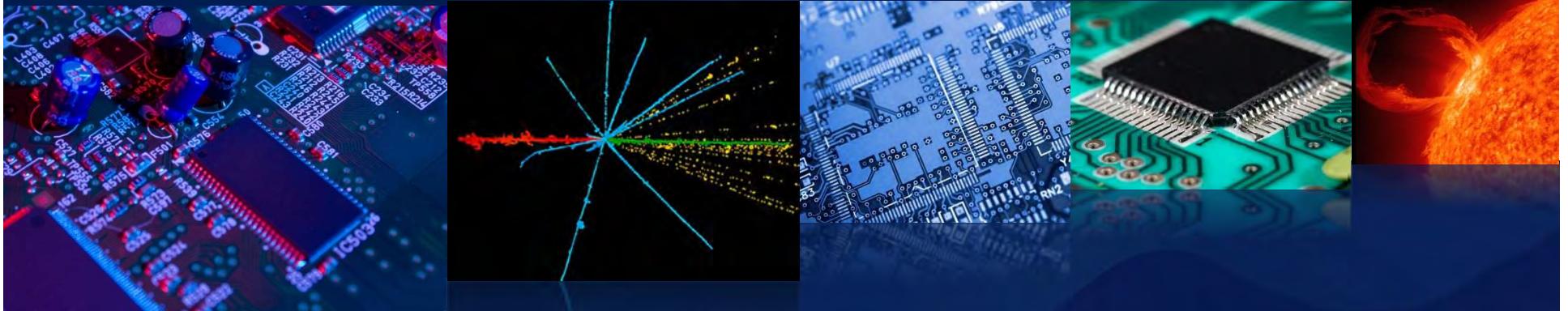


When the Chips are Down...



Christopher Frost

ISIS Facility, Rutherford Appleton Laboratory, UK



Your PC ran into a problem and needs to restart. We're just collecting some error info, and then we'll restart for you. (0% complete)

If you'd like to know more, you can search online later for this error: HAL_INITIALIZATION_FAILED



Schaerbeek, Belgium

May 18th 2003, 22:30

4096 (2^{12}) votes added to an electronic voting machine



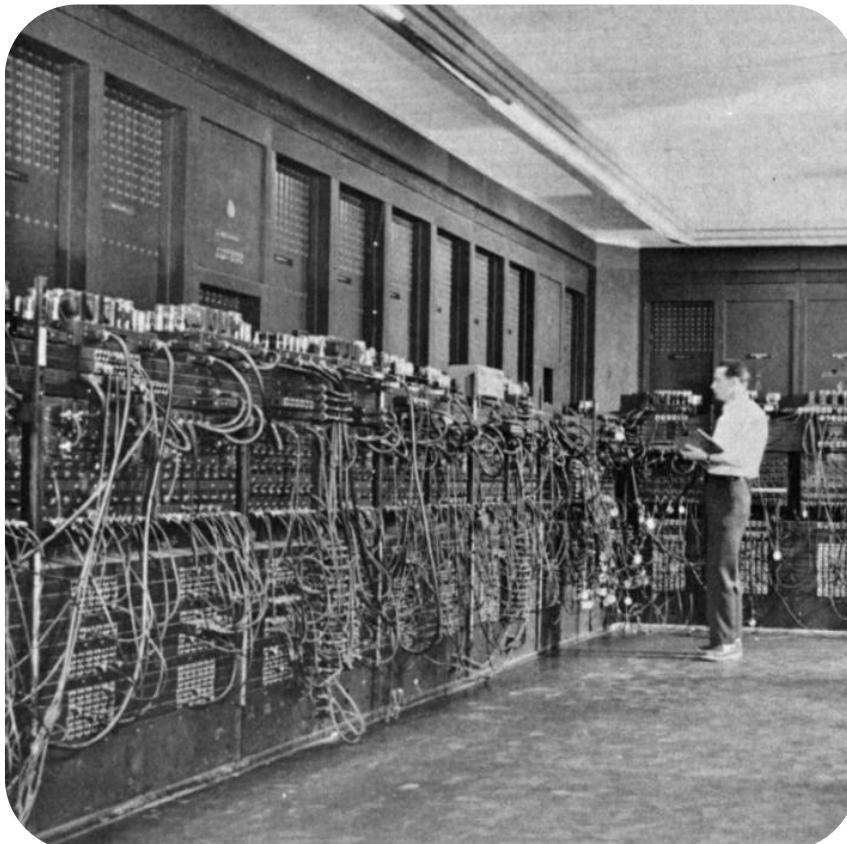
official report concluded the error was caused by an “spontaneous” random binary inversion – a single bit error

0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1

4096



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1946 ENIAC Computer

0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1

BITFLIP



Presper Eckert & ENIAC (1946)

In 1948 Presper Eckert complained about cascading effect of single-bit errors in one of the first electronic computers ENIAC; but this was from 'antenna pickup'



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Sources: Daniel Lyons "Sun Screen", Forbes magazine Nov 2000;
Cisco 12000 Single Event Upset Failures Overview and Work
Around; www.cisoc.com; James F. Ziegler and Helmut Pucher,
SER-History, Trends and Challenges, Cypress 2004

SUN Microsystems - 2000

Flagship computer systems had problem with memory

Cypress Semiconductor Corporation - 2001

\$1bn factory ground to halt every month due to single bit-flip in network

Los Alamos ASIC-Q Supercomputer - 2002

When it was first installed... [it] couldn't run more than an hour or so without crashing.

