How to braai electronics

or

Radiation Effects on Electronics and Radiation Hardness Testing

by Arno Barnard

For

[S]outhern [A]frican [I]nstitute for [N]uclear [T]echnology and [S]ciences

Empowerment through education, training and practice

Summer School 2023

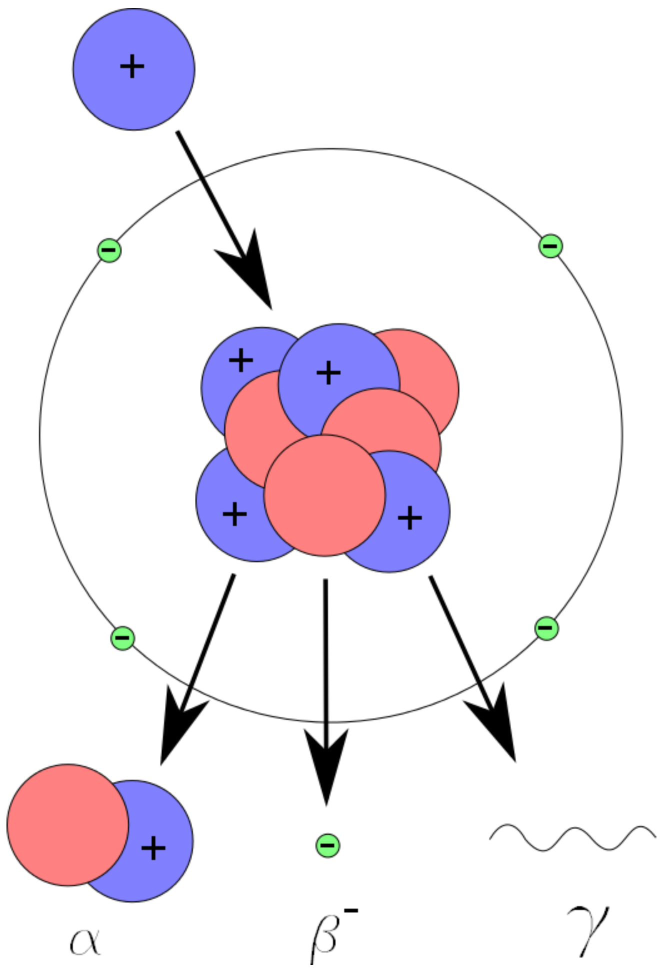
19 January 2023

Presentation Overview

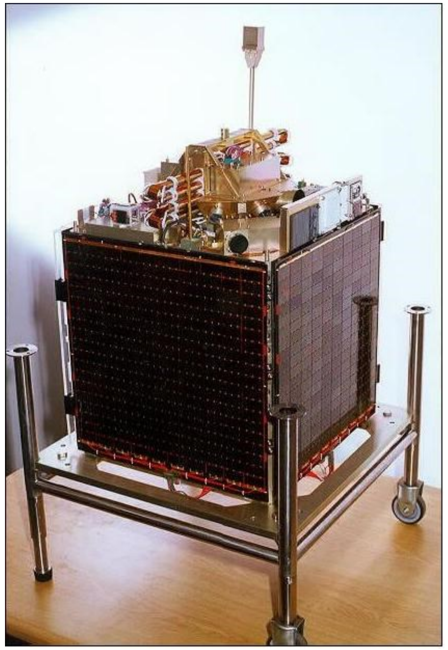
- Introduction – The Satellite Arena
- Radiation Hardness Assurance Overview
- Basic Mechanisms in Electronics
- iTL Proton Testing Setup
- Dosimetry importance
- Some SEE Testing Results from A-line and NTV-line
- Conclusions and So what?

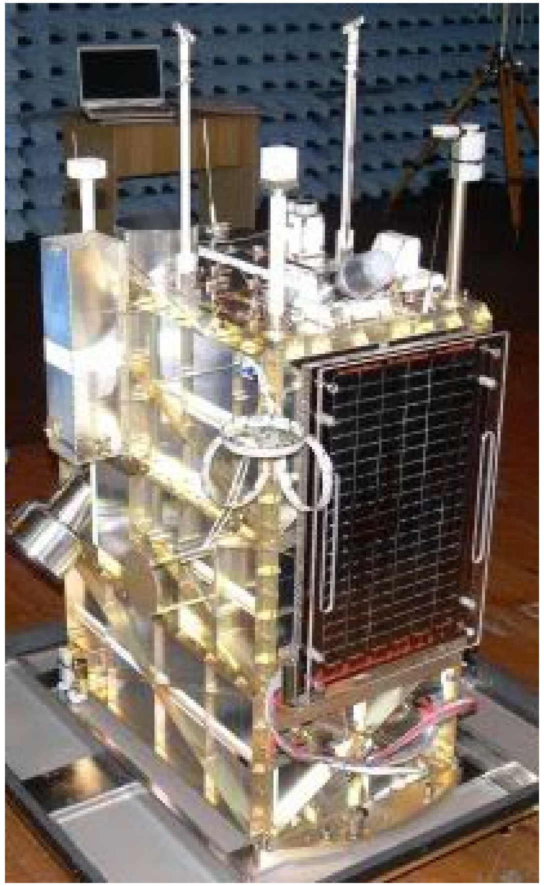
What is Radiation?

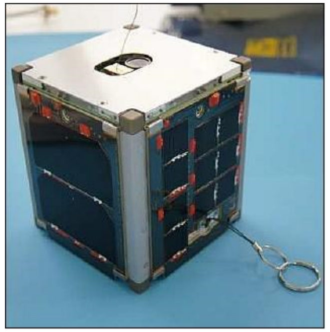
- **Radiation is the result of nuclear interactions.**
- **Various high energy particles are expelled including:**
  - Alpha particles (atoms, protons, neutrons)
  - Beta particles (electrons, positrons)
  - Photons (up to X-ray and γ-ray)
- **Remaining material can be ionized, the original element, or totally different element**

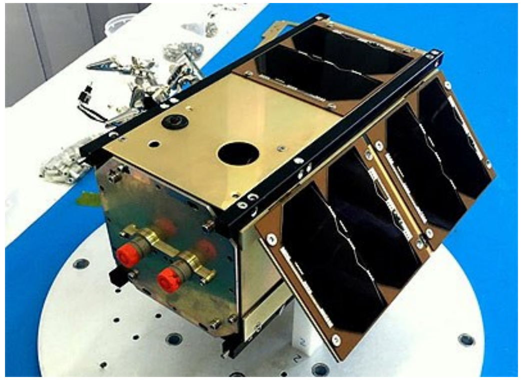


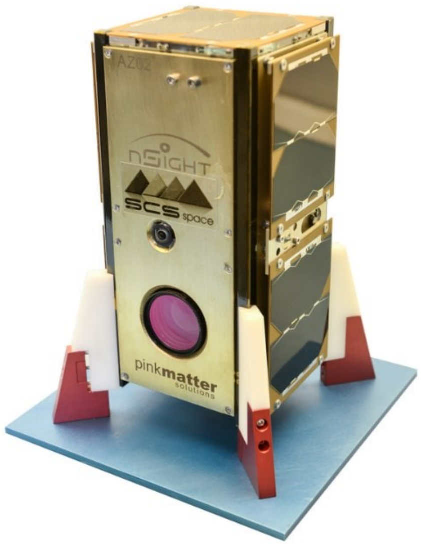
South African satellites 1999 - 2021

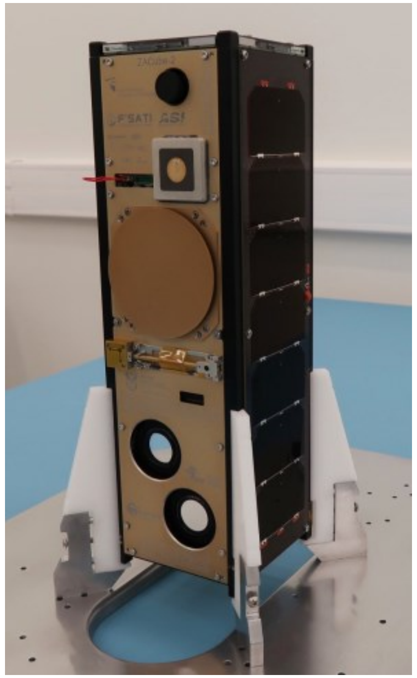












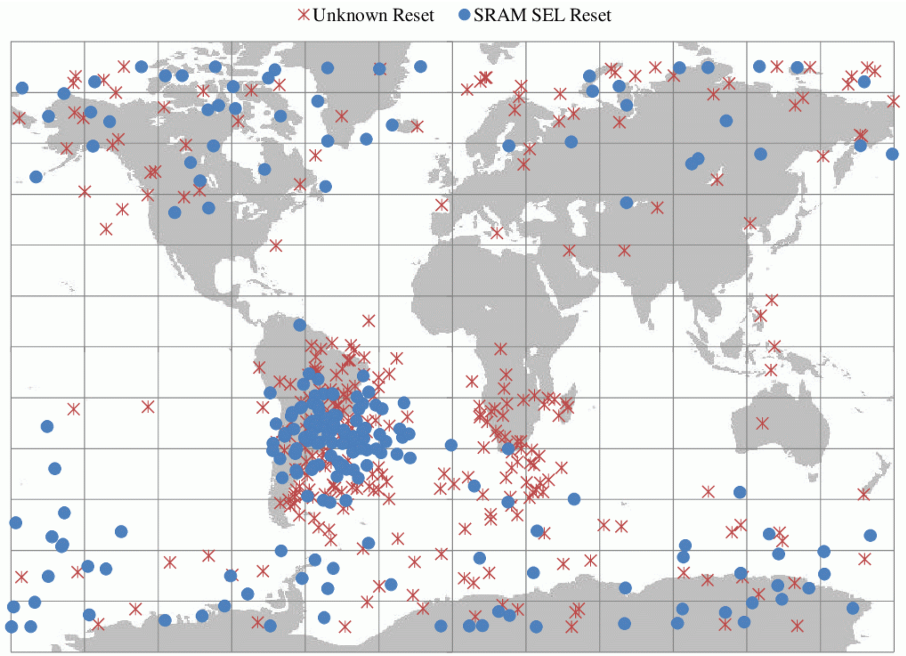
Satellite Issues with Radiation

South African satellites and radiation testing

- 1999 – SUNSAT – "well known" Commercial-off-the-shelf (COTS) parts used – no radiation testing
- 2009 – Sumbandila Satellite – COTS parts, TID testing of major parts – no SEE testing
- Current trend – Cubesats – Tshepisosat – ZA-Aerosat – nSight – ZA-Cube 2 - MDASats – all COTS parts

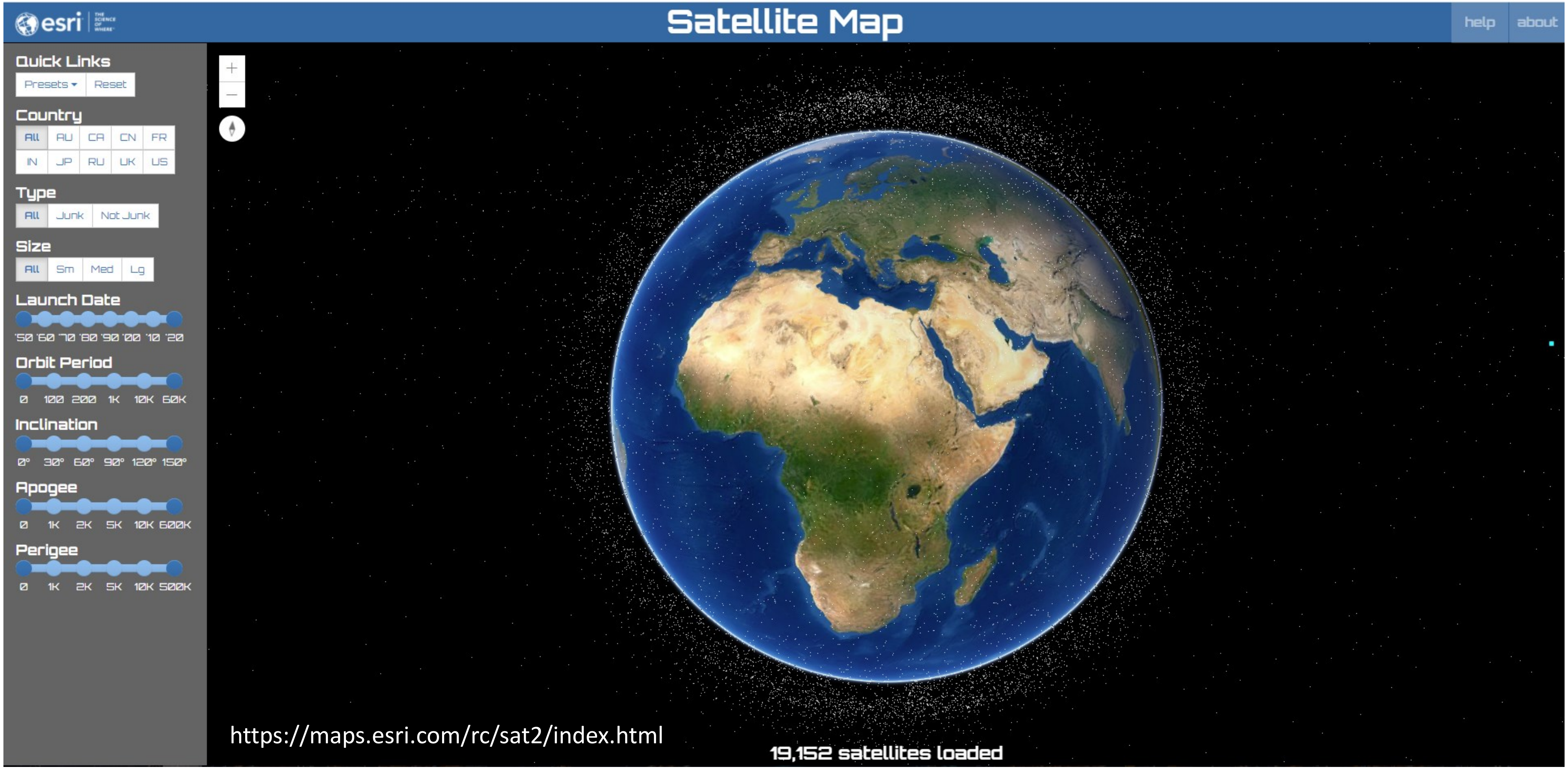
SEE problem history

- SUNSAT – SRAM upsets – OBC code re-write to get operational
- Sumbandila Satellite – Micro-SEL in SRAM



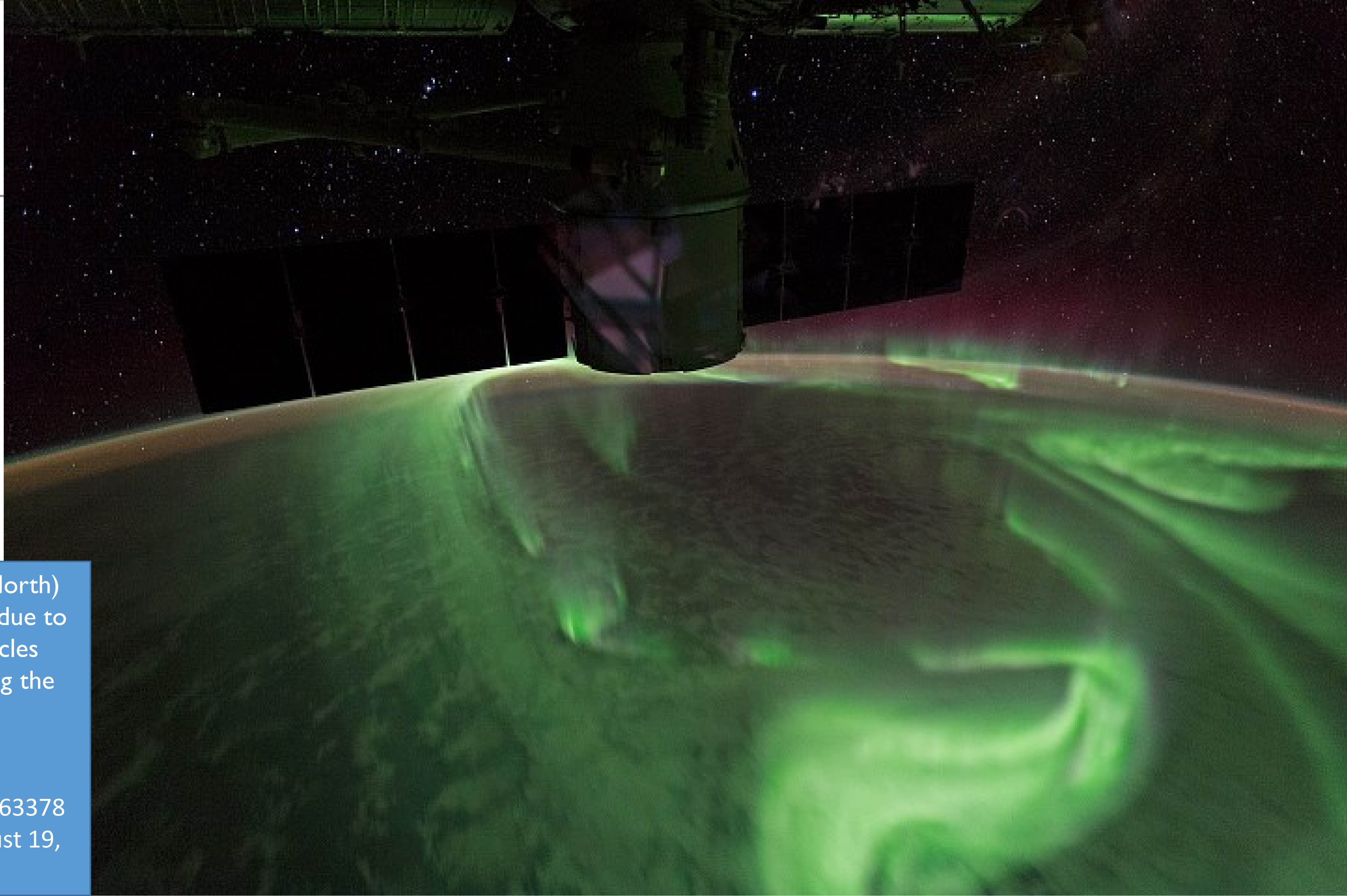
Barnard, A. and Nwosa, C.: COTS Based On-Board-Computer on South Africa's Sumbandilasat: A Radiation and In-Orbit Performance Analysis. In: *2011 IEEE Radiation Effects Data Workshop*, pp. 1–4. IEEE, jul 2010. ISBN 978-1-4577-1281-4. ISSN 2154-0519.

The Satellite Arena



https://maps.esri.com/rc/sat2/index.html

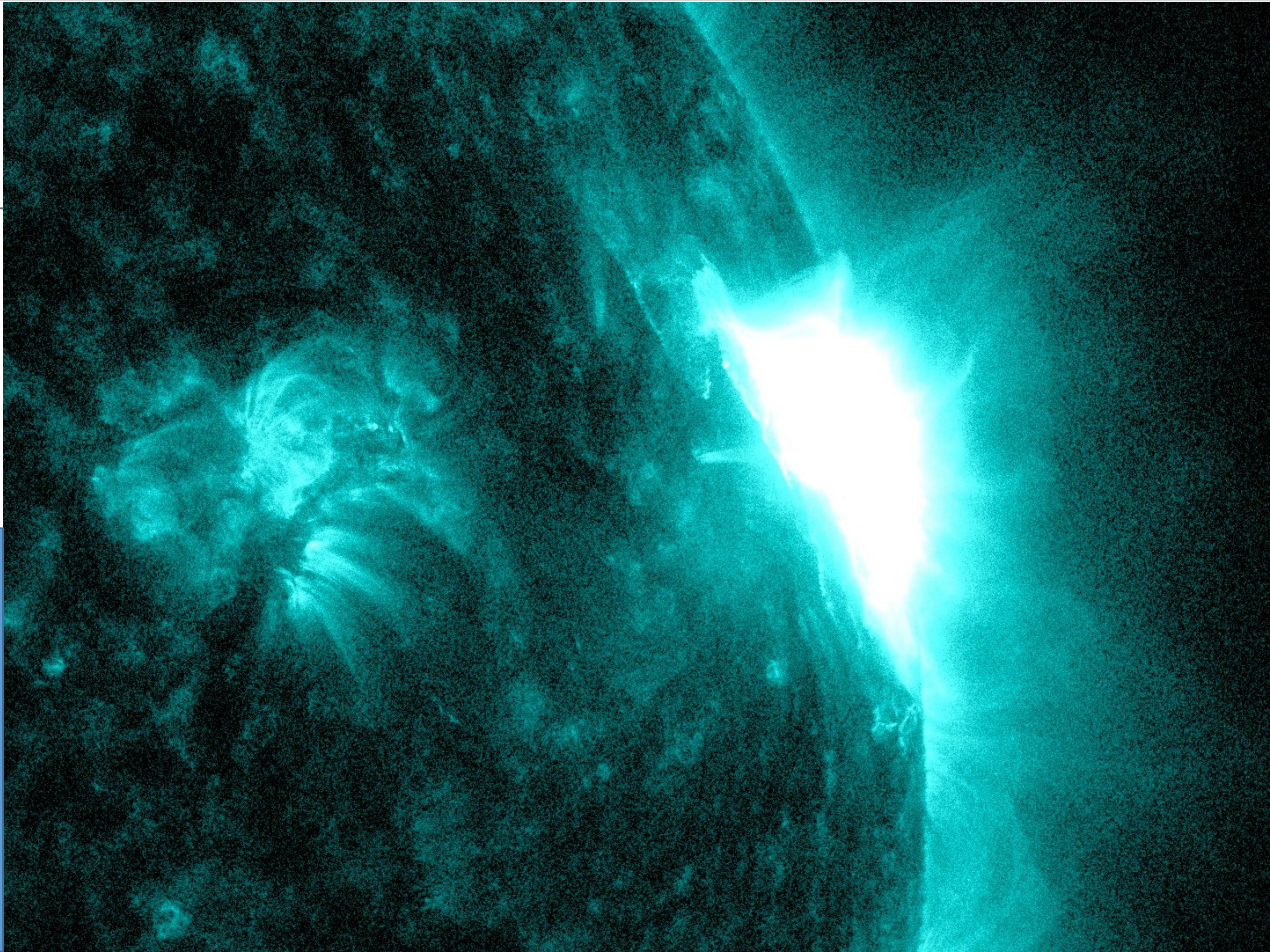
Earth – II



Auroras – Borealis (North) and Australis (South) due to trapped charged particles interacting and ionising the upper atmosphere.

