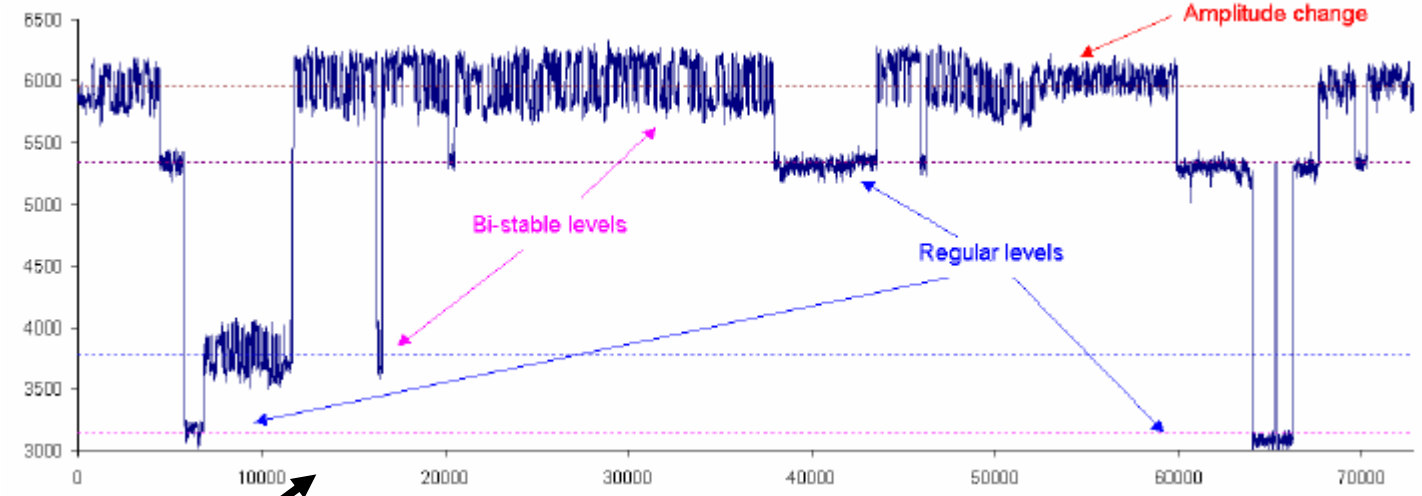


Multi-bistable RTS

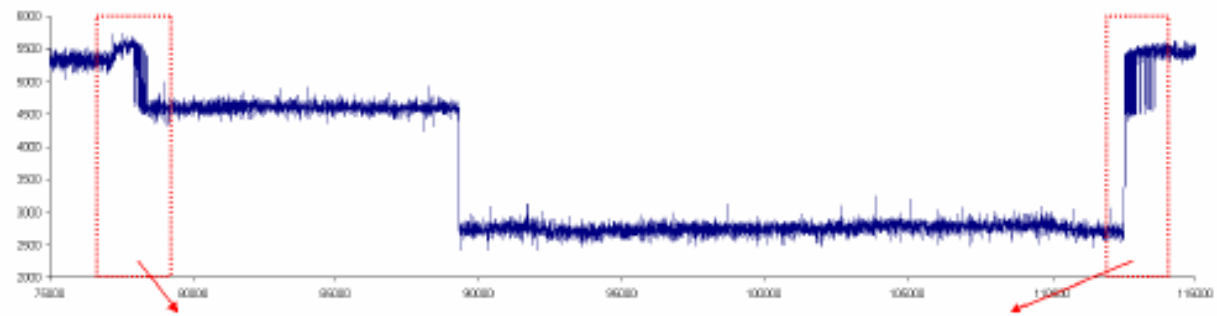
Zoom



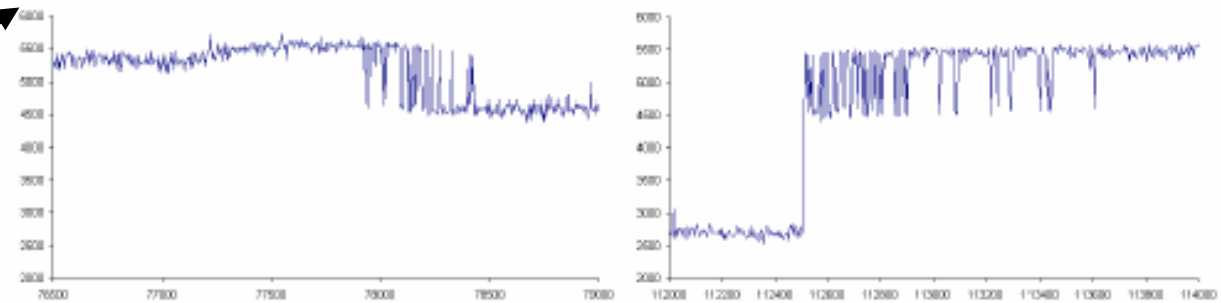
STAR250 Results (4)



Complex Multi-Level



Transient Phenomena



Conclusions

- TH7890M CCD & STAR250 APS studied in detail
- Behaviour is similar
  - Activation energy for time constants ~ 0.8 - 1.0 eV
  - Activation energy for amplitudes ~ 0.5 eV
  - Large number of multi-level RTS pixels
    - Doesn't fit Poisson statistics for >1 defect in a pixel
    - Can single defects be multi-level ?
    - No 'Low frequency noise' RTS – probably now have better SNR/time resolution and can see these as multi-level
- Same with CCD57 and STAR1000 ?
- What is the defect ?

E centre calculations

(after Nelson et al.

Appl. Phys. Lett., Vol. 73, 1998)