Cisco Systems - 2003

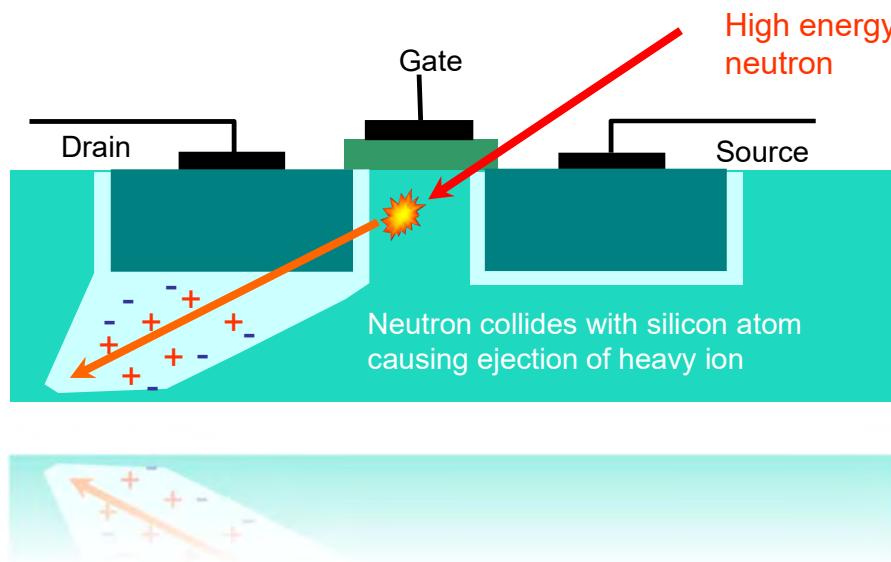
High end internet router cards suffered failures



BITFLIP

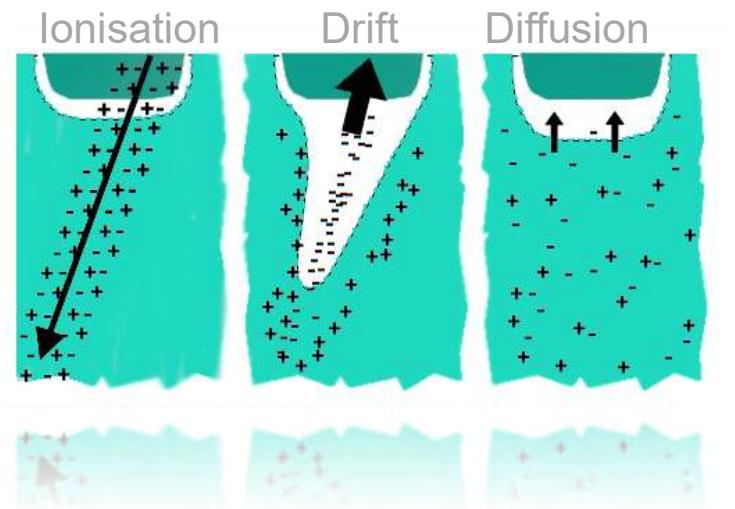


A Single Event Effect (SEE) is when a highly energetic particle present in the environment, strikes sensitive regions of an electronic device disrupting its correct operation



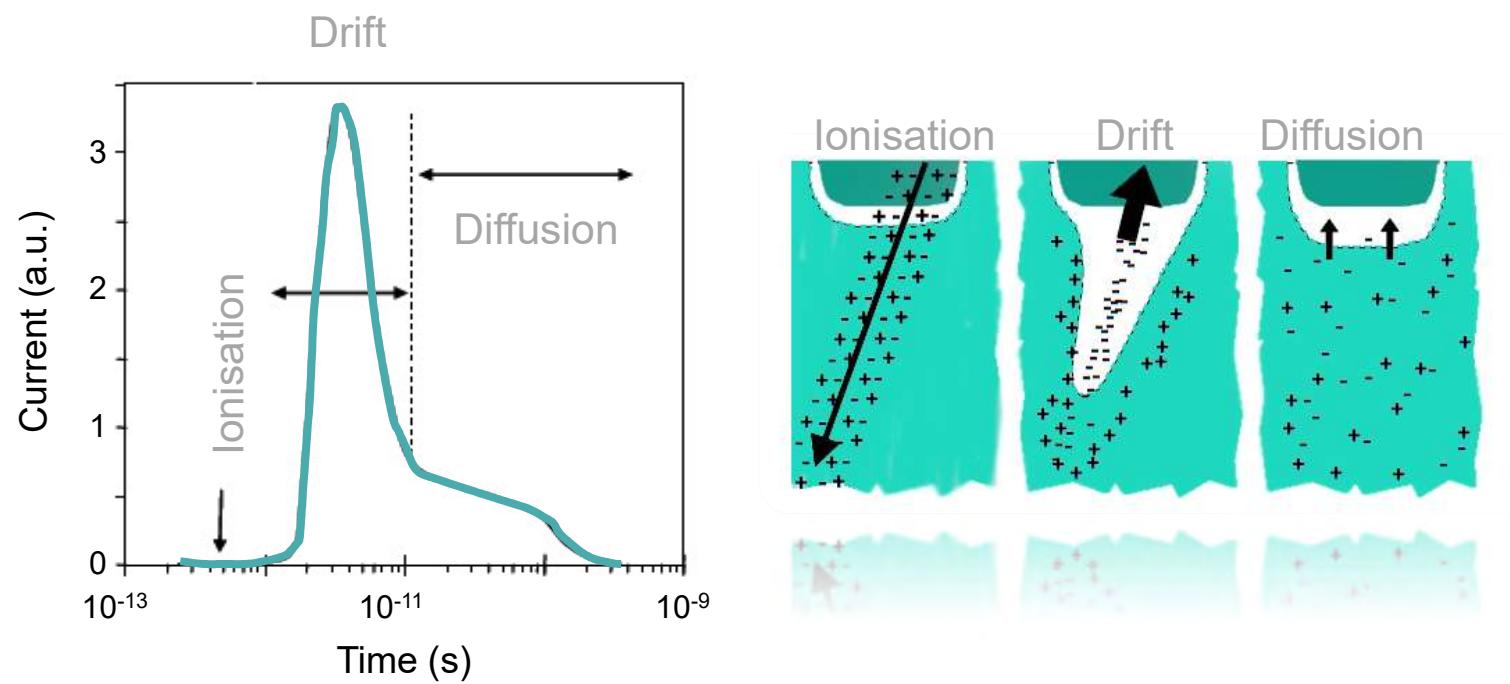
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A Single Event Effect (SEE) is when a highly energetic particle present in the environment, strikes sensitive regions of an electronic device disrupting its correct operation