Credit: Astronaut photograph ISS052-E-63378 was acquired on August 19, 2017

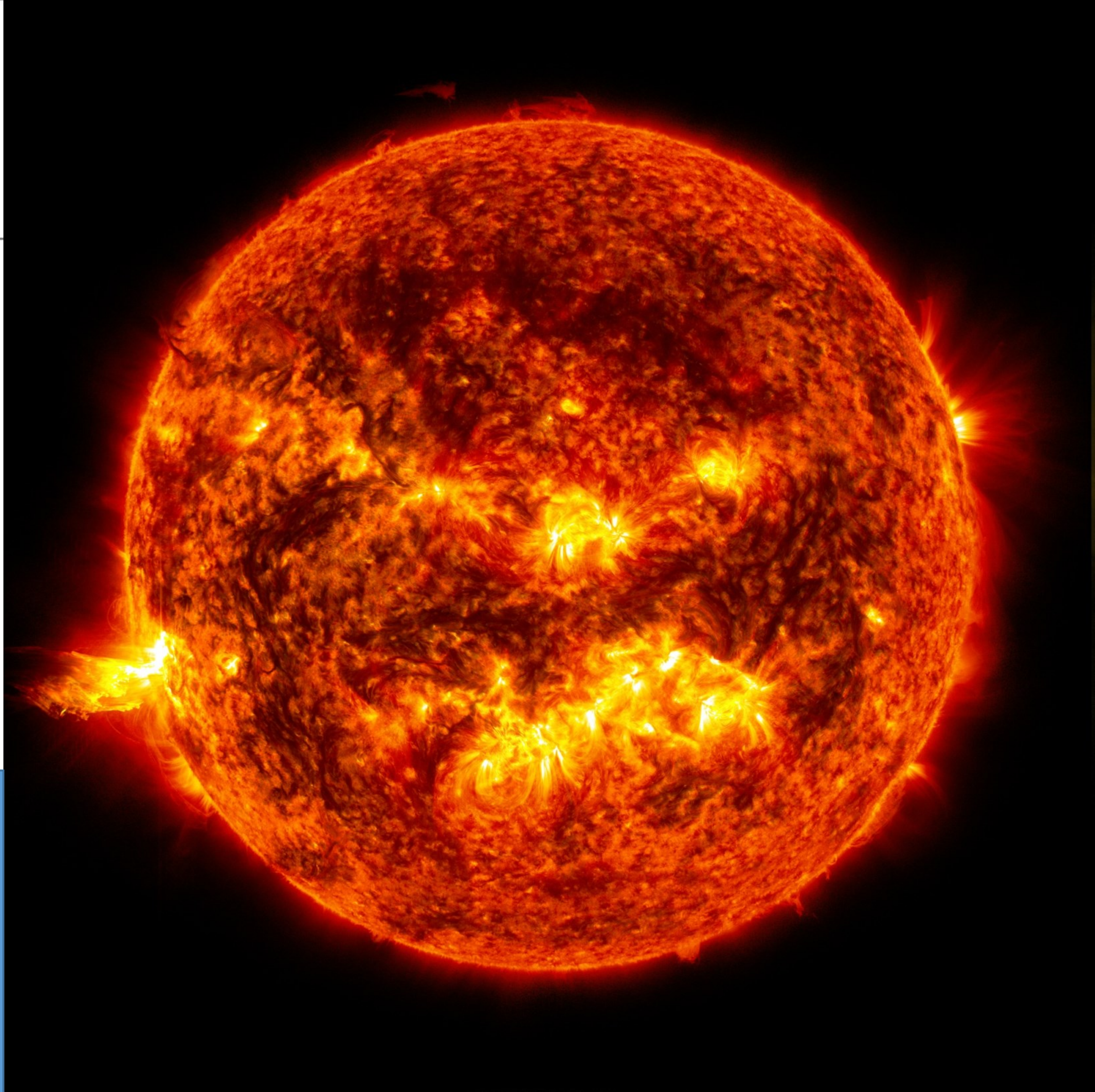
Sol – I



NASA's Solar Dynamics Observatory captured this image of a solar flare on the right side of the sun on May 22, 2013. This image shows light in the 131 Angstrom wavelength, a wavelength that shows material heated to intense temperatures during a flare and that is typically colorized in teal.

Credit: NASA/SDO

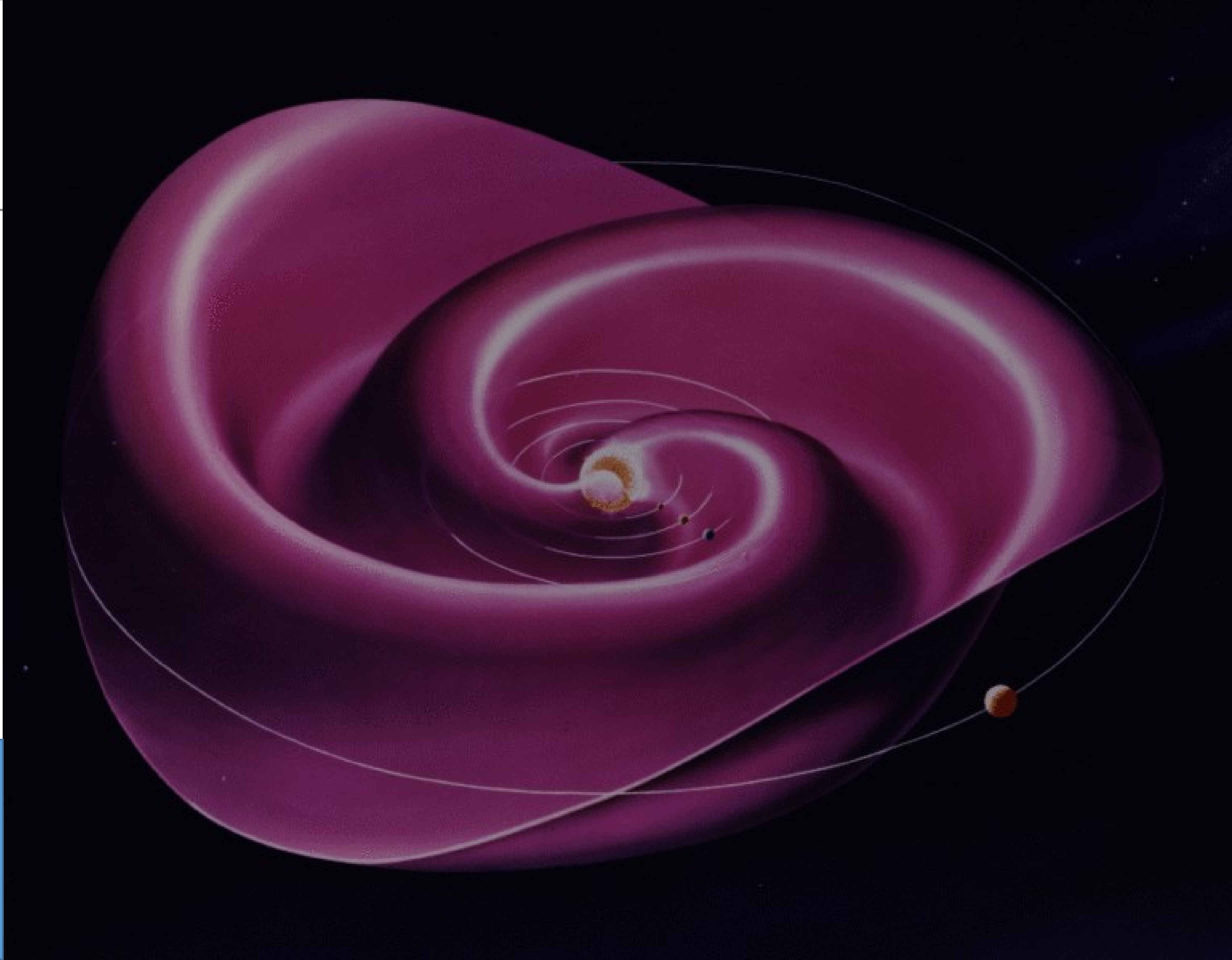
Sol – II



This image from June 20, 2013, at 11:15 p.m. EDT shows the bright light of a solar flare on the left side of the sun and an eruption of solar material shooting through the sun's atmosphere, called a prominence eruption. Shortly thereafter, this same region of the sun sent a coronal mass ejection out into space..

Credit: NASA/SDO

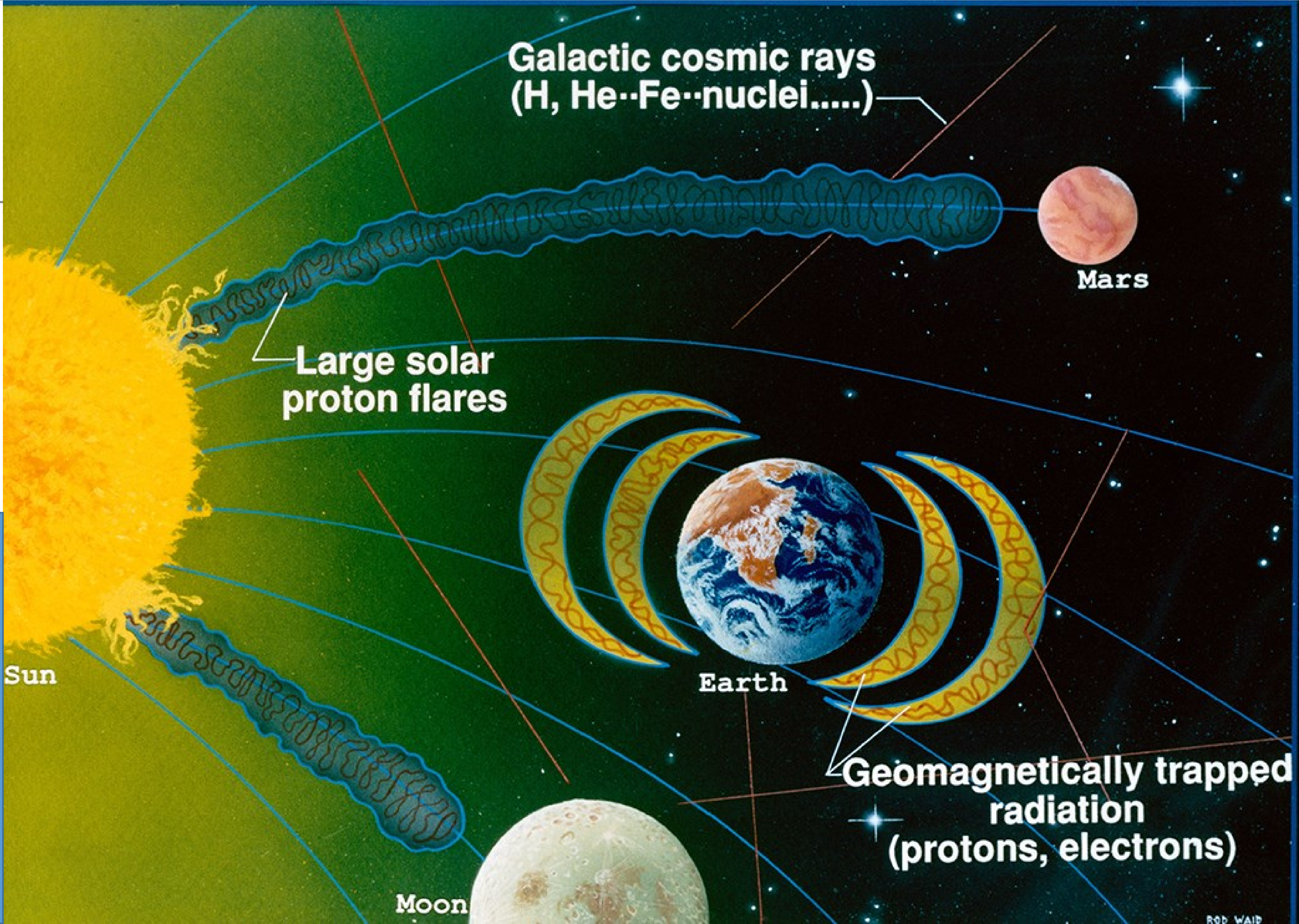
Sol – III



The heliospheric current sheet results from the influence of the Sun's rotating magnetic field on the plasma in the interplanetary medium (solar wind).

Credit: NASA/SDO

Earth – I

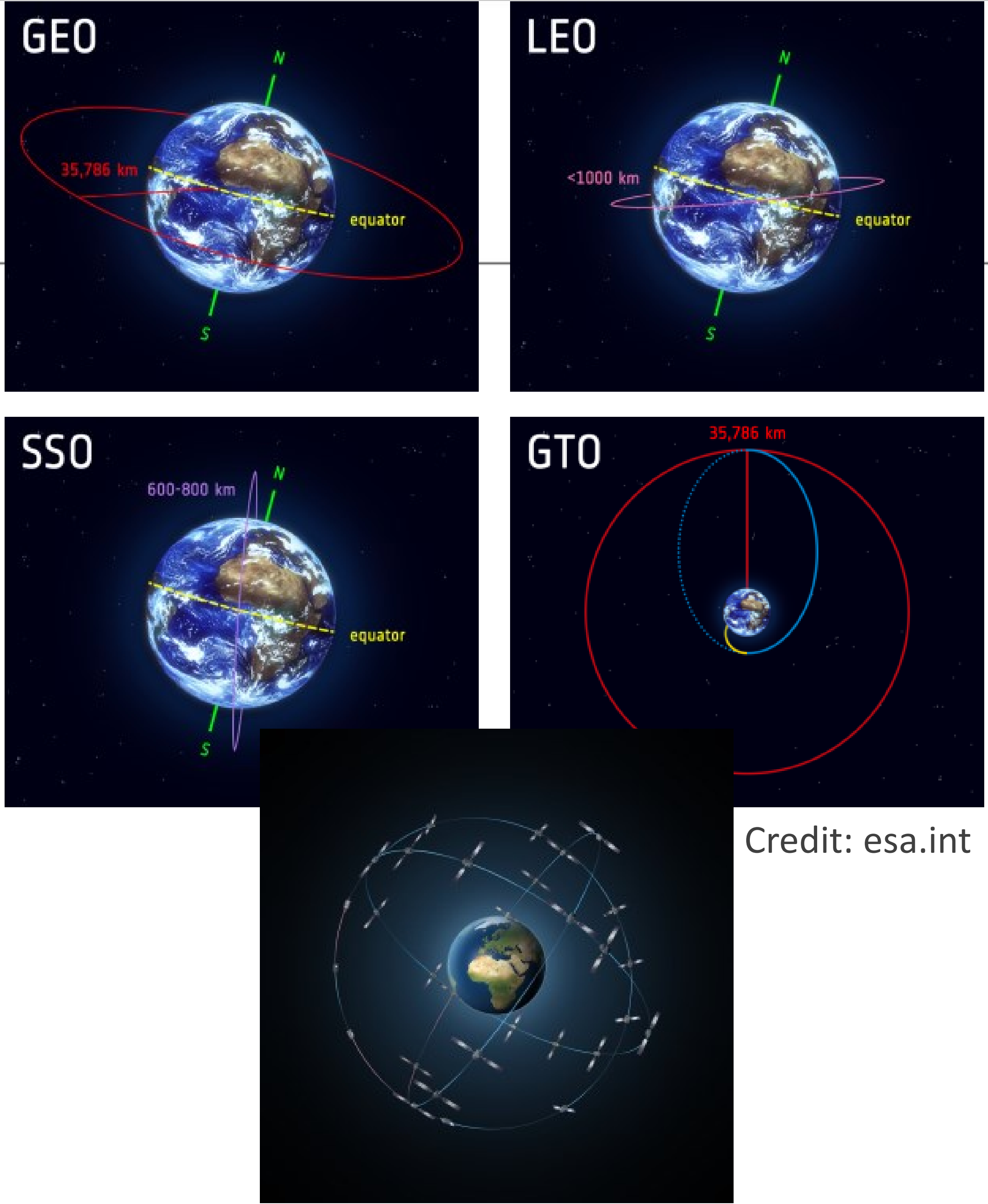


This is an artistic concept of the Space Radiation Environment showing the radiation belts, solar flares, elements within rays, the moon, Earth and Mars. The radiation environment of deep space is very different from that at Earth's surface or in low Earth orbit.

Credit: nasa.gov

Radiation Environment:
For the Spacecraft Designer

- **Main sources of energetic particles are:**
  - protons and electrons trapped in the Van Allen belts,
  - heavy ions trapped in the magnetosphere,
  - cosmic ray protons and heavy ions,
  - and protons and heavy ions from solar flares.
- **Levels of sources are affected by solar cycle that lasts about eleven years, ~ 4yr min, ~7yr max**
- **Large variation depending on mission**
  - Low Earth Orbits (LEOs)
  - Highly Elliptical Orbits (HEOs)
  - Geostationary Orbits (GEOs)
  - Planetary and Interplanetary missions



Credit: esa.int

Radiation Environment: For the Spacecraft Designer

Particles have various effects on environment, spacecraft and electronics:

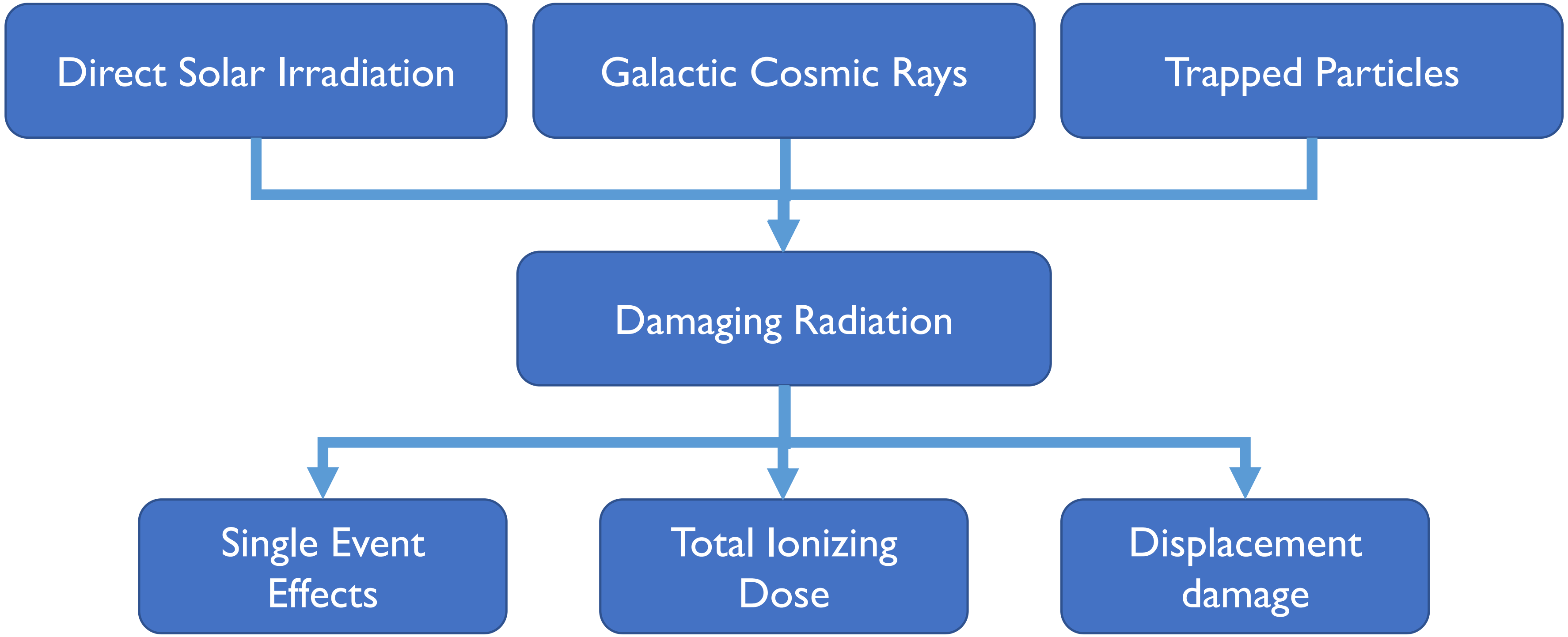
- **Thermosphere density changes**
  - Cycles follow sun rotation
  - Affects the atmospheric drag (very) LEO experience
  - Affects launch trajectory calculations
- **Spacecraft charging**
  - Lower energy electrons does no penetrate satellite outer skin but can charge satellite body
  - Can lead to ESD events between satellite structures
- **Radiation Effects on electronics**

Radiation Environment: For the Spacecraft Designer

Radiation Source	Models	Effects of Solar Cycle	Variations	Types of Orbits Affected
Trapped Protons	AP8-MIN; AP8-MAX	Solar Min - Higher; Solar Max - Lower	Geomagnetic Field; Solar Flares; Geomagnetic Storms	**LEO**; HEO; Transfer Orbits
Galactic Cosmic Ray Ions	CREME; CHIME; Badhwar & O'Neill	Solar Min - Higher; Solar Max - Lower	Ionization Level	**LEO**; GEO; HEO; Interplanetary
Solar Flare Protons	SOLPRO; JPL92	Large Numbers During Solar Max; Few During Solar Min	Distance from Sun Outside 1 AU; Orbit Attenuation; Location of Flare on Sun	**LEO** (I>45°); GEO; HEO; Interplanetary
Solar Flare Heavy Ions	CREME; JPL92; CHIME	Large Numbers During Solar Max; Few During Solar Min	Distance from Sun Outside 1 AU; Orbit Attenuation; Location of Flare on Sun	**LEO**; GEO; HEO; Interplanetary