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A Single Event Effect (SEE) is when a highly energetic particle present in the environment, strikes sensitive regions of an electronic device disrupting its correct operation



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A Single Event Effect (SEE) is when a highly energetic particle present in the environment, strikes sensitive regions of an electronic device disrupting its correct operation

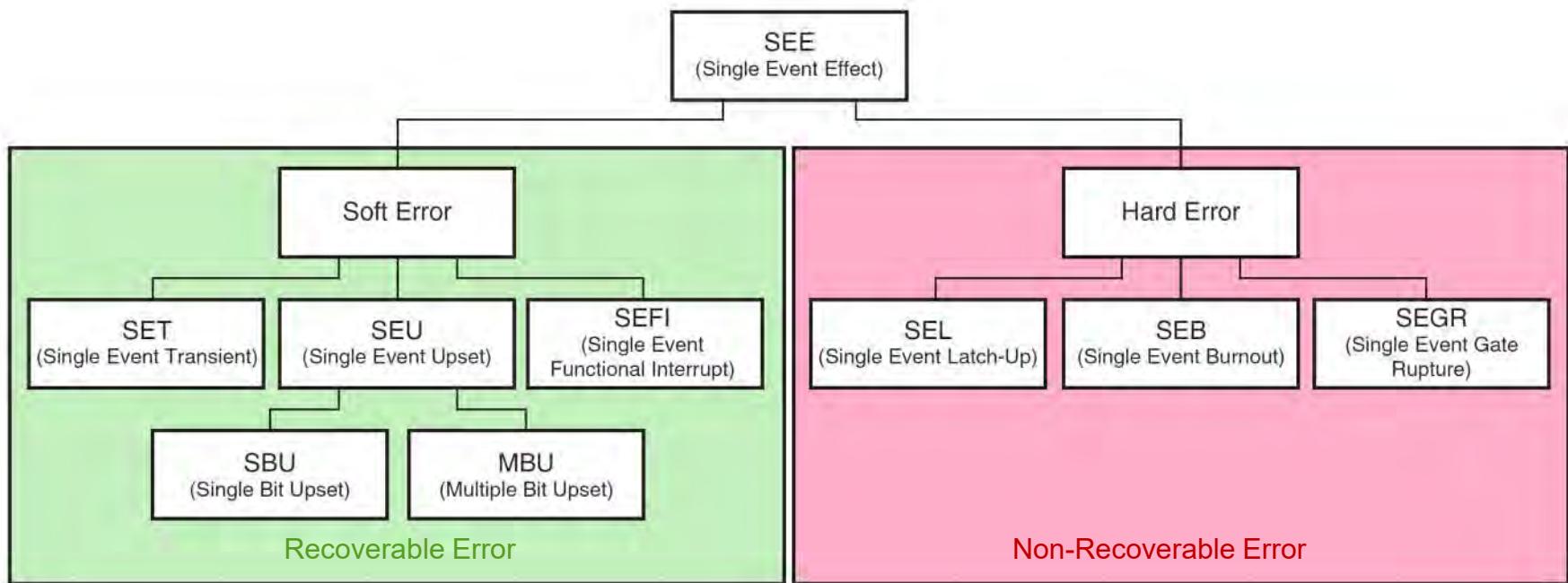


Diagram Courtesy: Xilinx



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A Single Event Effect (SEE) in Louisiana in 1992

Normally expected from radioactive contamination

Bizarre circumstances led to just such a problem



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A Single Event Effect (SEE) in Louisiana in 1992

Normally expected from radioactive contamination

Bizarre circumstances led to just such a problem

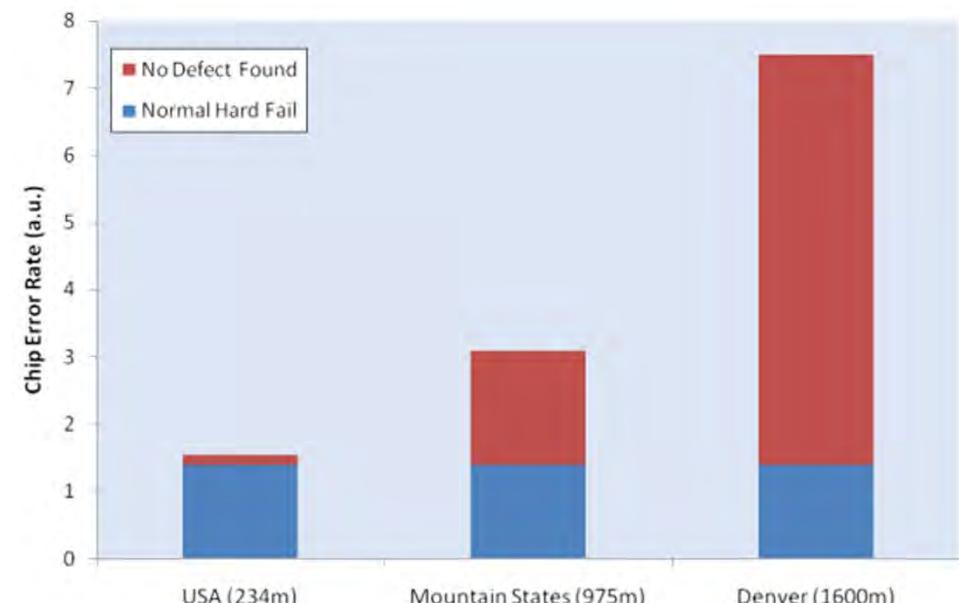


Thorium 90



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Single Event Effects - IBM Mainframe Repair Records 1981-1984