Source: http://radhome.gsfc.nasa.gov/radhome/papers/seeca3.htm

Radiation Hardness Assurance - I



Radiation Effects on Electronics - I

Main Radiation effects on electronics can be grouped as follows:

- **Total Ionizing Dose Effects**
  - Long term cumulative effects that degrade component performance over time
- **Single Event Effects**
  - Single events that can cause a variety of instantaneous or longer term effects
- **Displacement Damage**
  - Damage to crystalline lattice

Two major charge deposition mechanisms:

- Direct ionization – particle directly ionizes target material along track
- Indirect ionization – particle interact with heavy nuclei that recoils and creates ionized track

Radiation Effects on Electronics - II

Charge deposition:

- **Heavy Ions – Linear Energy Transfer (LET)**
  - Can be calculated for specific Ion with specific energy in specific target material
  - Gives indication of how deep (“where”) ion deposits most energy – according to Bragg curve

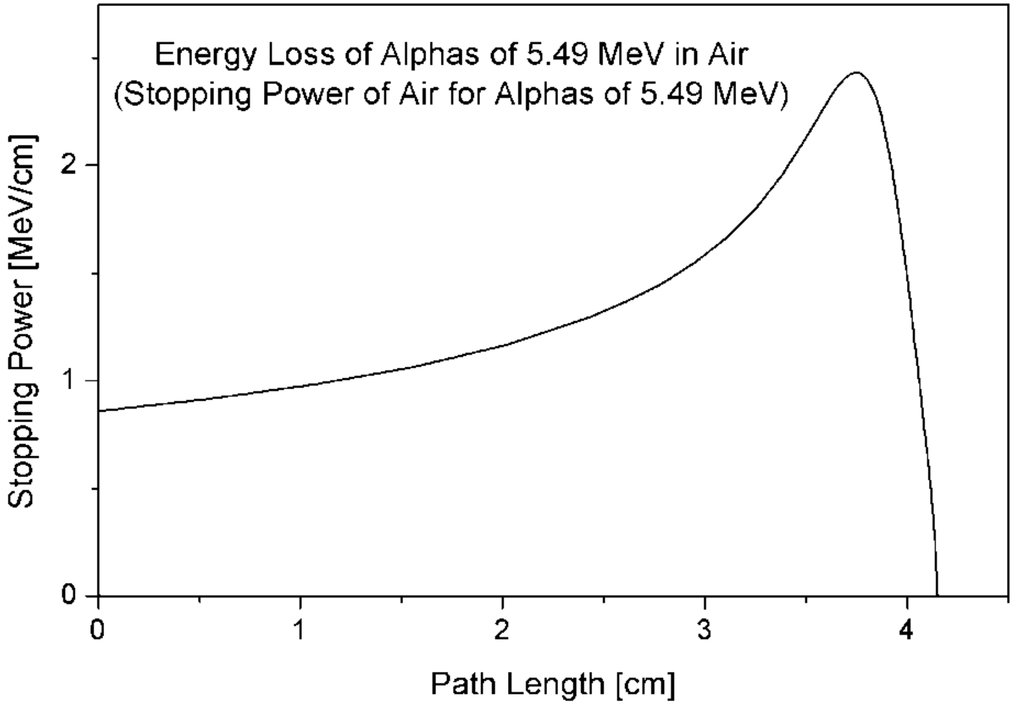


Image: http://commons.wikimedia.org/wiki/File:Bragg_Curve_for_Alphas_in_Air.png

Radiation Effects on Electronics - III

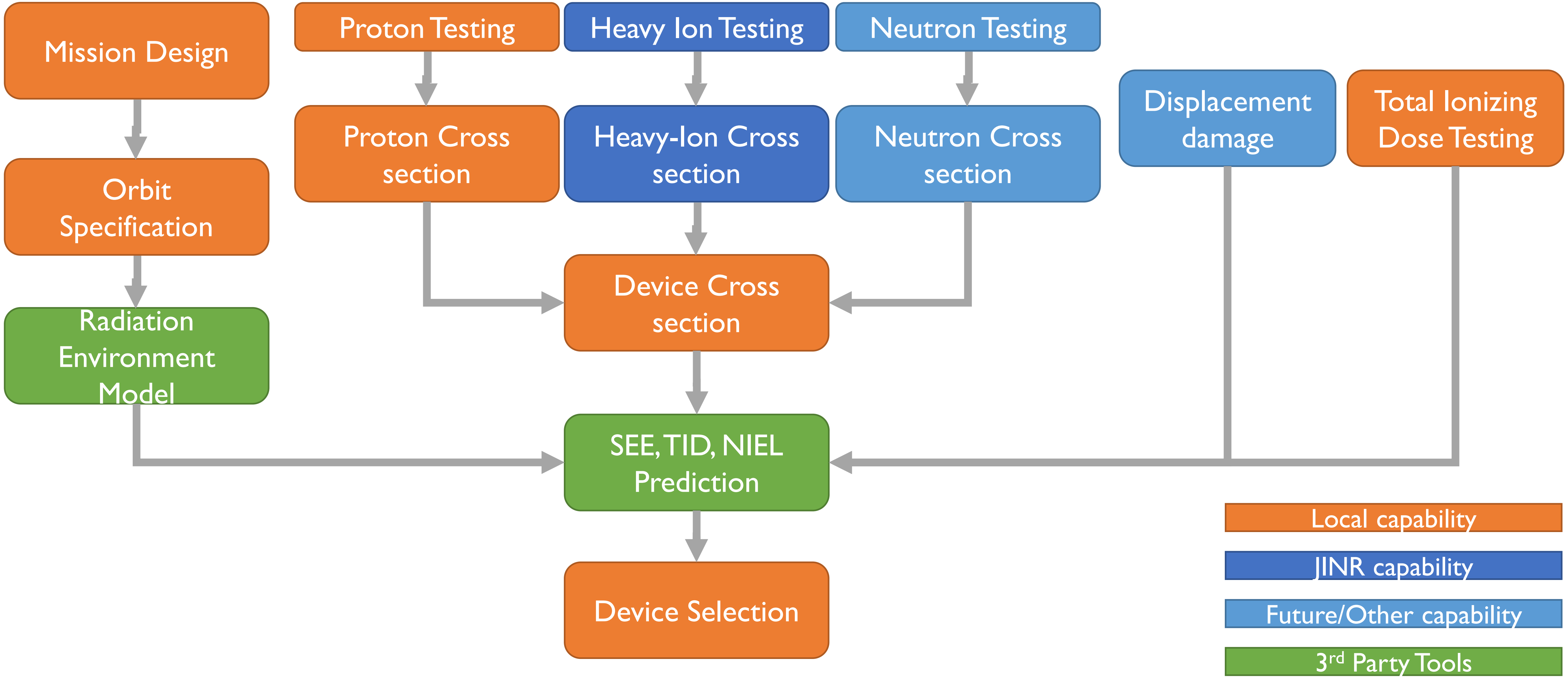
Charge deposition:

- **Proton (and light Ion) Interactions**
  - Single proton = not enough LET to create ion track except in VERY sensitive devices
  - 4 MeV proton has typical LET of 0.15mm in Silicon, we try to test with 66MeV!
  - Indirect ionization through proton interaction with target material, creating secondary particle ion tracks
- **Neutrons**
  - Interaction with target nuclei, creates secondary particle ion tracks
  - Significant source of errors in avionics

Charge deposition:

- **Early mechanisms – track size**
  - Ionized track is column with high density ions in centre and radial distribution of decreasing density
  - Tracks can be up to 1um in diameter (GCR up to 100um) – note most current IC's made with 45-180nm processes
  - This track makes a nice conductor
- **Early mechanisms – recombination and diffusion**
  - Ions recombine slowly with "free" electrons
  - Ions diffuse slowly through material

Radiation Hardness Assurance - II



Total Ionizing Dose (TID) Mechanism in MOS Devices

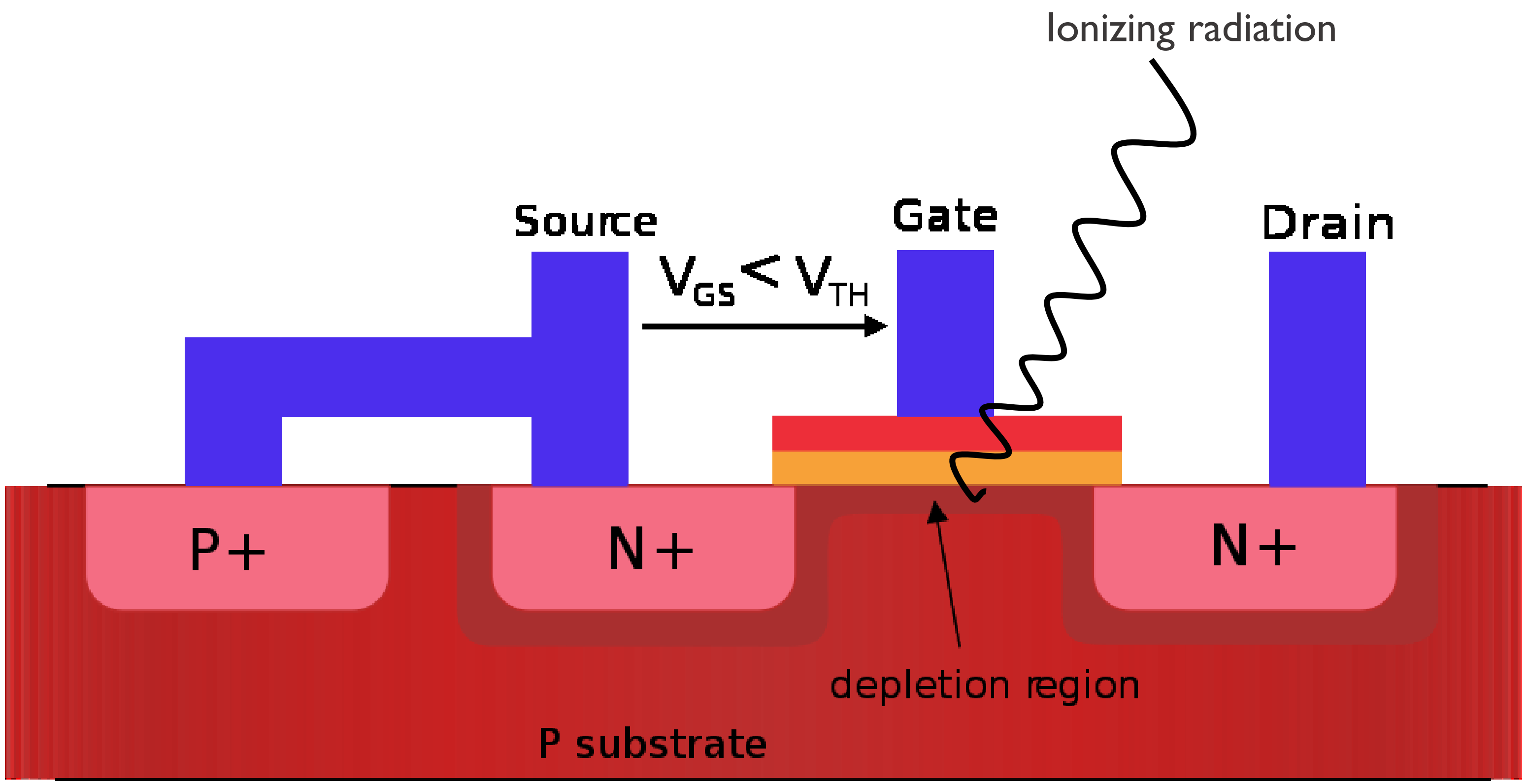


Image: modified from http://en.wikipedia.org/wiki/File:MOSFET_functioning_body.svg

Total Ionizing Dose (TID) Mechanism in BJT Devices - ELDRS

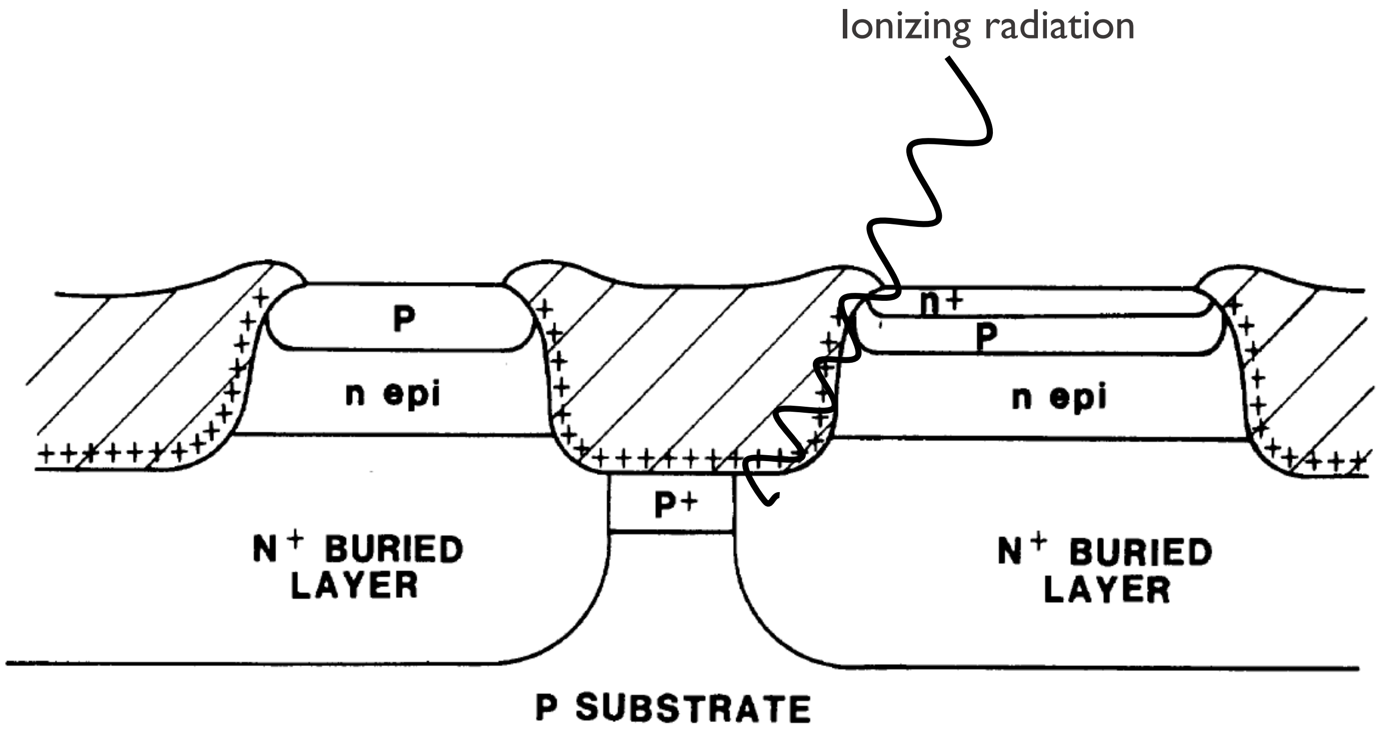


Figure 1. Typical cross section of recessed field oxide bipolar structure utilizing walled emitters.

IEEE Transactions on Nuclear Science, Vol. NS-30, No. 6, December 1983
TOTAL DOSE EFFECTS IN RECESSED OXIDE DIGITAL BIPOLAR MICROCIRCUITS

Single Event Effects - I

What is a SEE?

- "Unwanted or erroneous response from an electronic device triggered by the passage of a high energy particle through the active region of that device"
- Sounds simple, but analysis is VERY complex
- Above processes are statistically driven
- So from prediction point of view:
  - What is the chance that a 8.9MeV proton is trapped,
  - hits the satellite,
  - penetrates a specific IC and MOSFET's active region,
  - that is at the right depth and in a sensitive state to cause a problem for the system?
- More on this later ...

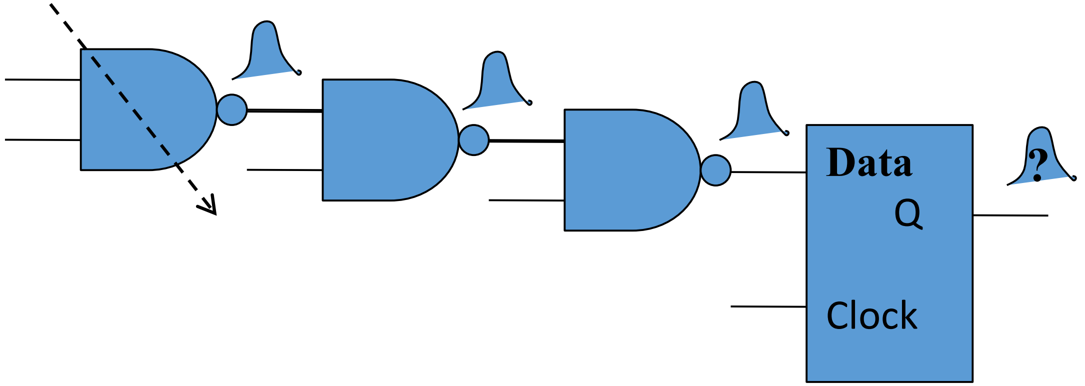
Main particles to test for SEE's:

- **Heavy Ions – from He to Ni**
  - Primarily direct ionization
  - Some indirect ionization from collisions with other particles
- **Protons**
  - Predominantly indirect ionization from collisions with other heavy nuclei
  - Some direct ionization in new very sensitive devices
- **Neutrons**
  - Entirely indirect ionization from collisions with other nuclei

Single Event Effects - II

Effects on devices:

- **Single Event Transient (SET)**



  - Error probability depends on timing of SET w.r.t. Clock signal
  - Very fast clock long SET = higher probability of SET becoming something WORSE!

Effects on devices:

- **Single Event Upset (SEU)**
  - SET latched becomes SEU
  - Also from "upsetting" bi-stable circuit i.e. RAM cell, used as registers, memory, latches etc.
- **Multi-bit Upset (MBU)**
  - Systemic and geometric
  - High density small feature sized memory arrays
  - One strike can upset multiple circuits

Single Event Effects - III

Effects on devices:

- **Single Event Functional Interrupt (SEFI)**
  - SEE causing extended operational disruption
  - i.e. SET/SEU causing a clock to stop clocking
- **Single Event Snap-Back**
  - Mostly on SOI devices – parasitic BJT is switched on
- **Single Event Latch-up (SEL)**
  - Parasitic p-n-p-n structure of bulk CMOS triggered into regenerative forward bias
  - Large current can flow = destructive, not enough heat dissipation
  - Usually power cycle required to clear

Effects on devices:

- **Single Event Gate Rupture (SEGR)and Single Event Burnout (SEB)**
  - Mostly on high voltage power MOS devices
  - Destructive
  - Sensitive regions have parasitic BJT's that can be triggered into regenerative forward bias

Displacement Damage - I

Effects on devices:

- Crystalline structure is damaged by displacing particle – becomes interstitial
- Doped regions sensitive to this effect
- Solar cells degrade mostly due to DD

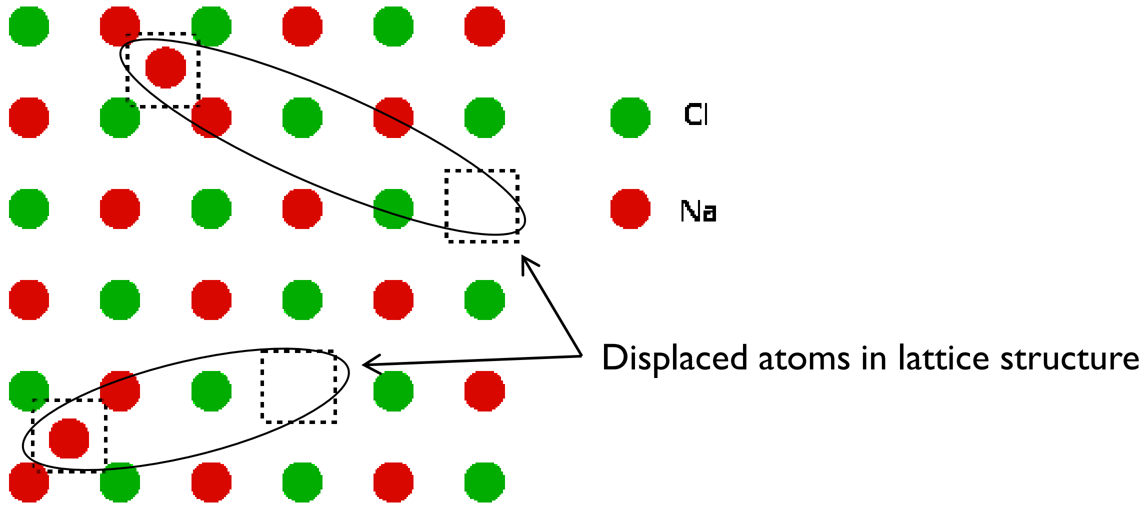


Image: modified from http://en.wikipedia.org/wiki/File:Naclfrenkeldefect.svg

TID Testing - I

- Accurate dosimetry required
- Gamma rays have enough energy to cause ionization in materials
- Co-60 decays ejecting gamma rays with known energies

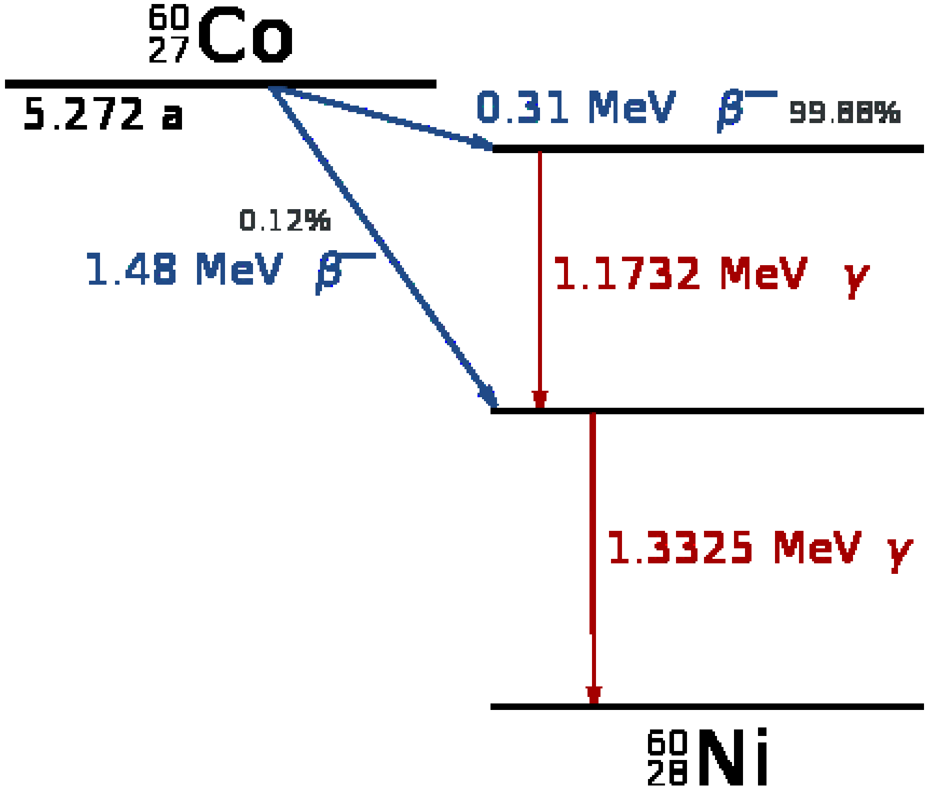
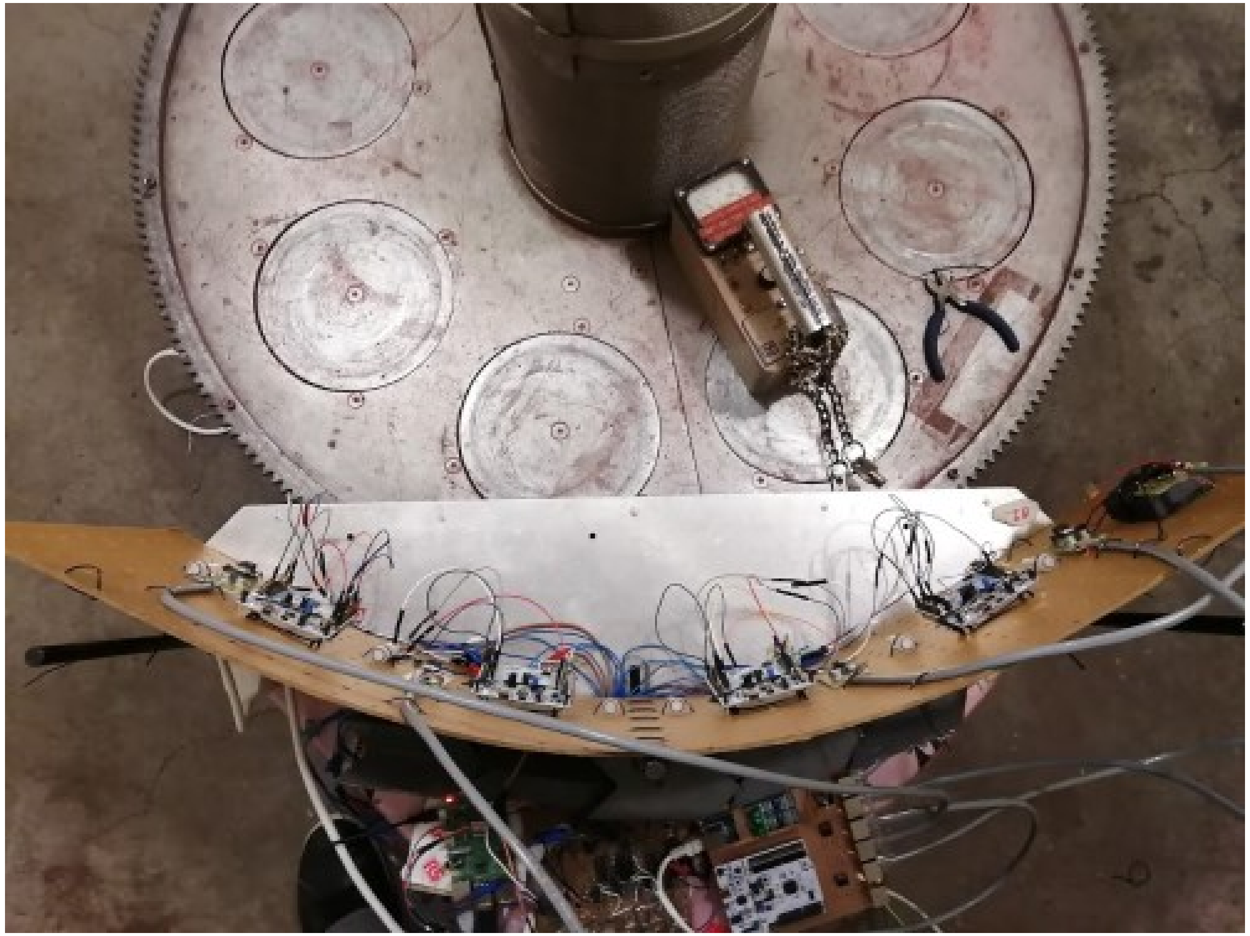


Image: http://commons.wikimedia.org/wiki/File:Cobalt-60_Decay_Scheme.svg

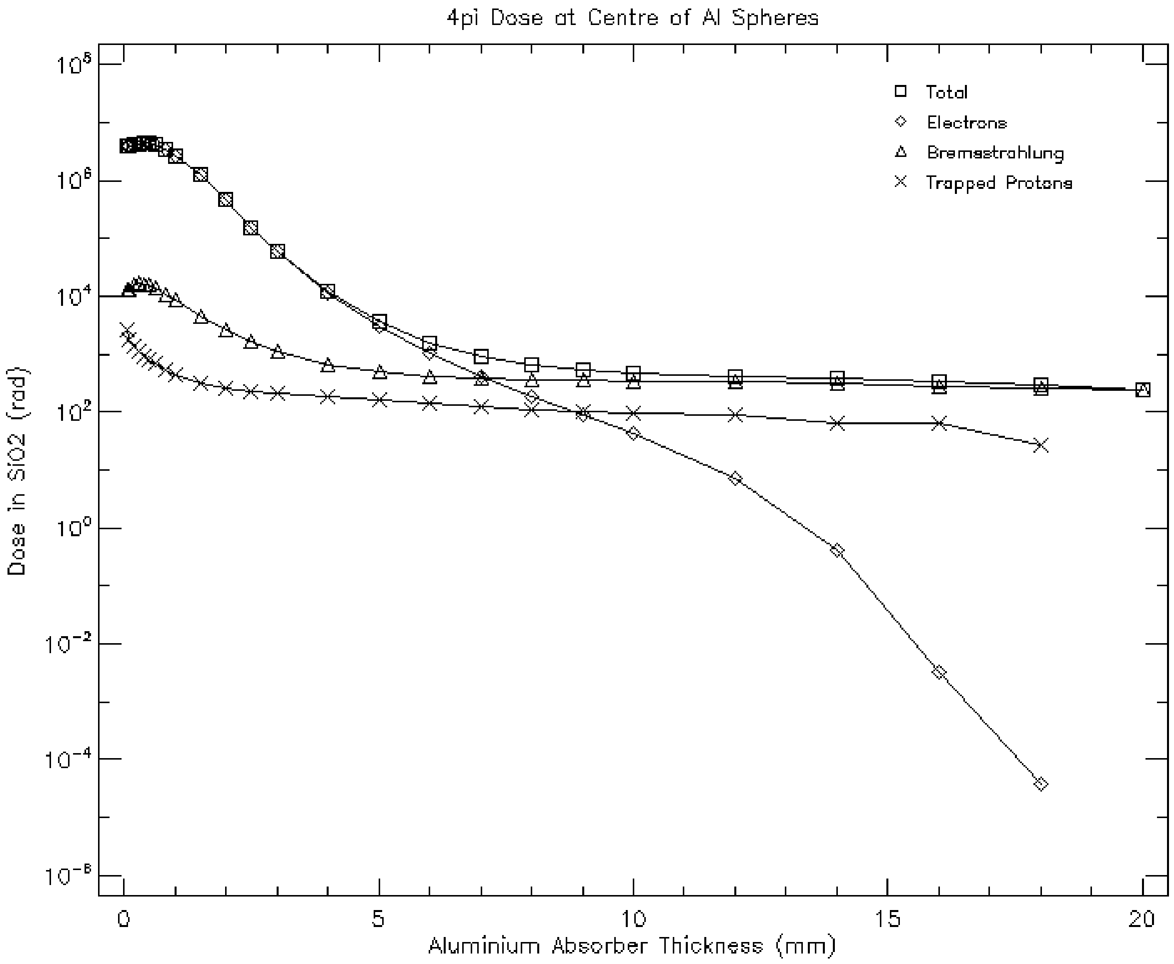
TID Testing - II

- Can do pre-post measurement tests or full in-situ testing
- Co-60 has a half-life of 5.26 years
- No other energy required to create radiation
- Testing is fairly inexpensive
- Gamma radiation is a quiet killer – Geiger counters and safety officers required
- Dose rates of up to 10kRad(Si)/hr (100Gy/hr) can be acceptable
- ELDRS requires long testing times at low dose rates
- ESL has tested over 30 different devices



TID Testing - III

- **How much dose is enough?**
  - SPENVIS – SHIELDOSE 2 – ZA Aerosat @ 350km
  - 1 year mission
- **Shielding**
  - 3mm Al = 60kRad
  - 4mm Al = 12kRad
  - 5mm Al = 3.7kRad

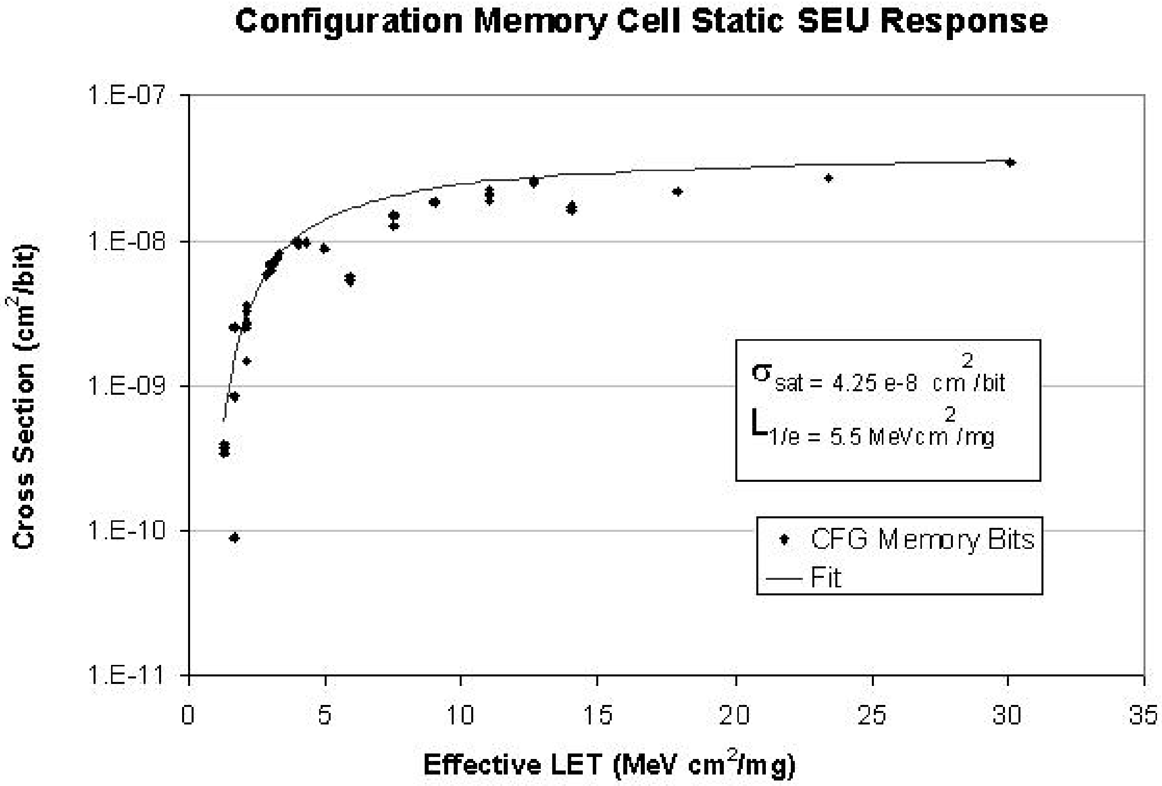


Graph generated using SPENVIS, http://www.spenvis.oma.be

SEE/DD Testing

- **Three interesting facts:**
  - Space radiation environment changes and we are still learning
  - We cannot simulate (in foreseeable future) full range of space environment particles at reasonable rate/schedule
  - Semiconductor industry creates new technologies at very high rate
- **SEE / DD testing is done using high energy particles – usually accelerator based**

- **SEE Cross Section Curve**



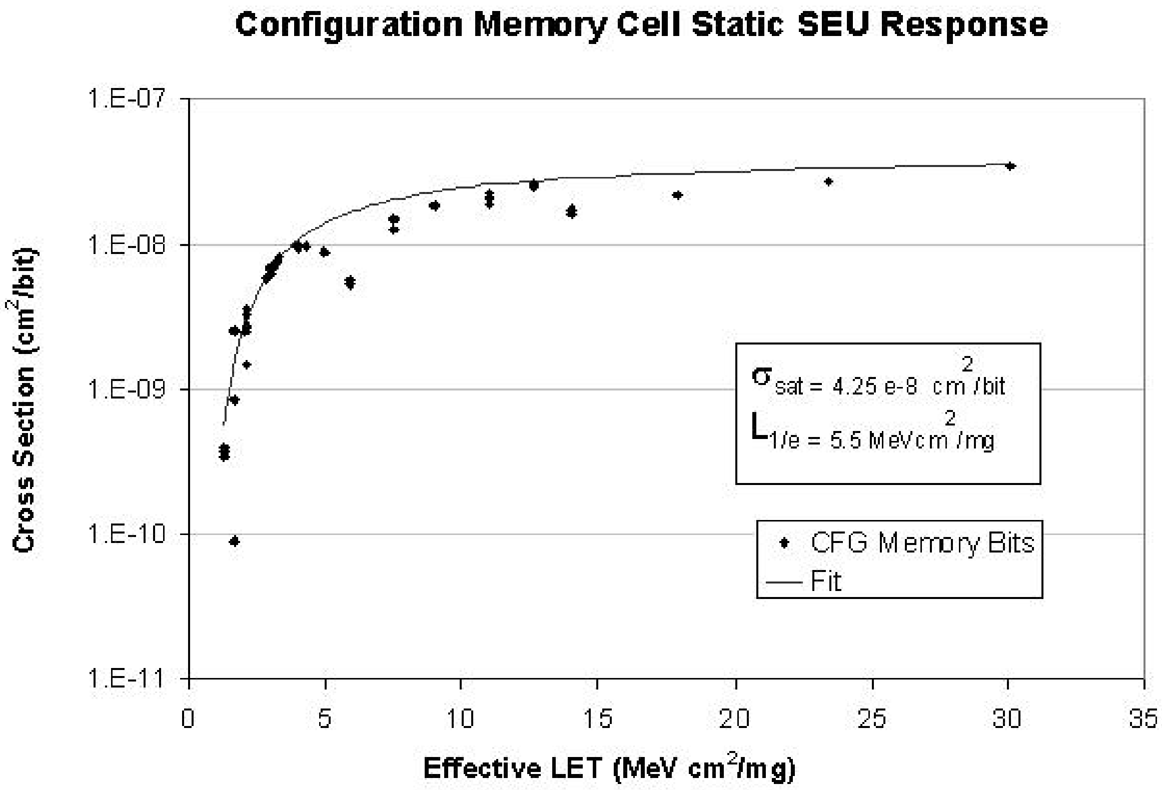
Mitigation Techniques

- **TID**
  - Shielding
  - Biasing annealing effect
  - Temperature annealing effect
- **SEE**
  - Shielding has little effect
  - SEB – reduce drain-source voltage, use p-channel MOSFET
  - SEGR – reduce drain-source voltage
  - SEL – monitor circuitry (current limit), reduce supply voltage
  - SEU/SEFI/SET – High level design
    - EDAC / TMR / DMR / SET filters / Watchdogs / Scrubbing

BREAK TIME – 5 Minutes

SEE/DD Testing

- **SEE / DD testing is done using high energy particles – usually accelerator based**
- **To determine SEE Cross Section Curve**
- **Verify mitigation techniques**



Proton-Beam based SEE Testing - I

Context

- We consider COTS components in Low Earth Orbit (LEO) experiencing SEEs
- Protons dominate in LEO, but Galactic Cosmic Rays (GCR) and Electrons are present

Sources for SEE testing

- Radioactive materials with alpha particle decay
- Pulsed laser
- High-energy particle beams
    - Proton, Neutron and Heavy-Ion

Proton-Beam based SEE Testing - II

Some international proton options (>125MeV)

- JYFL/RADEF (Finland)
- PIF – PSI (Switzerland)
- TRIUMF (Canada)
- 12 Candidates for NASA - 2016 (USA)

(<100MeV)

- UC Davis – Crocker Nuclear Laboratory
- Lawrence Berkeley National Laboratory
- Texas A&M University

A case for protons at iTL

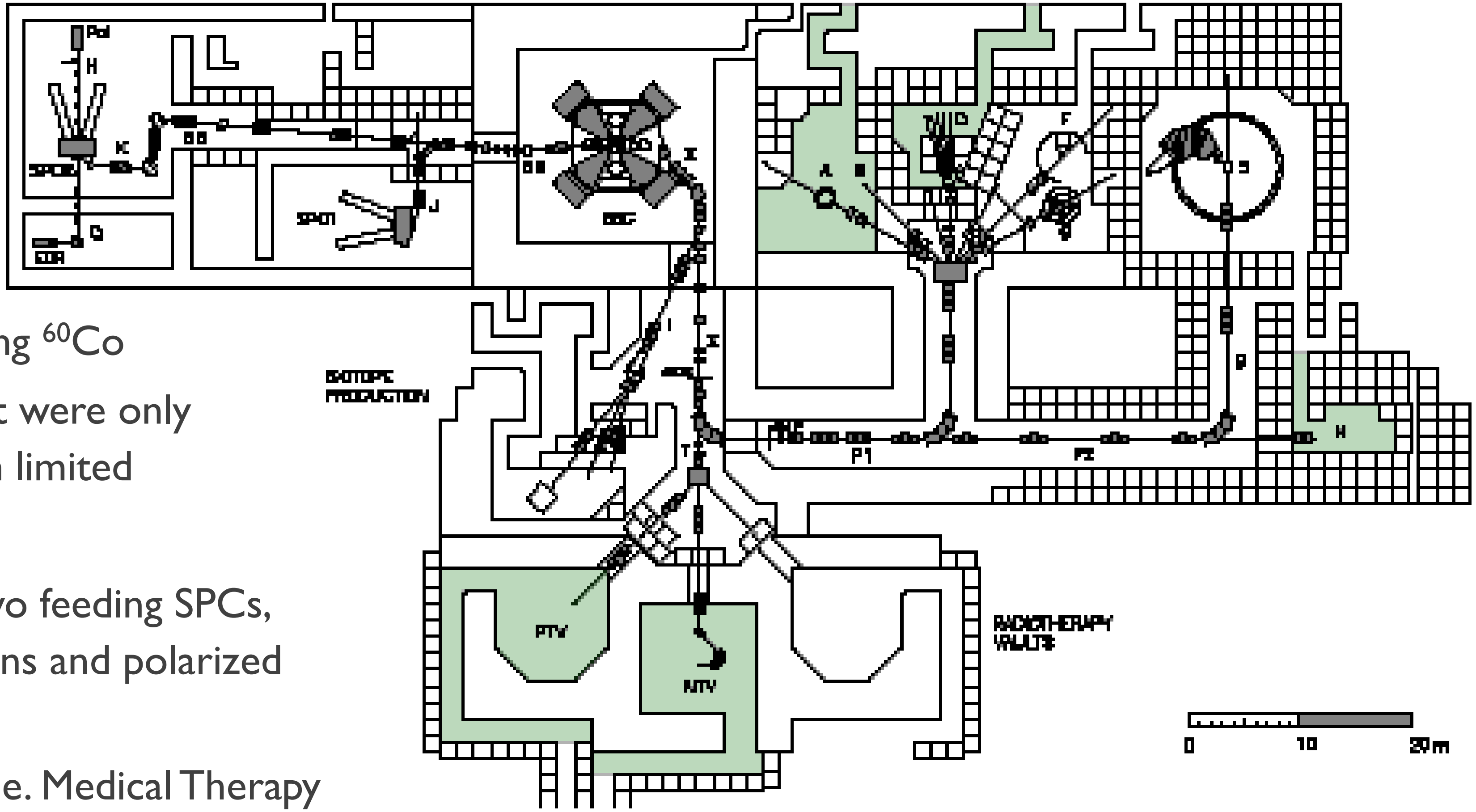
- Protons are an easier alternative than heavy-ions
- Proton beam is effective in component screening
- iTL predominantly produces proton beam
- Proton usage will give most opportunities to align with iTL schedule