Reproduced from J.F.Ziegler et al IBM. J. Res. Develop. 40, 1996, p3

Source: National Elevation
Dataset: USGS



Victor F Hess
1883-1964

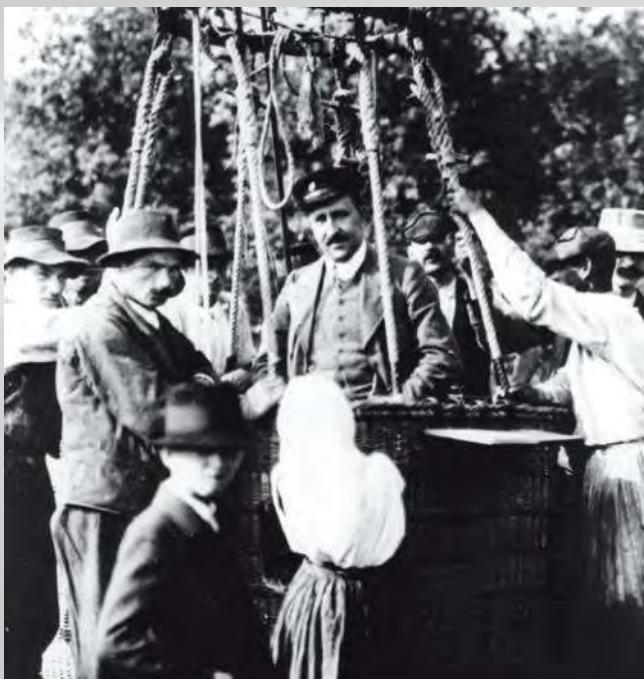


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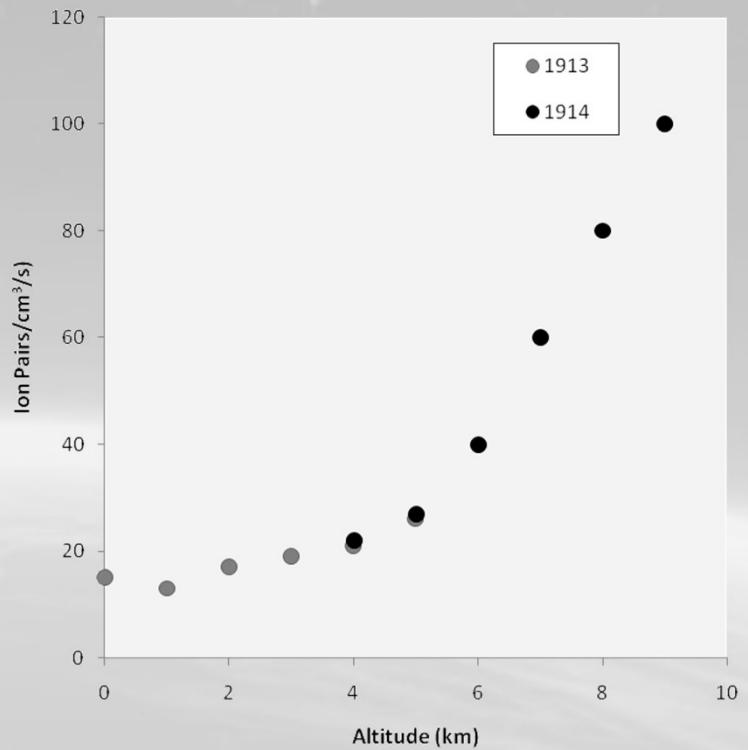
"I concluded that this ionization might be attributed to the penetration of the earth's atmosphere from outer space by hitherto unknown radiation of exceptionally high penetrating capacity"

Victor F Hess

Nobel Prize Speech 1936



Nobel Lectures, Physics 1922-1941, Elsevier Publishing Company, Amsterdam, 1965



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“As I was able to observe no reduction in ionization during the eclipse I decided that, essentially, the sun could not be the source of cosmic rays, at least as far as un-deflected rays were concerned.”