Proton-Beam based SEE Testing - III

NRF National Research Foundation | iThemba LABS Laboratory for Accelerator Based Sciences

65 JOINT INSTITUTE FOR NUCLEAR RESEARCH SCIENCE BRINGS NATIONS TOGETHER 1956

Stellenbosch UNIVERSITY IYUNIVESITHI UNIVERSITEIT | forward together sonke siya phambili saam vorentoe



Historic testing in SA

- TID testing established since 2004 using ^{60}Co
- SEE Tests by Berner and van der Horst were only partially successful and documentation limited

iThemba LABS overview

- Main cyclotron is K= 200 SSC with two feeding SPCs, K=8 (protons) and K=11 (light/heavy ions and polarized protons), and 3MeV Tandetron
- Vaults designed for specific research, i.e. Medical Therapy (ended 2015), Spectrometry, Neutron interactions, Medical radio isotopes

Proton-Beam based SEE Testing - IV

Viable locations at iTL

- A-line (up to 2017)
- NTV-line (2016-2019)

iTL SEE test options

- SEU with 20MeV to 200MeV protons
- MBU with 20MeV to 200MeV protons
- SET with 20MeV to 200MeV protons
- SEFI with 20MeV to 200MeV protons
- SEL with >180MeV protons

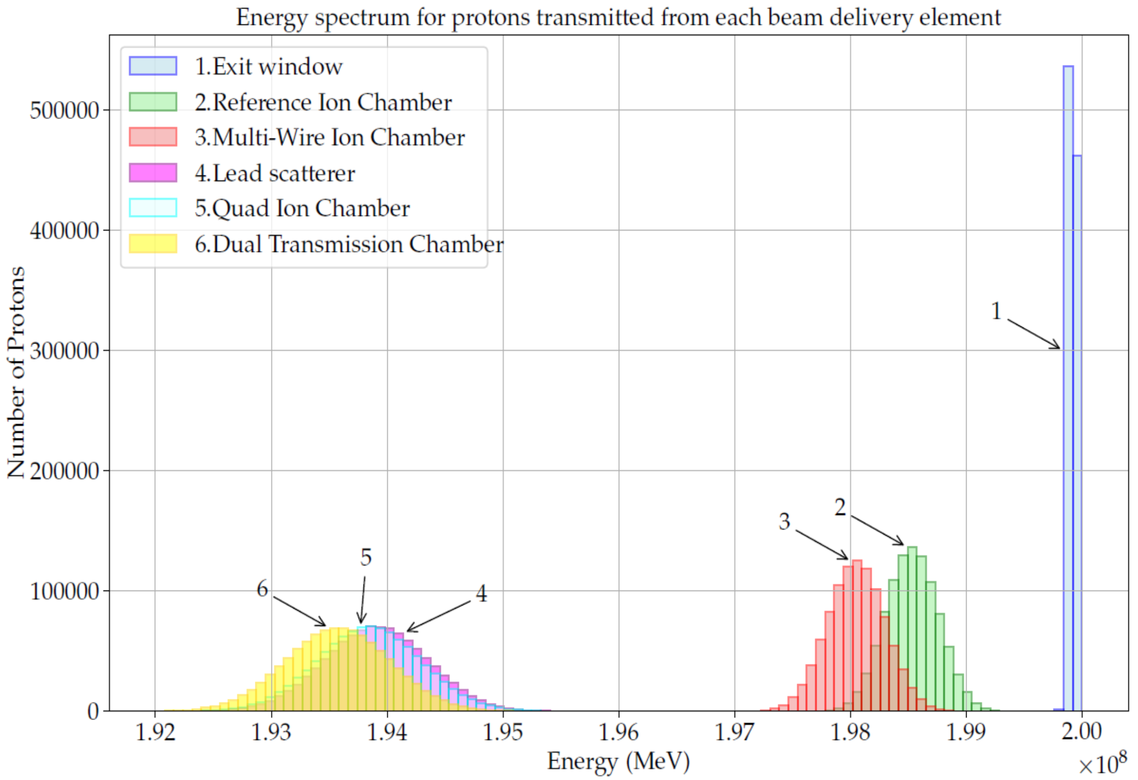
Practical changes to historic approaches at iTL

- Change to in-air testing
- Use passive beam spreading and collimation to create a uniform intensity beam spot
- Develop an accurate, affordable, easy to use dosimetry system
- Use collimators to provide the required beam spot size and shadow area to protect other devices
- Change to multi-DUT test capability
- Use SRIM simulation software for configuration design

Exploring the new iTL test setup – I

Energy spectrum over beam delivery system

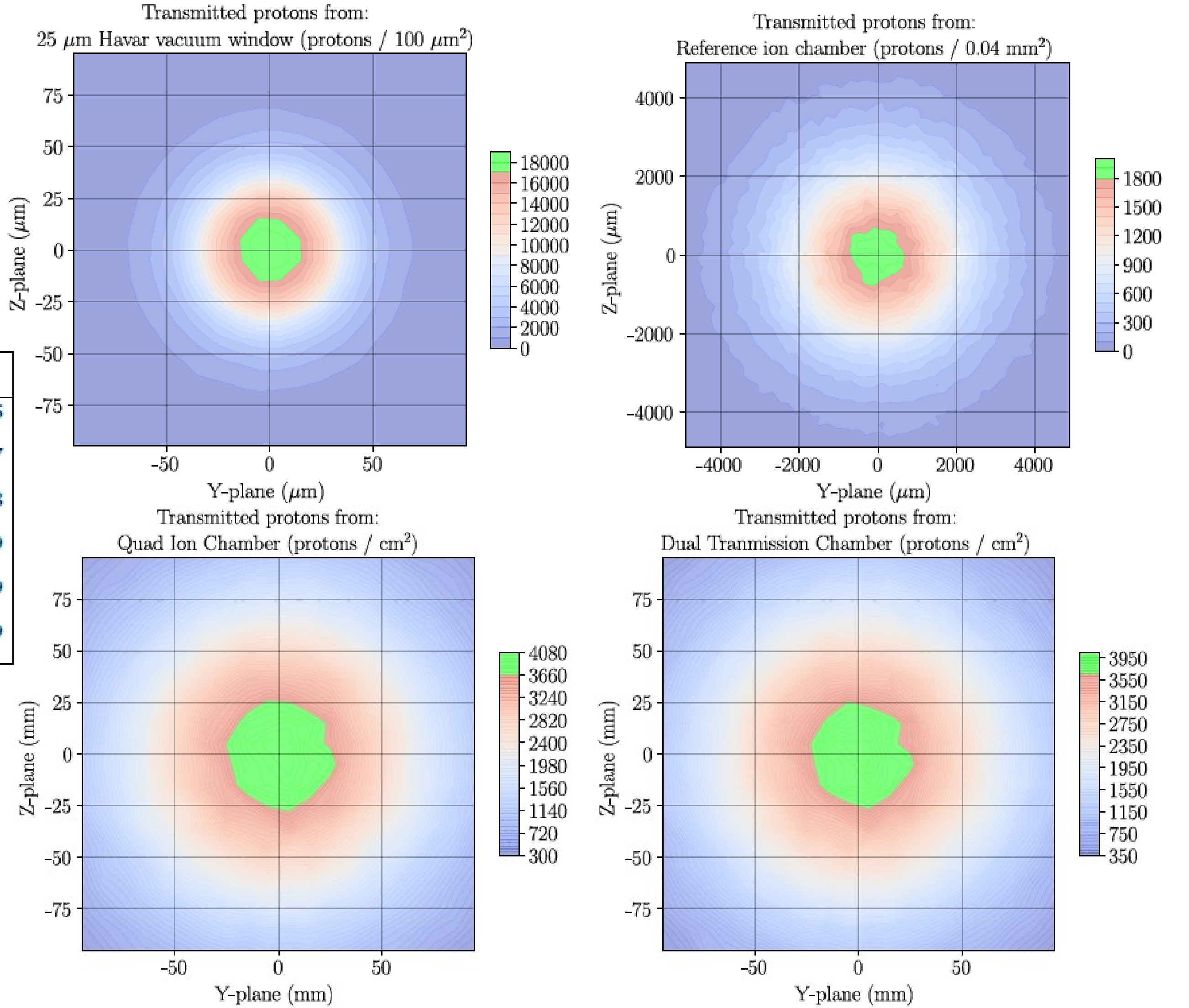
Nozzle element	μ_{Energy} (MeV)	σ_{Energy} (eV)	**Energy dispersion** (eV^2)
Exit window	199.9169	3.4116×10^4	1.1639×10^9
Reference Ion Chamber	198.5325	2.6672×10^5	7.1139×10^{10}
Multi-Wire Ion Chamber	198.0516	3.0340×10^5	9.2054×10^{10}
Lead sheet	193.9071	4.6676×10^5	2.1787×10^{11}
Quad Ion Chamber	193.8436	4.6782×10^5	2.1886×10^{11}
Dual Transmission Chamber	193.5771	4.7818×10^5	2.2865×10^{11}



Exploring the new iTL test setup - II

Beam spot size at each element – initial beam simulated as point source

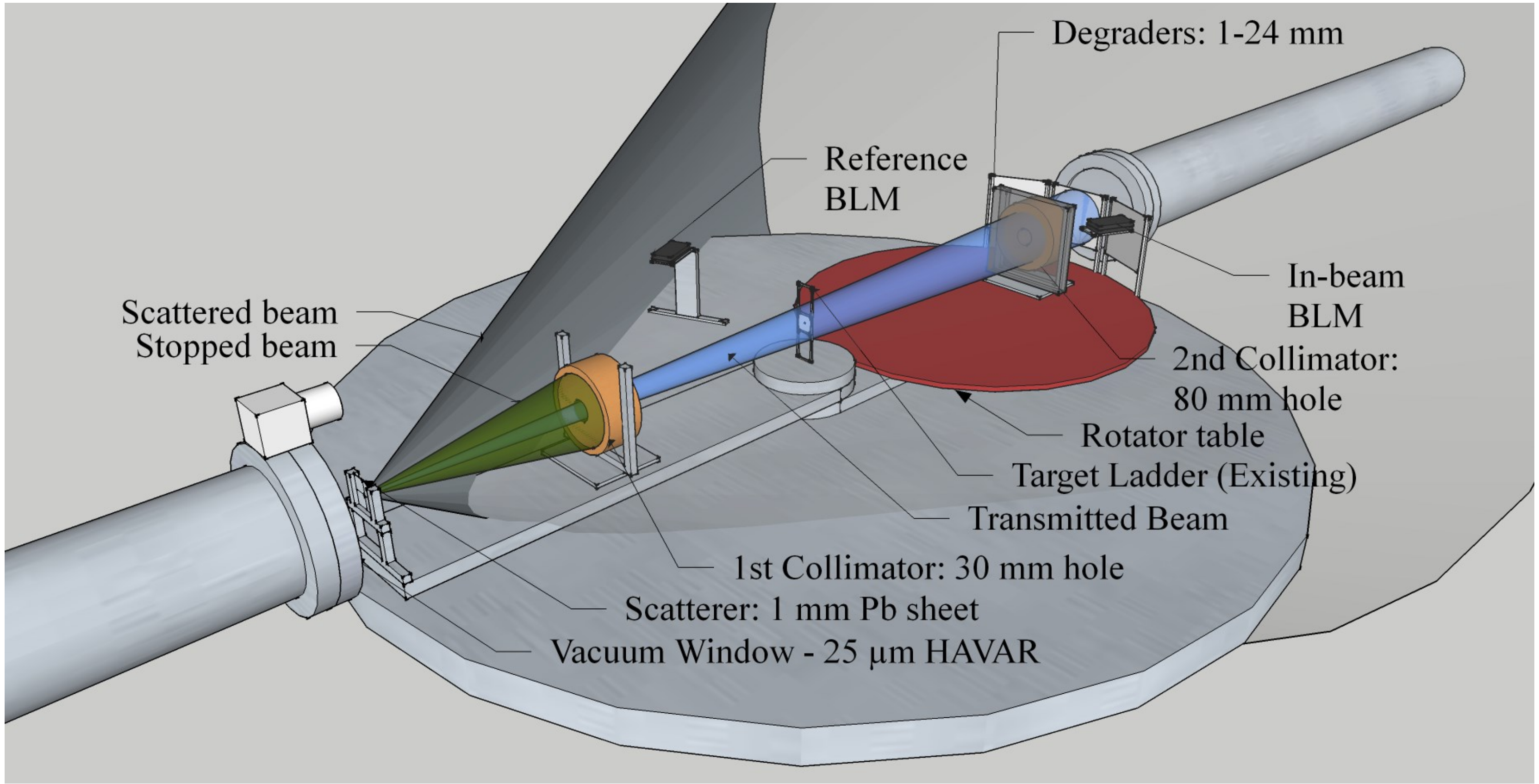
Nozzle element	μ_Y (Å)	μ_Z (Å)	σ_Y (Å)	σ_Z (Å)
Exit window	-4.0870×10^2	1.0725×10^3	7.9885×10^5	6.7909×10^5
Reference Ion Chamber	-3.0790×10^4	-4.4902×10^4	6.0748×10^7	5.2200×10^7
Multi-Wire Ion Chamber	-1.0313×10^5	-1.3632×10^5	1.7126×10^8	1.4129×10^8
Lead sheet	-1.1486×10^6	-9.7959×10^5	1.8883×10^9	1.4958×10^9
Quad Ion Chamber	-1.1547×10^6	-9.8463×10^5	1.9018×10^9	1.5067×10^9
Dual Transmission Chamber	-1.1625×10^6	-9.9084×10^5	1.9176×10^9	1.5194×10^9



Exploring the new iTL test setup - III

A-line conceptual design

- HAVAR vacuum window
- Passive beam spreading
- In-air testing
- Multi-collimator for spot an shadow forming
- Beam Loss Monitor (BLM) based beam monitor, dosimetry and profile measurement
- Rotating platform for multi-DUT handling



Exploring the new iTL test setup - IV

Simulating the A-line beam

Material	Thickness (µm)	μ_{Energy} (eV)	σ_{Energy} (eV)	σ_Y (Å)	σ_Z (Å)
Al	125	6.5208×10^7	8.8860×10^4	2.1570×10^7	2.1030×10^7
Al	500	6.4410×10^7	1.3024×10^5	3.7805×10^7	3.7071×10^7
Al	2000	6.1141×10^7	2.3775×10^5	1.0538×10^8	1.0402×10^8
Pb	500	6.2694×10^7	2.1913×10^5	2.1682×10^8	1.9272×10^8
Pb	1000	6.0389×10^7	3.4875×10^5	3.0994×10^8	2.9819×10^8

Table 3.3: Summary of proton energy and distribution statistics of 66 MeV proton point-beam passing through Al and Pb scattering sheets of varying thickness and 500 mm air.

Material	Thickness (µm)	Energy loss (%)	Energy straggle (%)	Spread factor	Spread / Loss
Al	125	1.200	0.134	1.000	26.894
Al	500	2.409	0.197	1.753	23.546
Al	2000	7.362	0.360	4.885	21.548
Pb	500	5.009	0.332	10.052	61.939
Pb	1000	8.502	0.528	14.369	54.191

Table 3.4: Analysis for Al and Pb scattering sheets of varying thickness and 500 mm air. Energy loss is versus 66 MeV, Energy straggle is as a % of 66 MeV, Spread factor is the average position σ vs average 125µm Al position σ, and Spread/Loss is in Å/eV.

- Need to determine the optimal passive beam spreading element
- Material must be available, affordable and easy to machine/form
- Should give best ratio of beam spread vs energy loss
- Spread the beam enough to get adequate beam spot within physical constraints of vault

Dosimeter selection and analysis - I

Dual Beam Loss Monitor as novel solution

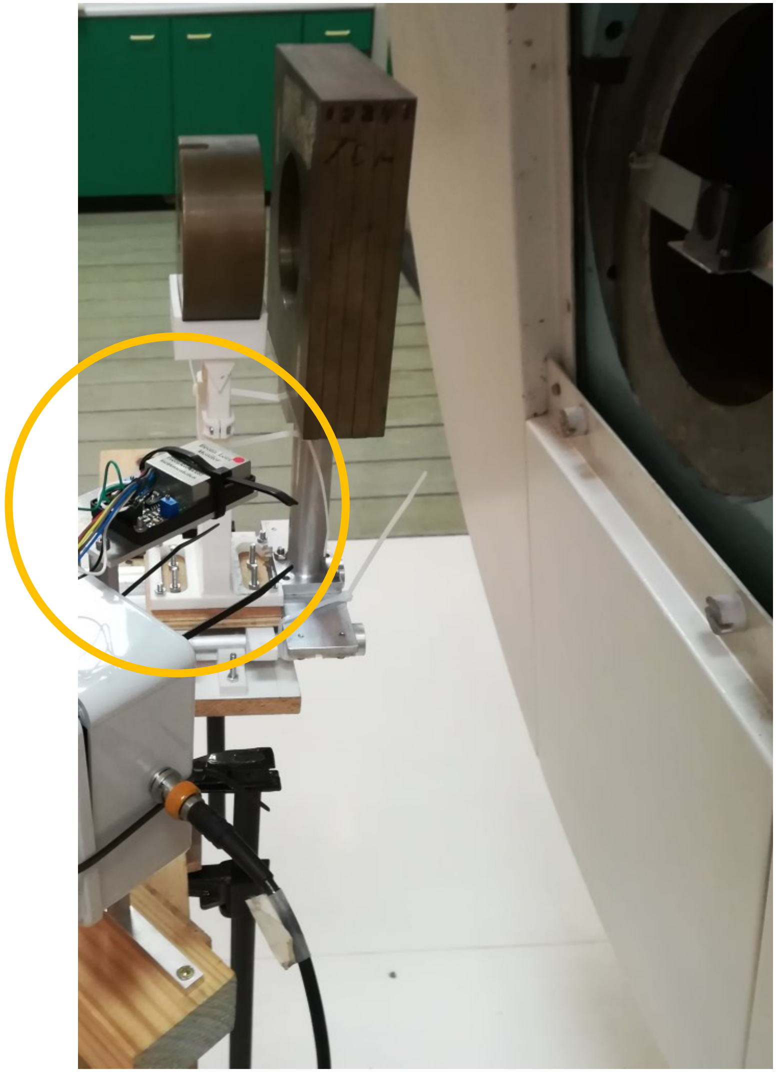
Not designed as dosimeter, but:

- Good spatial resolution – 7.34mm^2 square area
- Good sensitivity for protons – designed to detect MIPs
- Produces TTL pulses – easy to interface with
- Small physical size – easy to mount and move

Limitations

- Pulse bandwidth – ~100ns recovery time, thus 10MHz limit
- Fixed area, although small has saturation with high flux density

Need to investigate effectiveness as dosimeter/beam monitor



Dosimeter selection and analysis - II

BLM Saturation effects

Two sources of saturation

- Beam bunch frequency (bandwidth limit)
- Beam bunch density (flux over detector area)
- Use Bernoulli trials to calculate probabilities

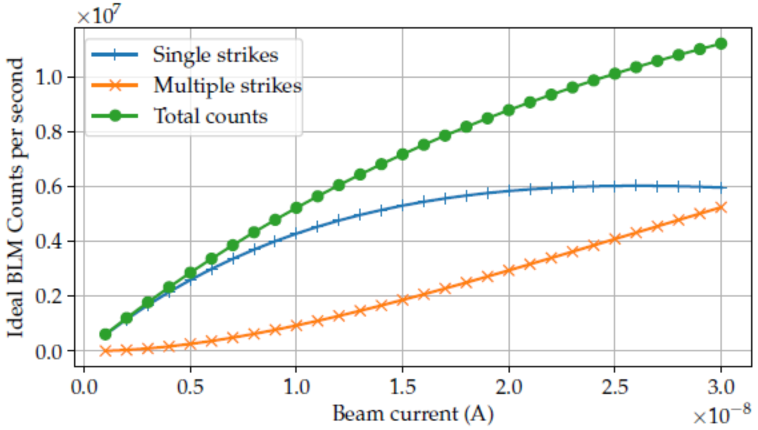


Figure 3.10: Expected BLM counts using SRIM data for NTV setup in 2019. The average amount of protons passing through the detector area per 1×10^6 simulated protons were 100.761.

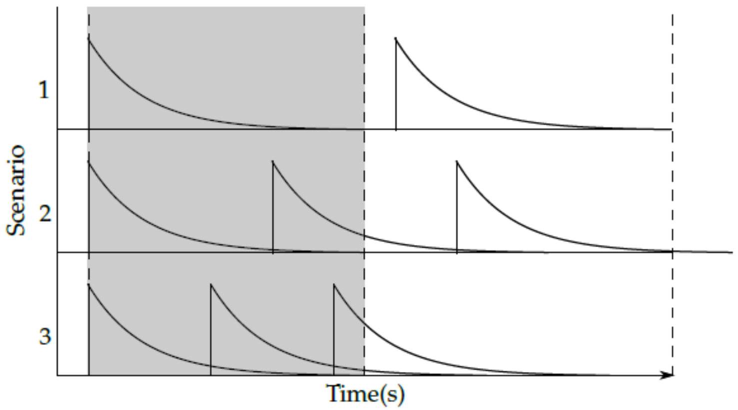


Figure 3.8: Illustration of three different scenarios associated with three frequency ranges of SSC beam pulses with BLM sensor recovery window edges shown with dotted lines. Beam frequency, from top to bottom, is: <1x sensor bandwidth, 1x - 2x sensor bandwidth, 2x - 3x sensor bandwidth.