Victor F Hess

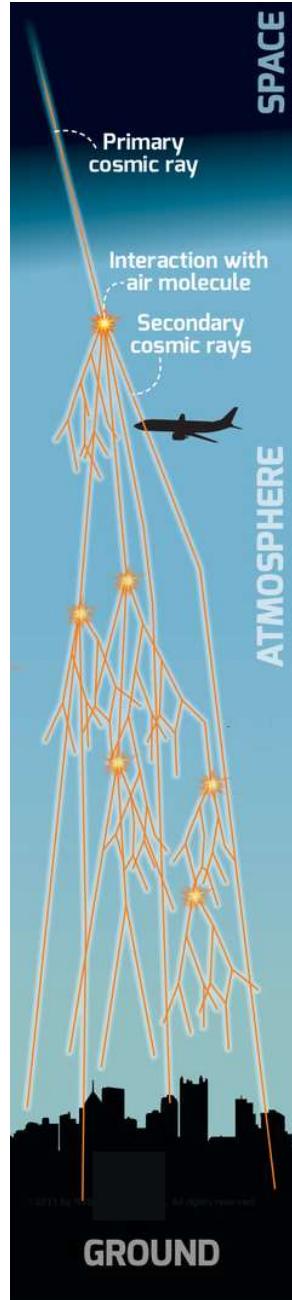
Nobel Prize Speech 1936



Nobel Lectures, Physics 1922-1941, Elsevier Publishing Company, Amsterdam, 1965



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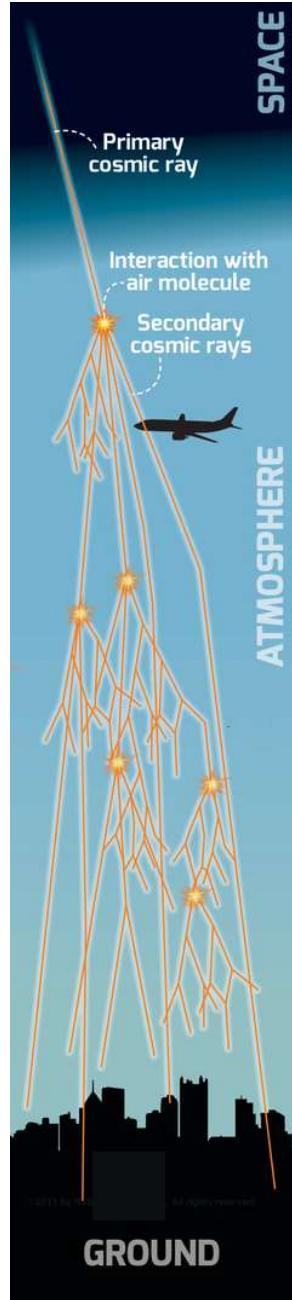
Cosmic Ray Neutrons at 'Ground Level'

Cosmic Rays generate neutron radiation at
ground level and **aircraft flight levels**

Cosmic Ray neutrons are a **major problem** in
electronic devices and systems



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Internet Infrastructure

CISCO ASR 9000 Router: Bug Report (Feb 2019)
“Cause is SEU (single event upset) soft error”



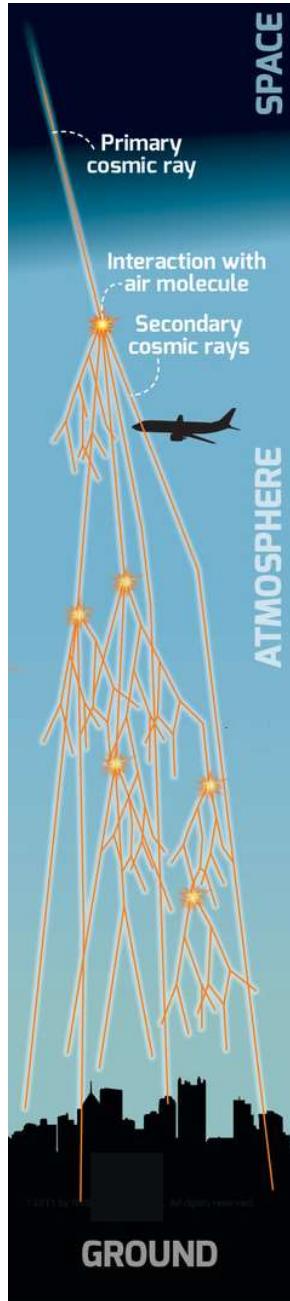
BUZZBLOG
Cisco says router bug could be result of
'cosmic radiation' ... Seriously?
UPDATED: See Cisco's further explanation below

Wired (by) Can the Internet Survive A
Cosmic Ray?

By Matt Stensland on March 11, 2019 at 10:30 AM ET
In a post on its blog, the company has detailed how the bug was triggered by a single event upset (SEU) in one of the router's memory chips. The bug caused the device to reboot, which in turn triggered a software bug that caused the device to drop calls.



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Court Case: Bookout vs Toyota (2013)

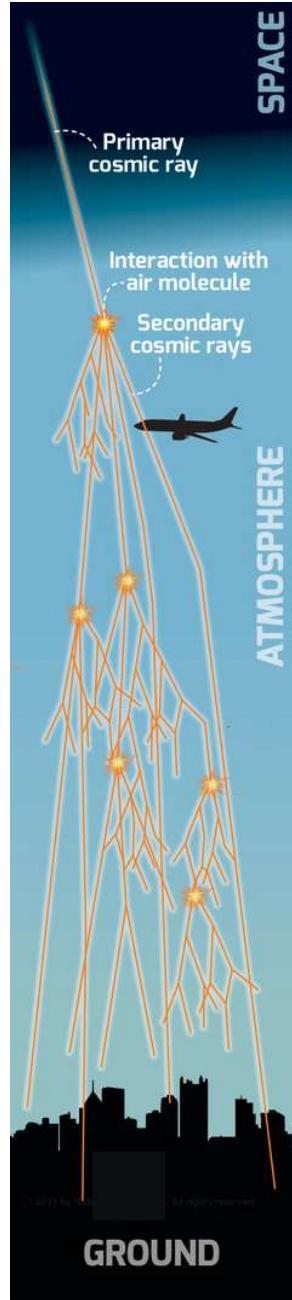
1 the time. There are cosmic rays coming from space. They
2 interact with particles in the atmosphere. I know how this
3 sounds, but it happens. And eventually they shoot
4 energized charged particles down into chips and they cause
5 a gate to flip.