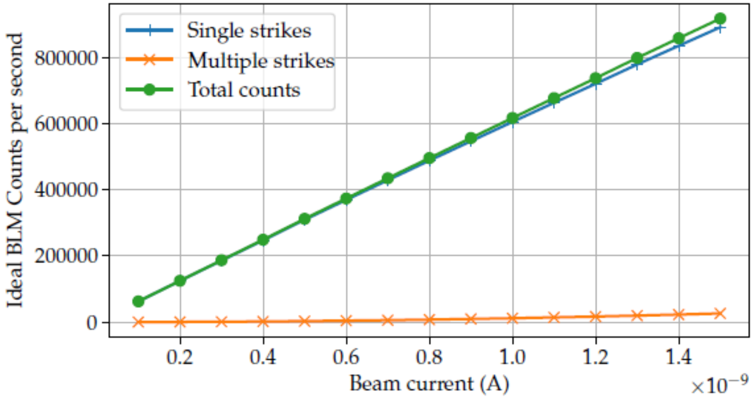
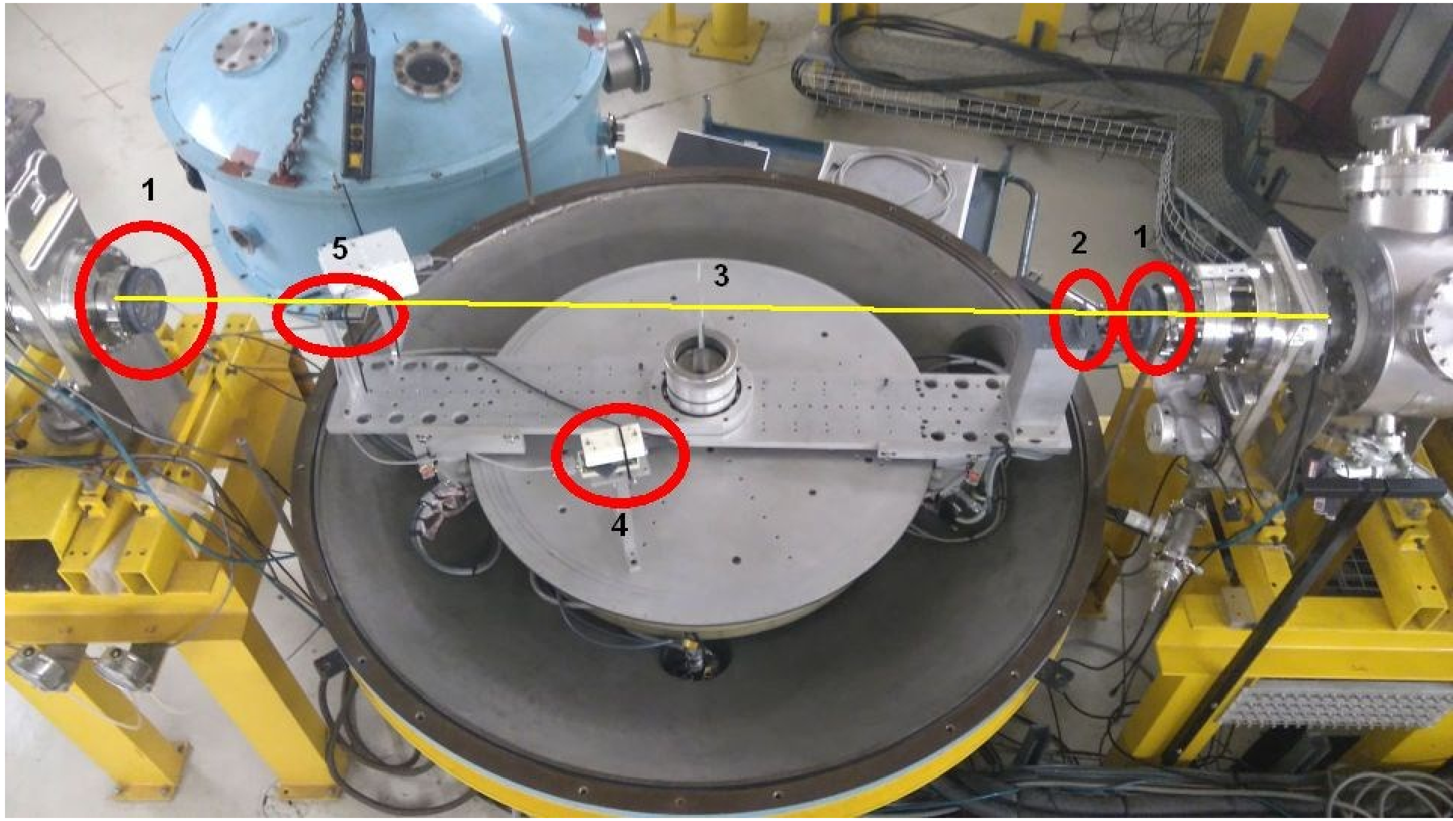


Figure 3.12: Expected BLM counts for small beam currents. The average amount of protons passing through the detector area per 1×10^6 simulated protons were 100.761.

A-line and NTV-line conversions

A-line (In air)

- Removal of scattering chamber walls
- Installation of vacuum windows
- Reconfiguration of vacuum system
- Installation of DUT positioning platform
- Mounting of BLMs
- Mounting of passive beam spreader sheet
- Two scintillating targets for pencil beam alignment
- Support electronics for positioning platform and BLMs

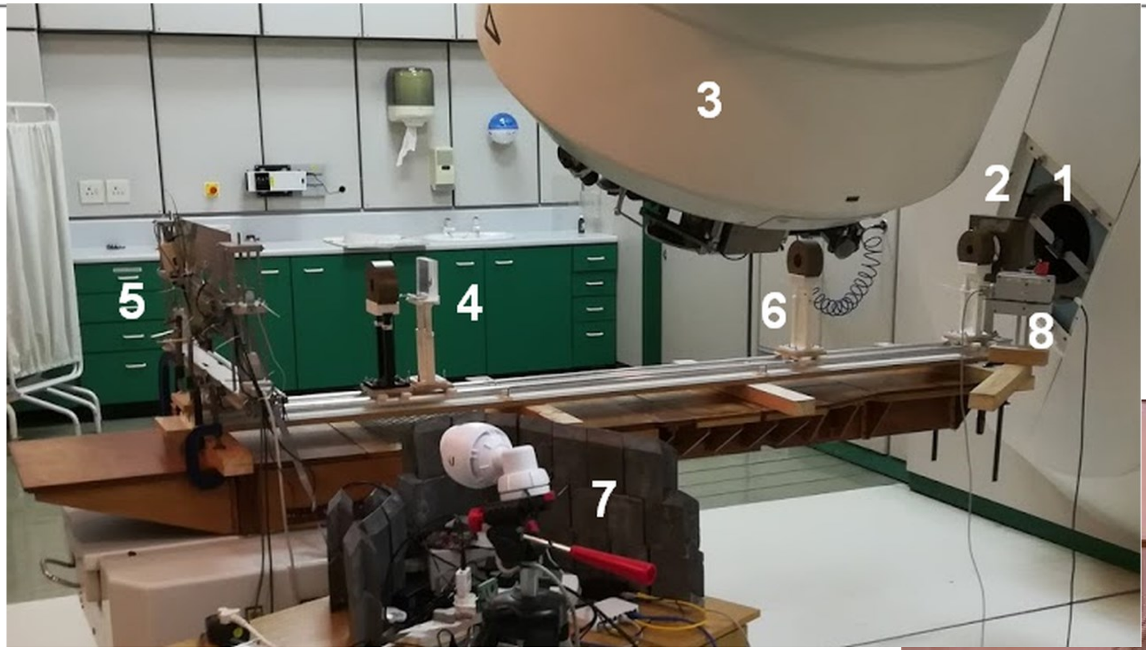


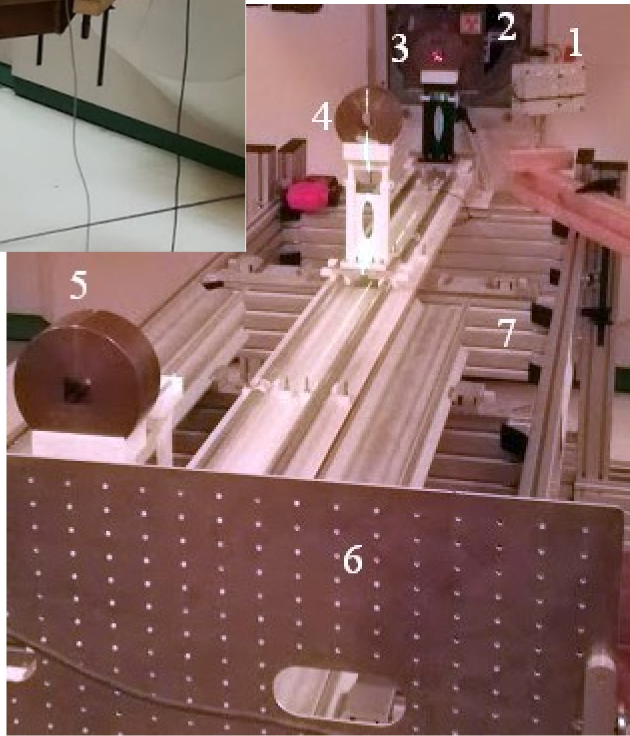
NRF National Research Foundation | iThemba LABS Laboratory for Accelerator Based Sciences | 65 Joint Institute for Nuclear Research, Science brings nations together, 1956 | Stellenbosch University Iyunivesithi Universiteit | forward together sonke siya phambili saam vorentoe

A-line and NTV-line conversions

NTV-line

- Removal of gantry angle indicator
- Mounting of passive beam spreader
- Mounting of collimators
- Mounting of DUT positioning platform
- Mounting of degrader sheet holder
- Mounting of BLMs
- Installation of support electronics
- 2018 addition of PRaVDA bench





Results from A-line and NTV-line - I

A-line verification – 2016

Aims:

- Verify in-air test methodology, compared to the in-vacuum testing
- Verify SRIM simulation accuracy, compared to the measured data
- Verify BLM as dosimetry system, compared to previous approaches

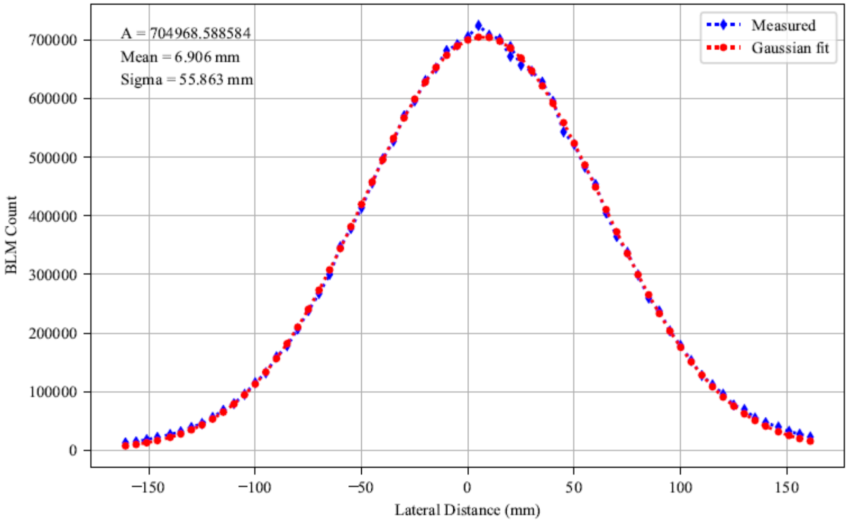


Figure 4.13: Gaussian fit of measured data from calibration run 2.

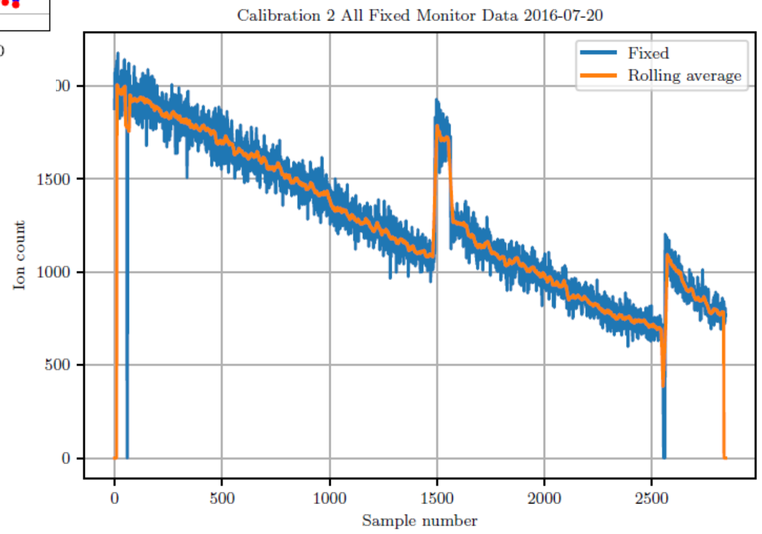


Figure 4.12: Fixed BLM data over all runs. Shift of beam current is clearly visible. Beam current was set to 2 nA by control room at the start of the measurements. The jumps in beam current is when the control room was asked to set the current again to 0.12 nA, 0.2 nA, and 0.13 nA respectively from samples 1500 to 1600.

Results:

- Simulated and measured beam spreading compared well: σ = 58.96mm vs σ = 57.16mm
- BLM interfacing verified and saturation observed – optimal beam current selection required at start of test

Non-availability of vault prohibited further development at A-line

Results from A-line and NTV-line - II

NTV-line 66MeV – Aims

- Verify in-air test methodology at NTV.
- Verify SRIM simulation accuracy compared to the measured data for the NTV configuration.
- Verify BLM as dosimetry system at NTV.
- Verify the quality of the beam spot and shadow areas, created using a series of collimators.
- Verify the quality and ease of use of the 3D-printed collimator stands.
- Verify the use of energy degrading sheets to enable SEE measurements over a range of energies.

Results from A-line and NTV-line - III

NTV-line 66MeV – Results I

- Full beam profile measurement using BLM, normalised using reference BLM values to compensate for beam current variations and correlated with DUT positioning platform positions

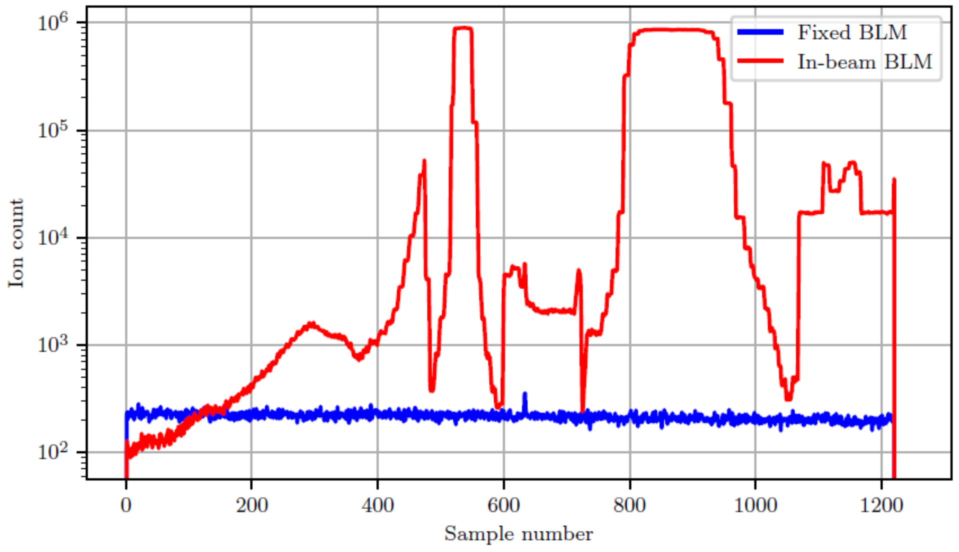


Figure 4.25: Second horizontal wide-beam profile measurement. With a lower (2.2 nA) intensity, unsaturated maximum values are produced. Note the data is not aligned with position information.

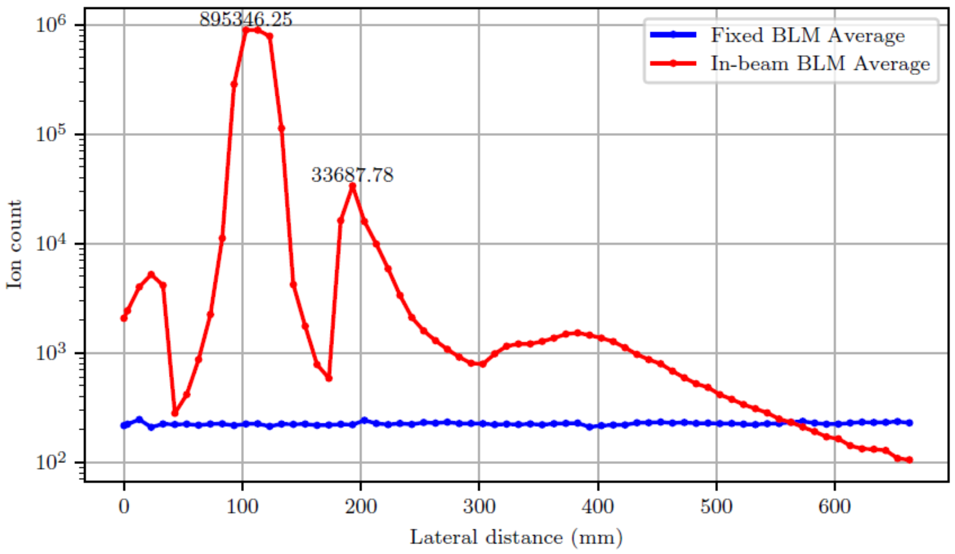


Figure 4.26: Position aligned data of the second horizontal wide-beam profile measurement. The beam spot centre is aligned with the 113 mm position on the positioning platform.

Results from A-line and NTV-line - IV

NTV-line 66MeV – Results II

- Central beam profile measurements, horizontal and vertical, using BLM

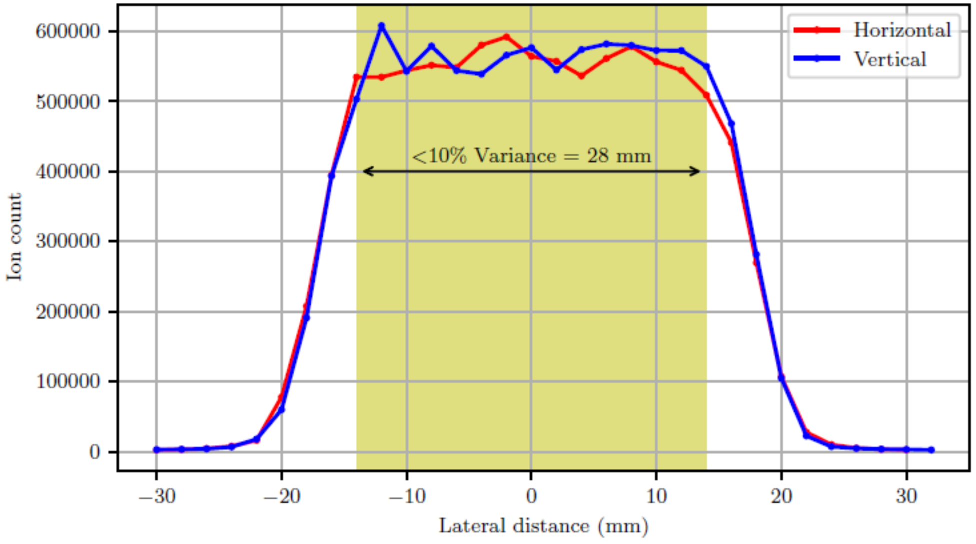


Figure 4.30: Normalized horizontal and vertical central beam spot profile showing good uniformity of the beam over the beam spot. Y-axis is ratio of in-beam BLM count to reference BLM count. Centre position (0 mm) corresponds to horizontal position 113 mm and vertical position 86 mm in Figures 4.28 and 4.29.

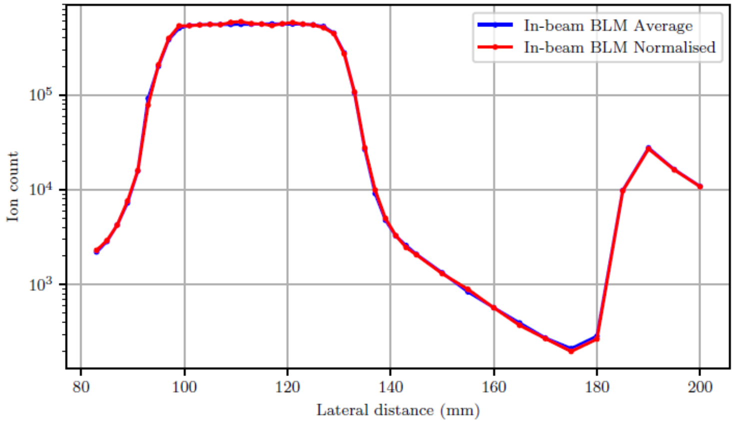


Figure 4.28: Central beam horizontal profile, averaged and normalised. Data is normalised to the average reference BLM count for the horizontal measurement. Standard deviation error bars are not shown as they are < 1% of the data value. The beam spot centre is aligned with the 113 mm lateral distance point.

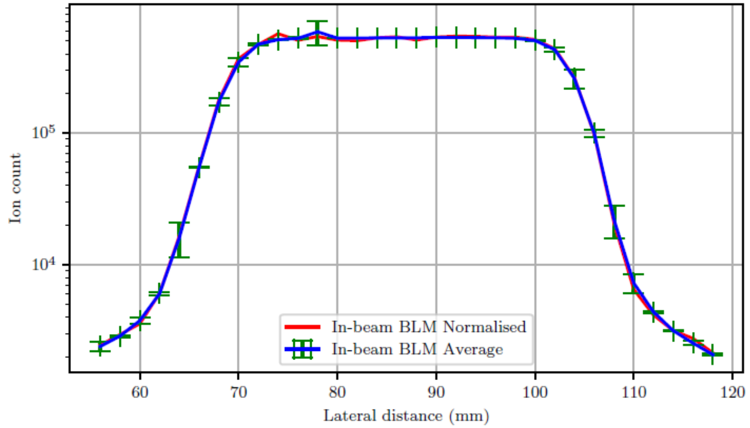


Figure 4.29: Central beam vertical profile, averaged and normalised. Data is normalised to the average reference BLM count for the vertical measurement. Standard deviation error bars are shown. The beam spot centre is aligned with the 86 mm lateral distance point.