Philip Koopman question by
Mr J Cole Portis for the Plaintiffs – 11 October 2013

Transcript of Bookout vs Toyota
October 2013 Oklahoma District Court



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Cosmic Ray Neutrons at 'Ground Level'

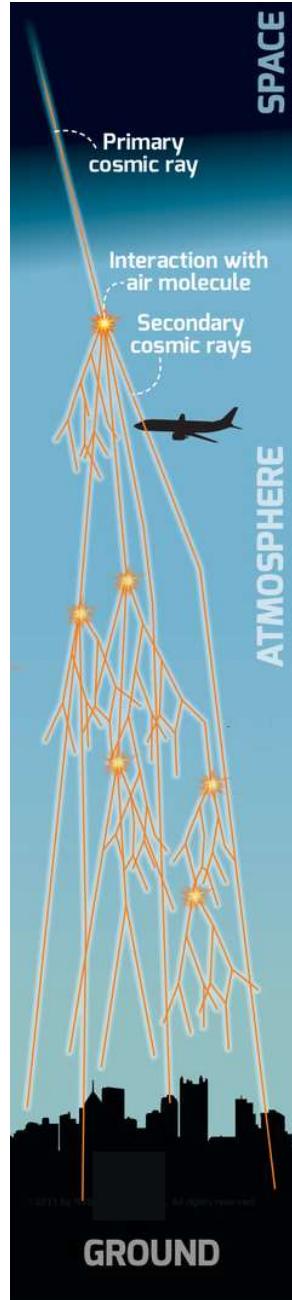
Cosmic Rays generate neutron radiation at
ground level and **aircraft flight levels**

Cosmic Ray neutrons are a **major problem** in
electronic devices and systems



~ once a minute





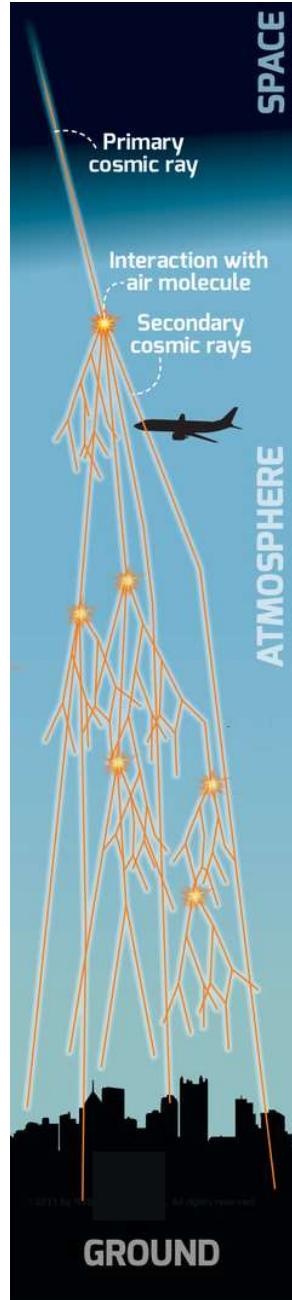
Cosmic Ray Neutrons at 'Ground Level'

~ 300 a minute
More neutrons at 35,000 feet

×300

~ once a minute





PERFORM Computer

Withdrawn in 1991 for tests following errors in SRAMs

Boeing E-3 AWACS

More than one upset per flight in 280 64k SRAMs

Autopilot Design Altered

Faults correlated with Lat and Long – fault every 200 flight hours

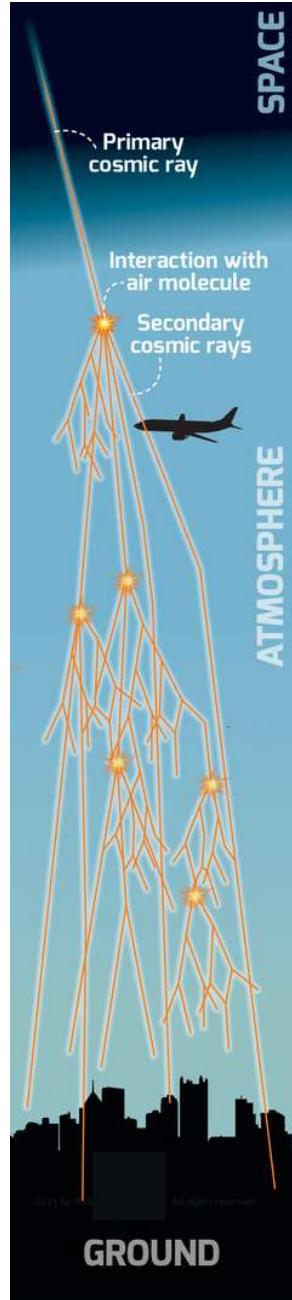
SAAB CUTE Experiment

Upset every 200 flight hours in 4Mbit SRAM in 1996

Sources: Single Upsets in
Avionics, Normal and Taber,
IEEE Trans. Nuc. Sci. Vol 40,
April 1993, p120