Results from A-line and NTV-line - V

NTV-line 200MeV – Aims

- Verify in-air test methodology at 200 MeV, compared to the previous 66MeV tests.
- Verify SRIM simulation accuracy, compared to the measured BLM data.
- Verify BLM as dosimetry system at 200 MeV, compared to the previous 66MeV tests.
- Verify the quality of the beam spot and shadow areas, compared to the previous 66MeV tests.
- Verify the creation of a larger beam spot, of at least 60mm diameter, at the target to enable whole board testing of CubeSat subsystems.
- Conduct a SEE test on CubeSat electronics, aiming to reproduce similar responses from the DUT as observed in space.
- Conduct a similar SEE test on candidate spacecraft electronics, and produce responses to compare against future on-orbit data.
- Identify if other responses can be observed using 200 MeV, than what was observed at 66 MeV.

Results from A-line and NTV-line - VI

NTV-line 200MeV – Results I

- SRIM simulations to determine passive beam spreader thickness
- Beam current very noisy (±20%), but BLM saturation level determined
- BLM interface not optimal, count scaling issues with new iTL data logger

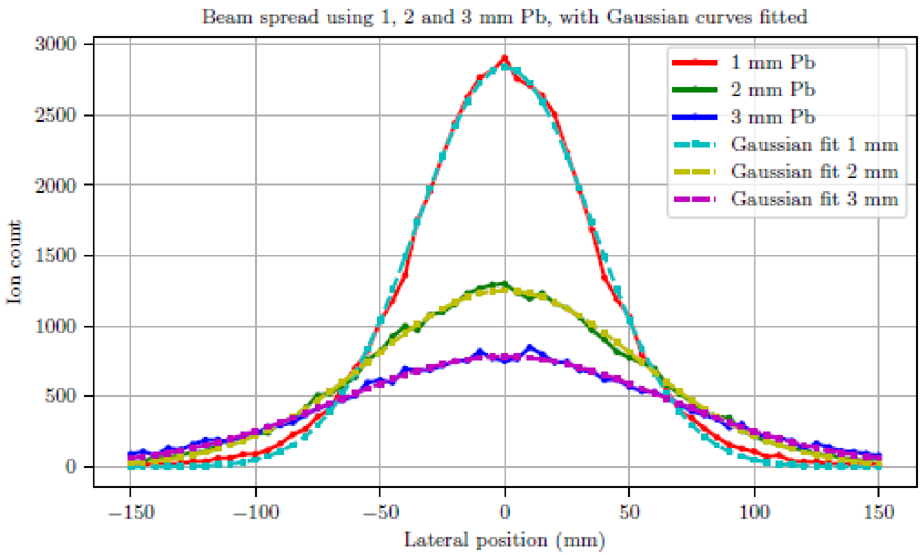


Figure 4.37: 5 mm×5 mm averaged centre slice of SRIM simulated beam spot intensity for 200 MeV protons, in NTV configuration using 1 mm, 2 mm and 3 mm Pb spreader over 4 m distance. Gaussian curve fitting for each case also shown.

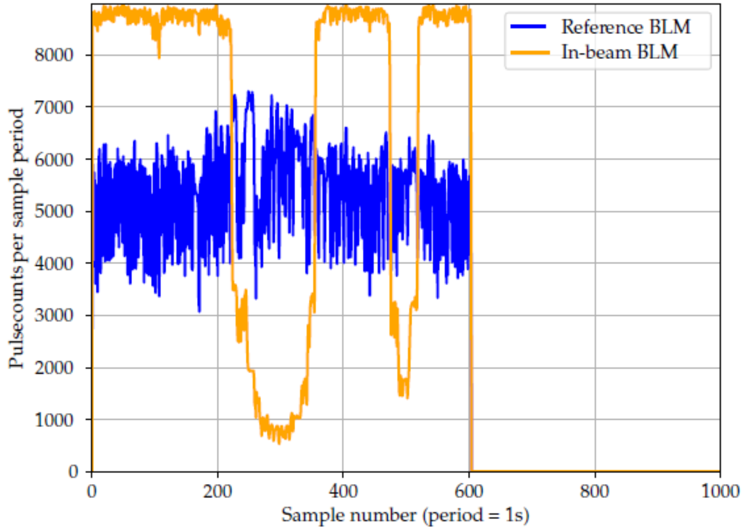


Figure 4.39: Raw per second sampled data from in-beam and reference BLMs. The in-beam BLM measurement seems to saturate at 9000 counts (20x pre-scaler used). The in-beam and reference data are both fairly noisy with the reference values changing by more than ±20%.

Results from A-line and NTV-line - VII

NTV-line 200MeV – Results II

- Central beam profile measurements, horizontal and vertical, using BLM

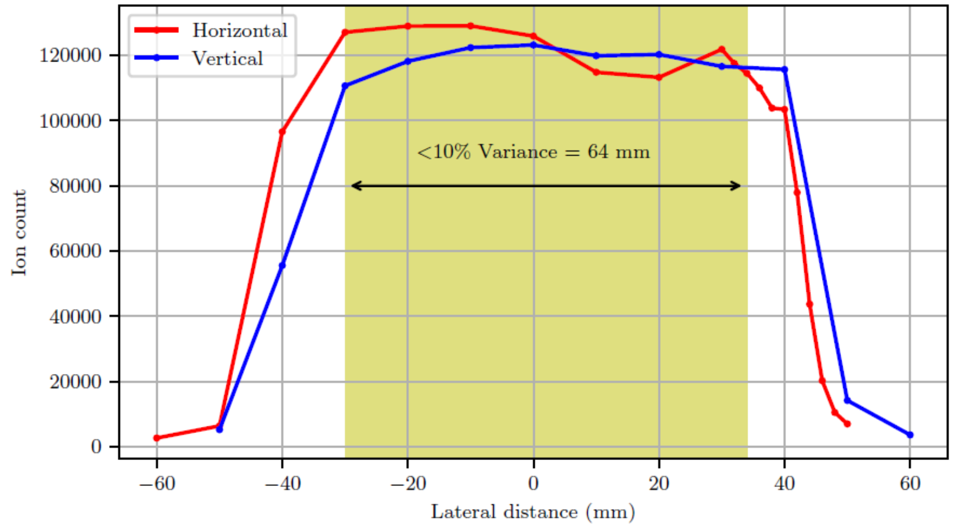


Figure 4.42: Combined horizontal an vertical beam spot profile measurements, both normalized to the reference BLM values. Beam current at 0.5 nA.

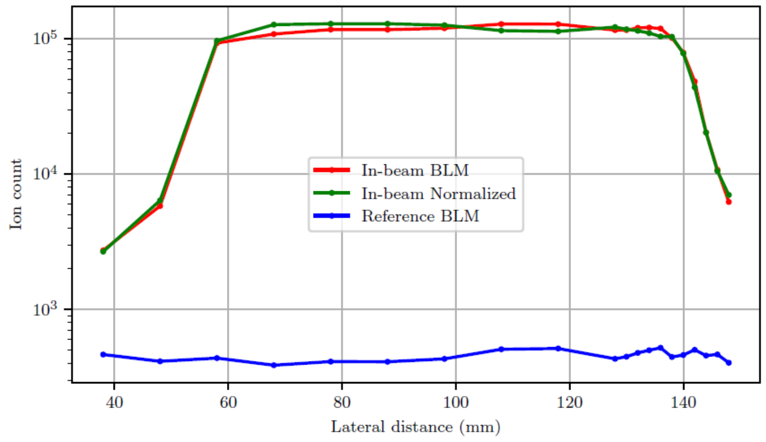


Figure 4.40: Horizontal profile measurement showing the in-beam BLM, normalized in-beam BLM (to reference) and reference BLM values. Beam current is 0.5 nA and the values are averaged and correlated to the positioning platform data.

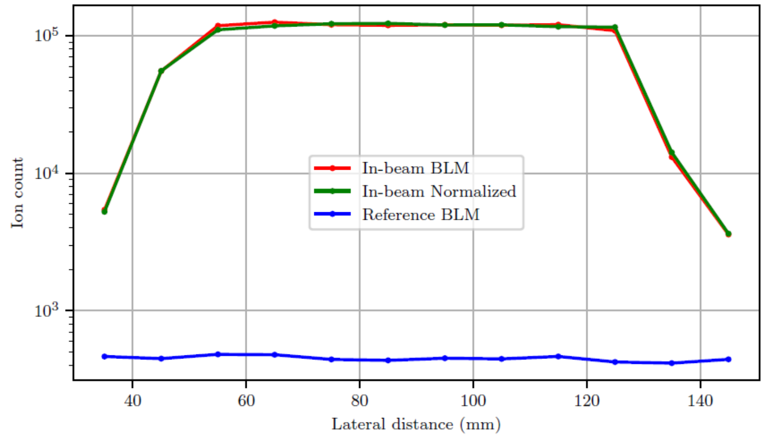


Figure 4.41: Vertical profile measurement showing the in-beam, normalized (to reference) and reference BLM values. Beam current at 0.5 nA.

Results from A-line and NTV-line - VIII

NTV-line 66MeV 2019 – Development Aims

- Measure the beam spot profile using the new independent DAQ interface to the BLMs.
- Create a better quality shadow compared to the 2017 NTV 66MeV experiment and measure the shadow intensity profile.

NTV-line 66MeV 2019 – Results

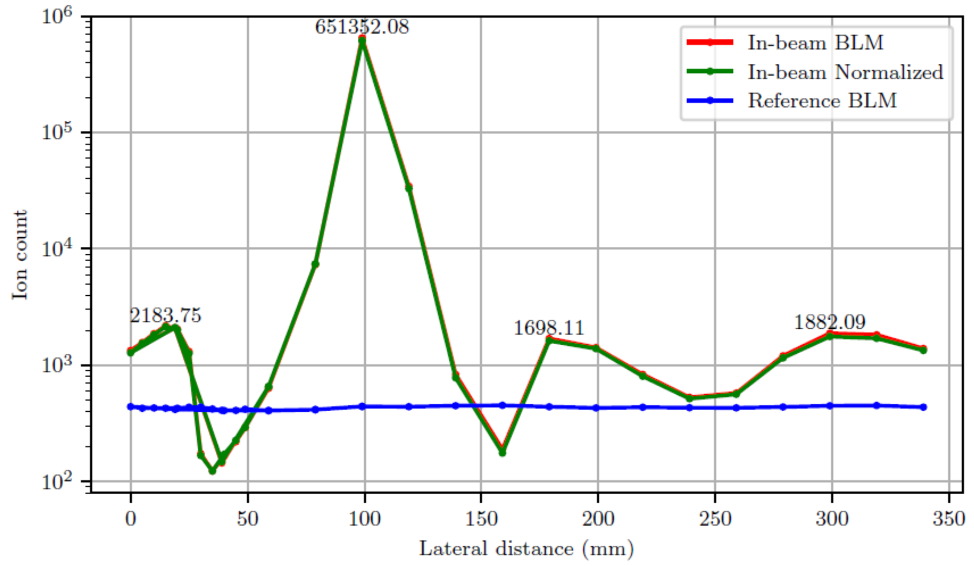


Figure 4.51: Wide horizontal profile - Raw in-beam BLM and reference BLM values - 2 nA.

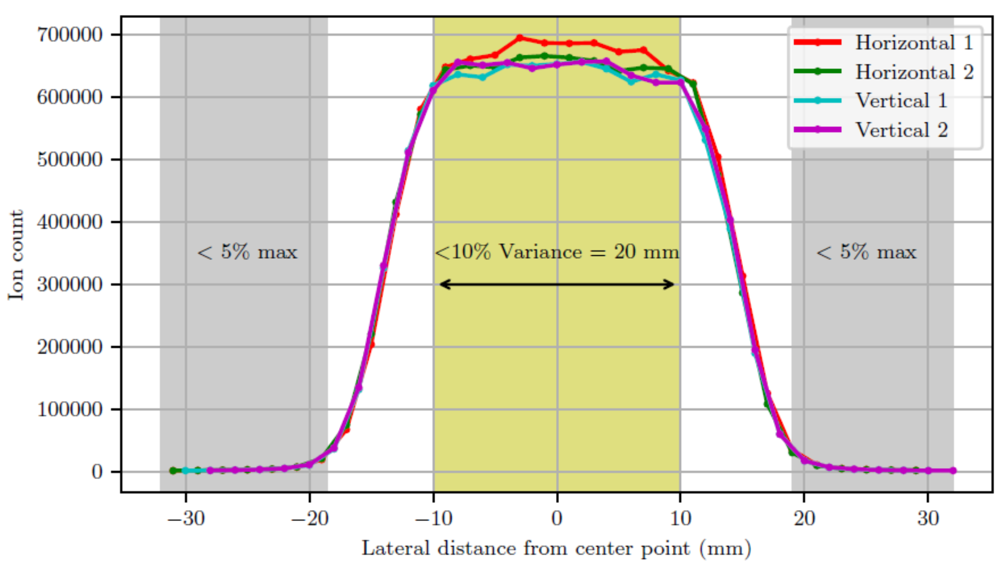
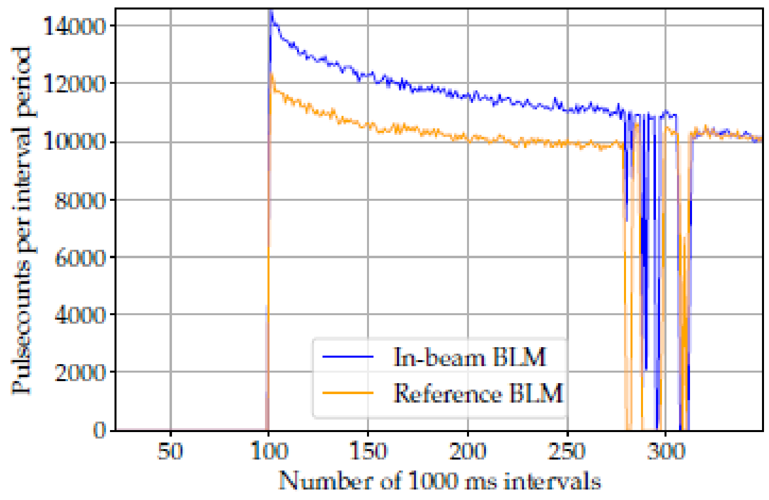


Figure 4.50: Combined central profile - Raw in-beam BLM values (this is true dose over spot) - 2 nA.

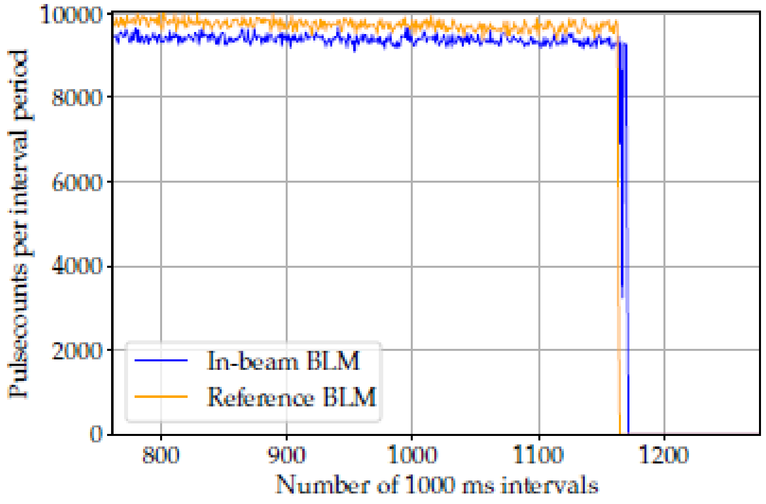
Results from A-line and NTV-line - IX

NTV-line 66MeV 2019 – Results II

- Startup transient in BLM measurements



(a) In-beam and reference BLM pulse rates showing decreasing transient behaviour immediately after start-up.



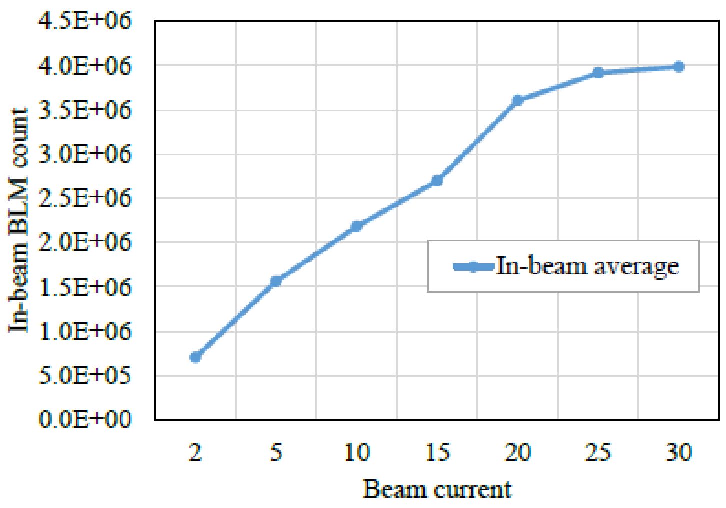
(b) In-beam and reference BLM pulse rates showing steady state values after roughly 800 seconds.

Figure 4.47: BLM calibration pulse counts showing (a) a settling period at start-up, and (b) a stable calibration count rate, for 66 MeV experiment in iTL NTV, January 2019.

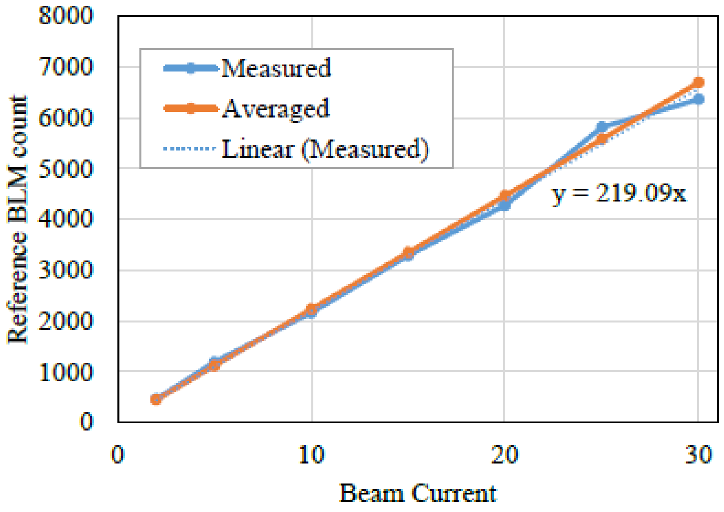
Results from A-line and NTV-line - X

NTV-line 66MeV 2019 – Results III

- Linearity of reference BLM measurements is very good, in-beam shows expected saturation
- New BLM logger produced much higher accurate count rates



(a) In-beam BLM average values as a function of the beam current supplied. Significant saturation of the measurement starts occurring above 15 nA.



(b) Reference BLM average values as a function of the beam current supplied. The relationship is very close to perfectly linear, as expected. Linear function fit to the measured data is shown.

Figure 4.48: Reference BLM to beam current over a range of currents.