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Real World Event

Qantas QF72 Flight Incident 2008

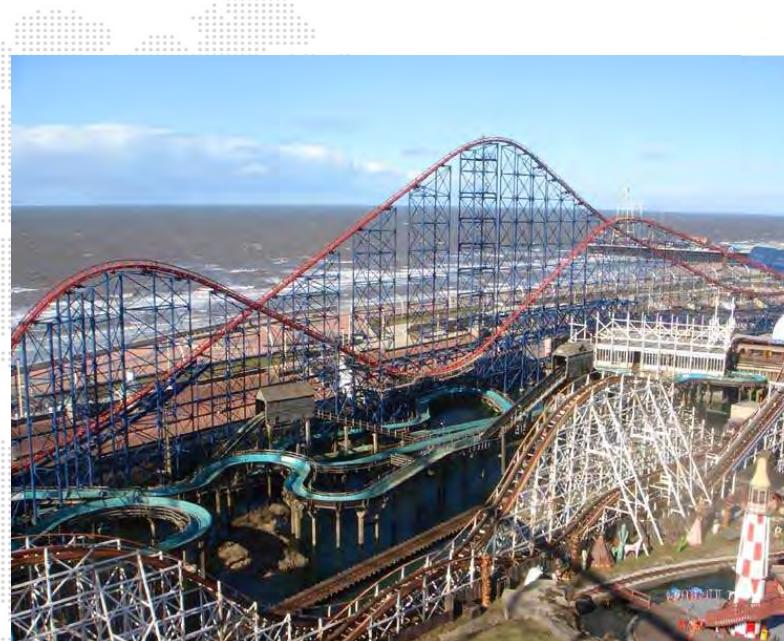
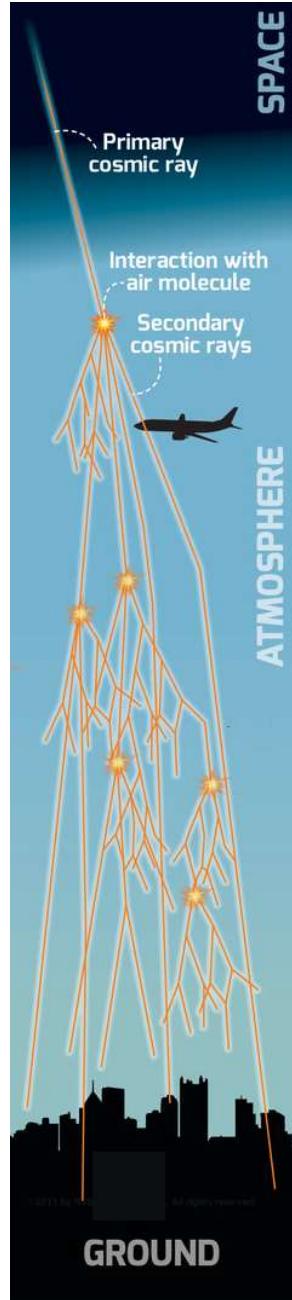
Cosmic ray neutrons implicated in major incident in October 2008



ATSB TRANSPORT SAFETY REPORT Aviation Occurrence Investigation AO-2008-070 Final



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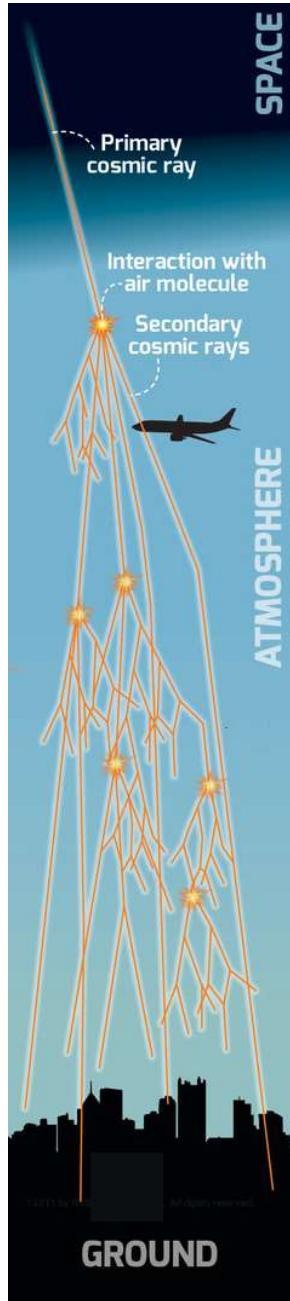
Blackpool Rollercoaster has a 213 ft drop



ATSB TRANSPORT SAFETY
REPORT Aviation Occurrence
Investigation AO-2008-070
Final



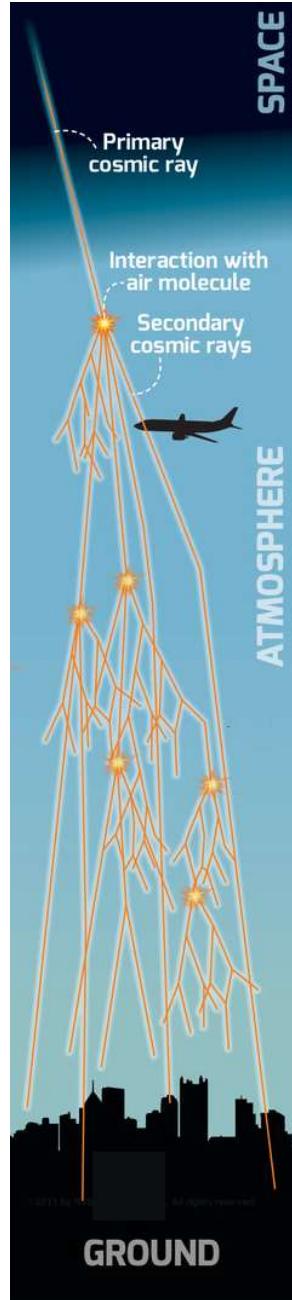
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ATSB TRANSPORT SAFETY
REPORT Aviation Occurrence
Investigation AO-2008-070
Final