SEE testing at iThemba LABS

Along with these beam configuration experiments, multiple users were accommodated for SEE testing, including:

- 3 Master's students and one researcher at A-line
- 2 Master's students, one industry partner, and one researcher at NTV line
- 2 Master's students at D-line

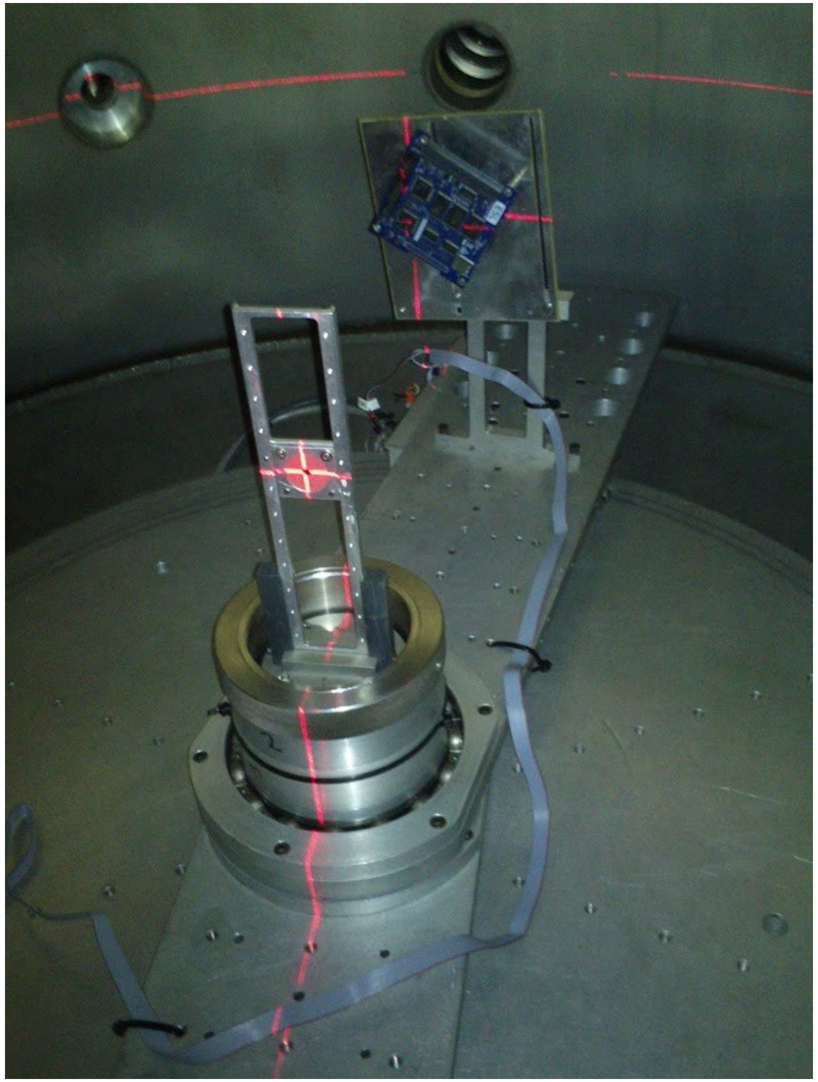
The research conducted by South African researchers through access to SEE testing included:

- accurately test the effectiveness of mitigation techniques applied on a CubeSat OBC,
- successfully provided a degraded energy environment for FPGA device characterisation,
- evaluate SET mitigation techniques applied in Xilinx and Microsemi FPGAs,
- recreate and observe similar device behaviour as observed with on-orbit devices,
- screened candidate spacecraft processors and imaging sensors,
- and investigate failure modes and sensitivity of an embedded Intel Atom processor

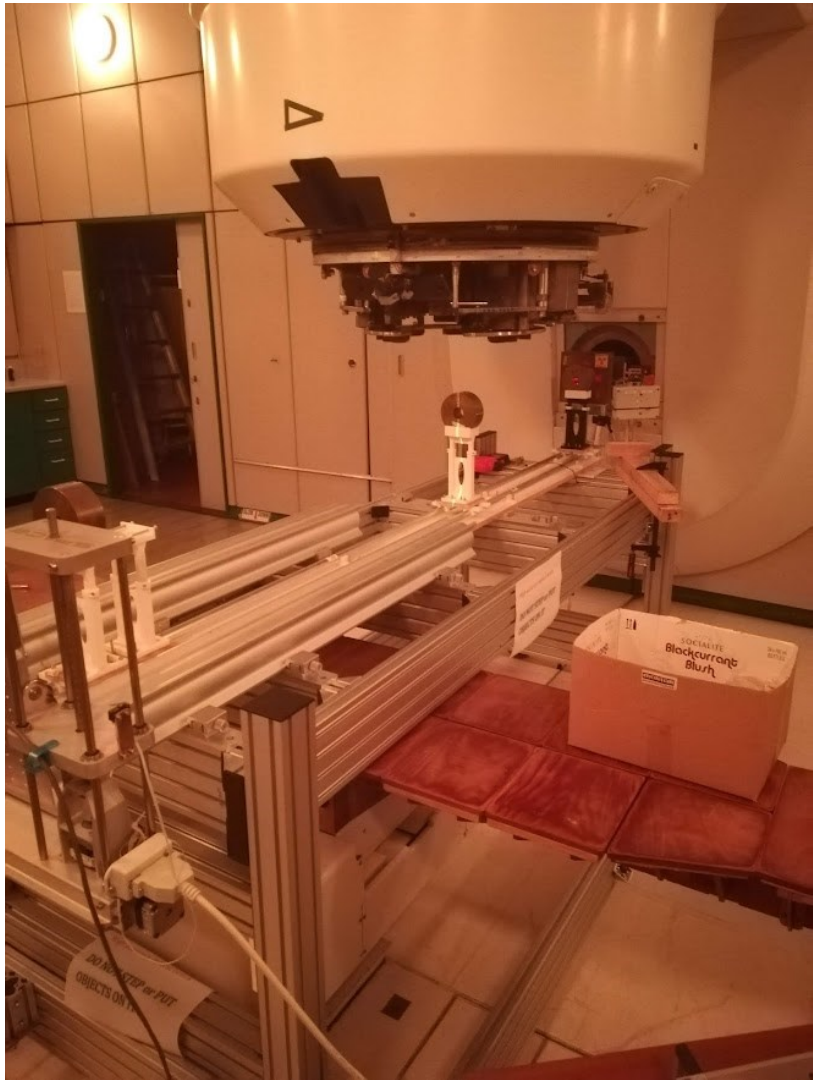
Obligatory pictures

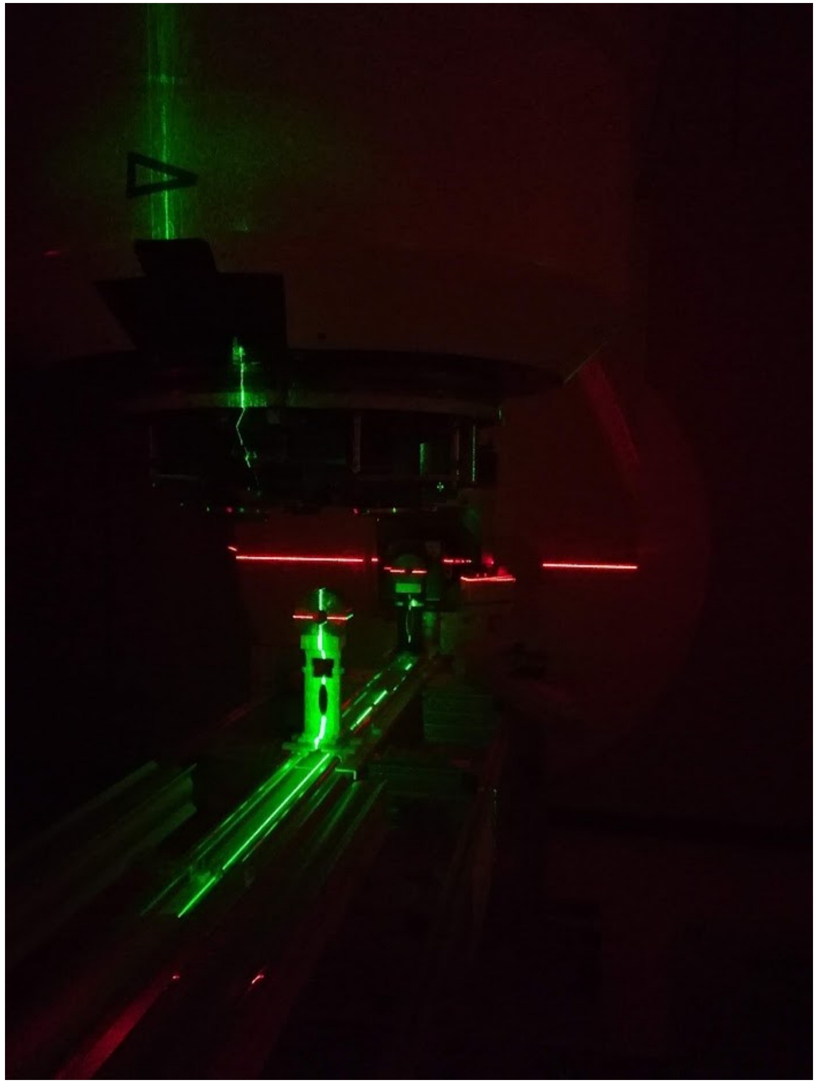
Obligatory pictures

Obligatory pictures



Obligatory pictures





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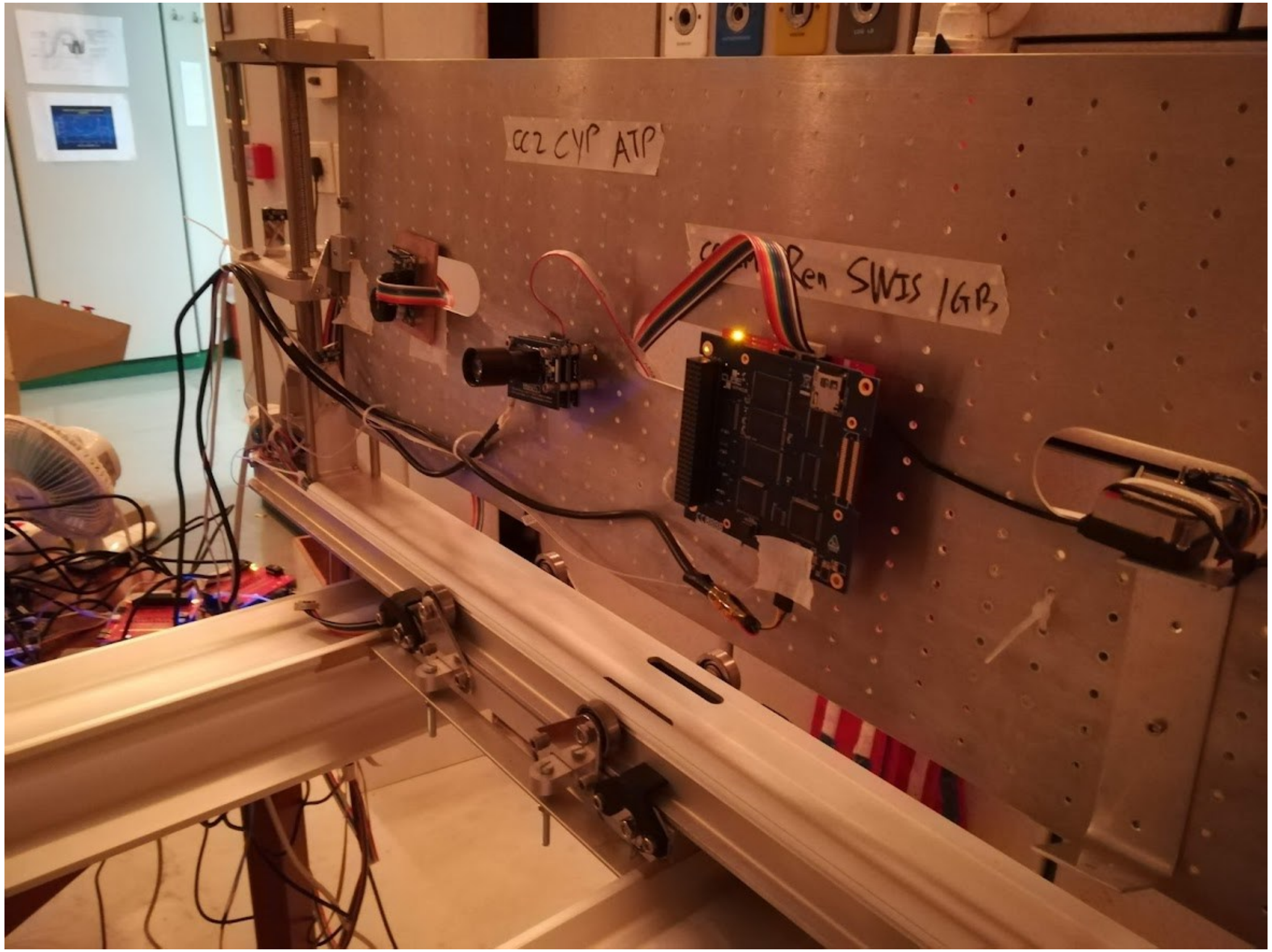

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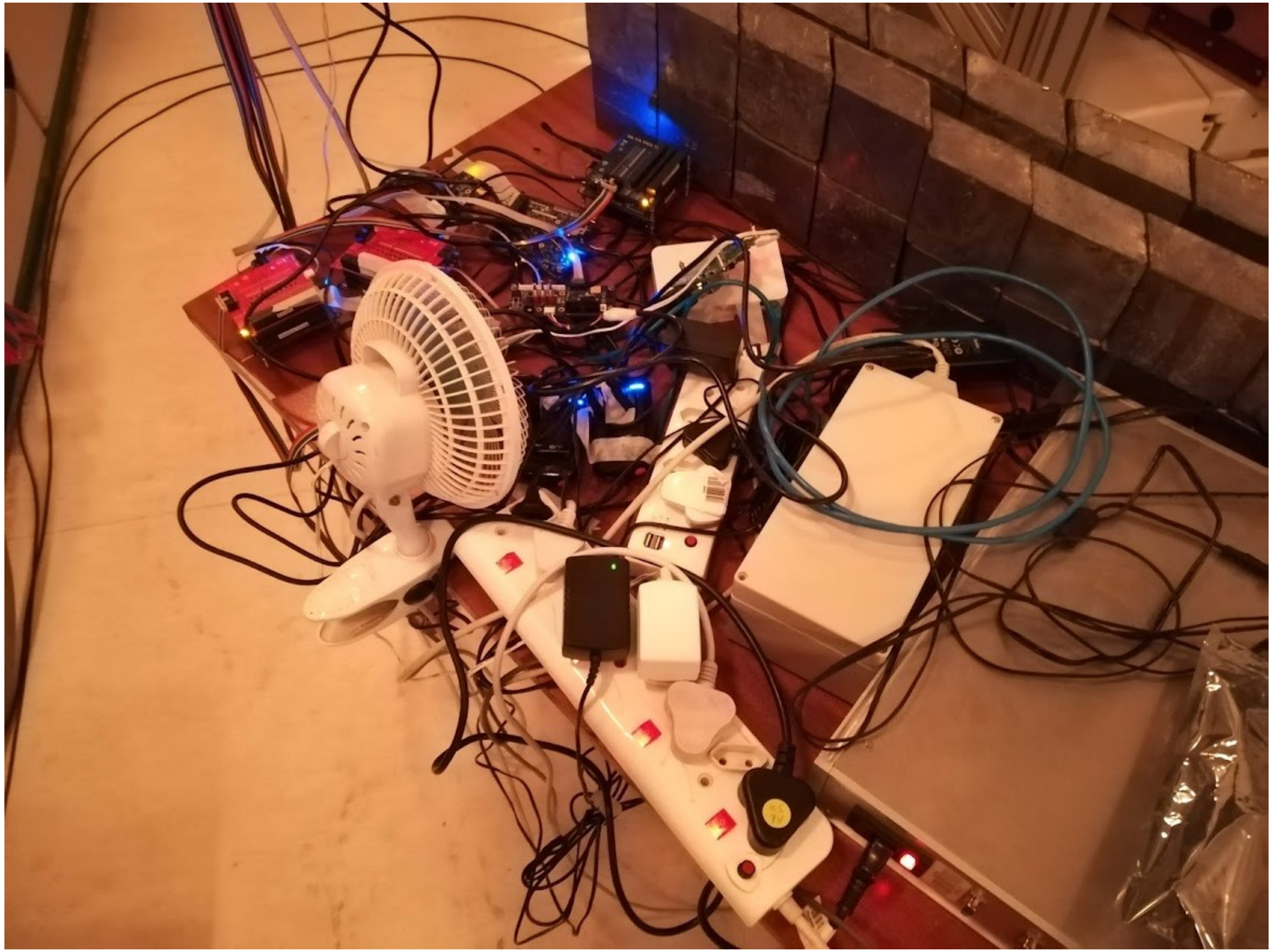

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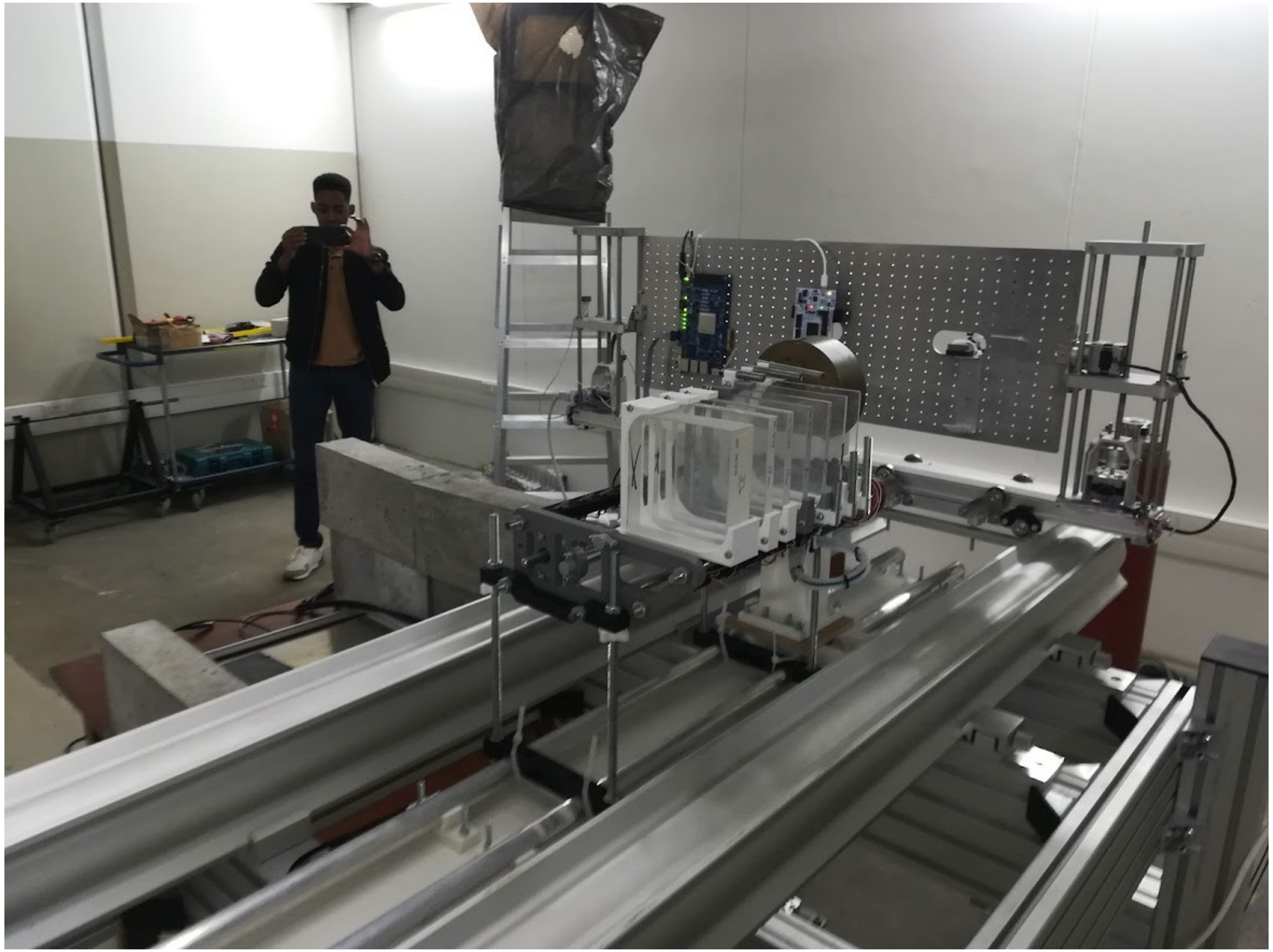

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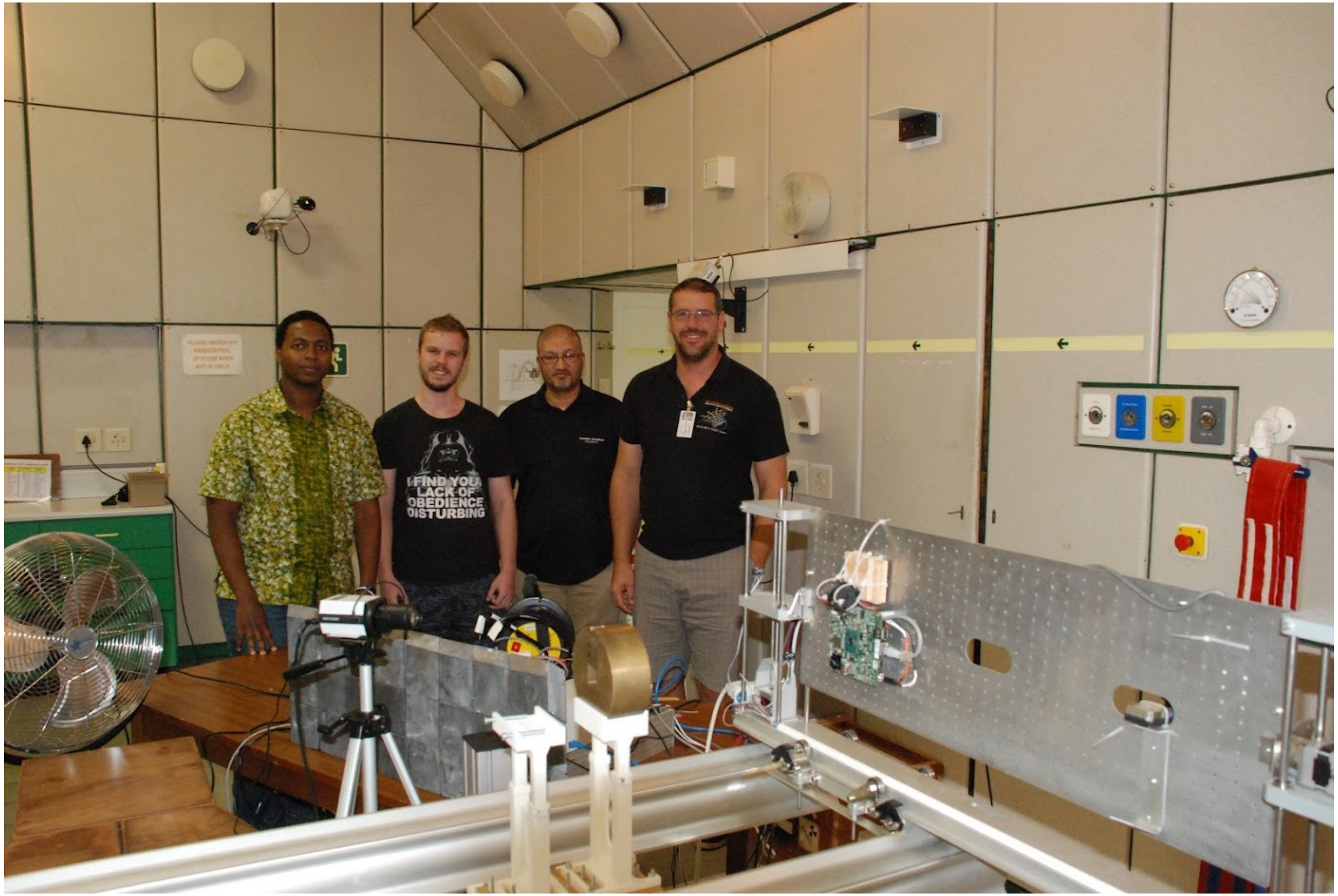

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