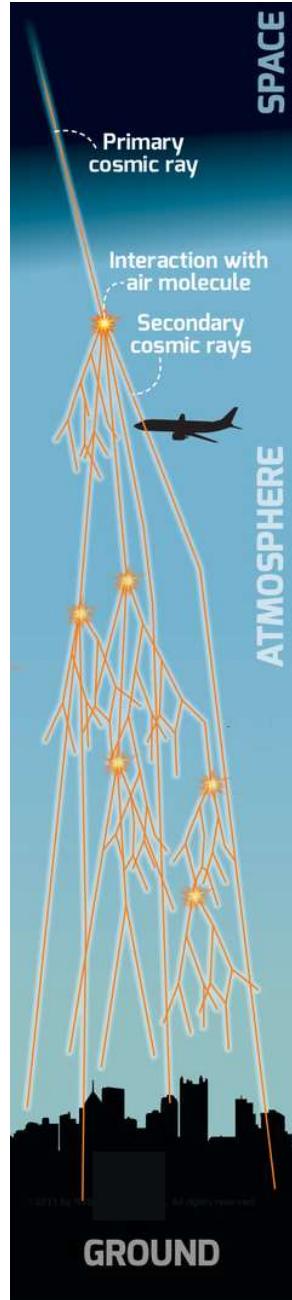
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ATSB TRANSPORT SAFETY
REPORT Aviation Occurrence
Investigation AO-2008-070
Final



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ATSB TRANSPORT SAFETY REPORT Aviation Occurrence Investigation AO-2008-070 Final



"There were significant logistical difficulties in obtaining access to appropriate test facilities...."

ISIS Spallation Neutron Source



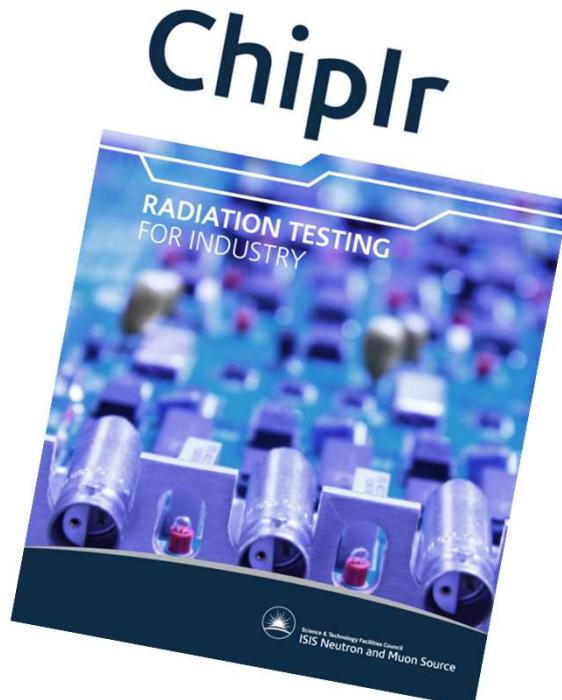
ISIS Spallation Neutron Source

Simple idea: extract a **high intensity, fast neutron beam** to mimic the atmospheric cosmic rays neutrons...



Beamline for the Accelerated Testing of Electronics

Simple idea: extract a **high intensity, fast neutron beam** to mimic the atmospheric cosmic rays neutrons...



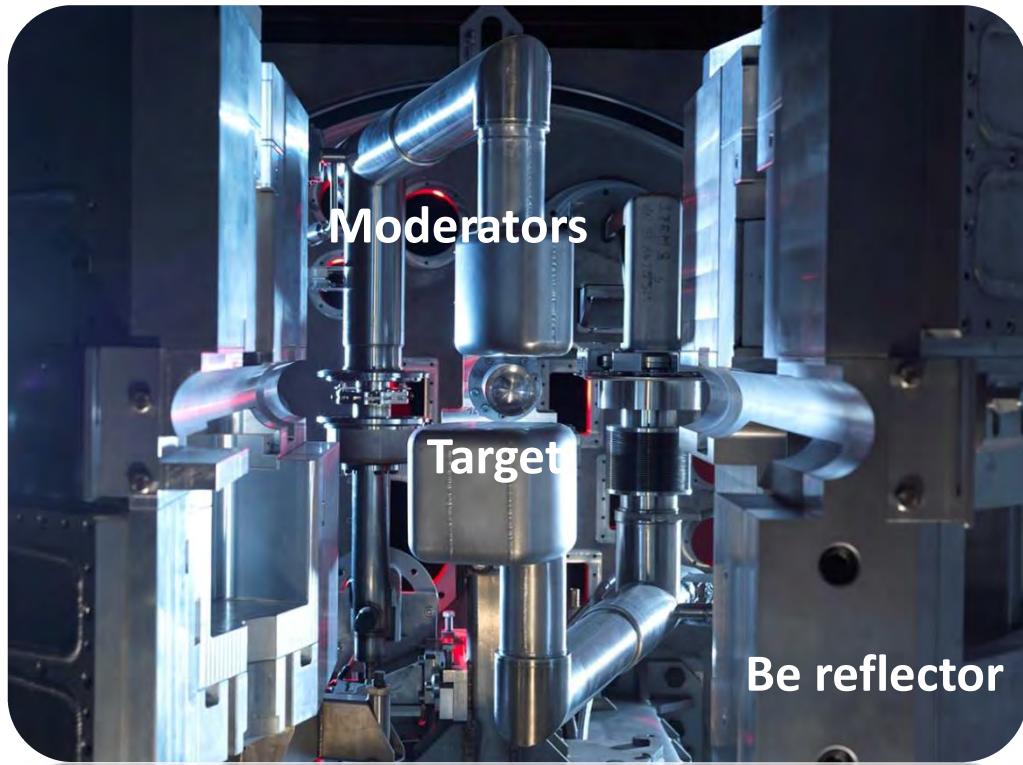
High flux: $>10^6 \text{ n/cm}^2/\text{s}$ ($>10\text{MeV}$)
Small - Large Area: $1\text{cm}^2 - 1\text{m}^2$



Science & Technology Facilities Council
ISIS

Beamline for the Accelerated Testing of Electronics

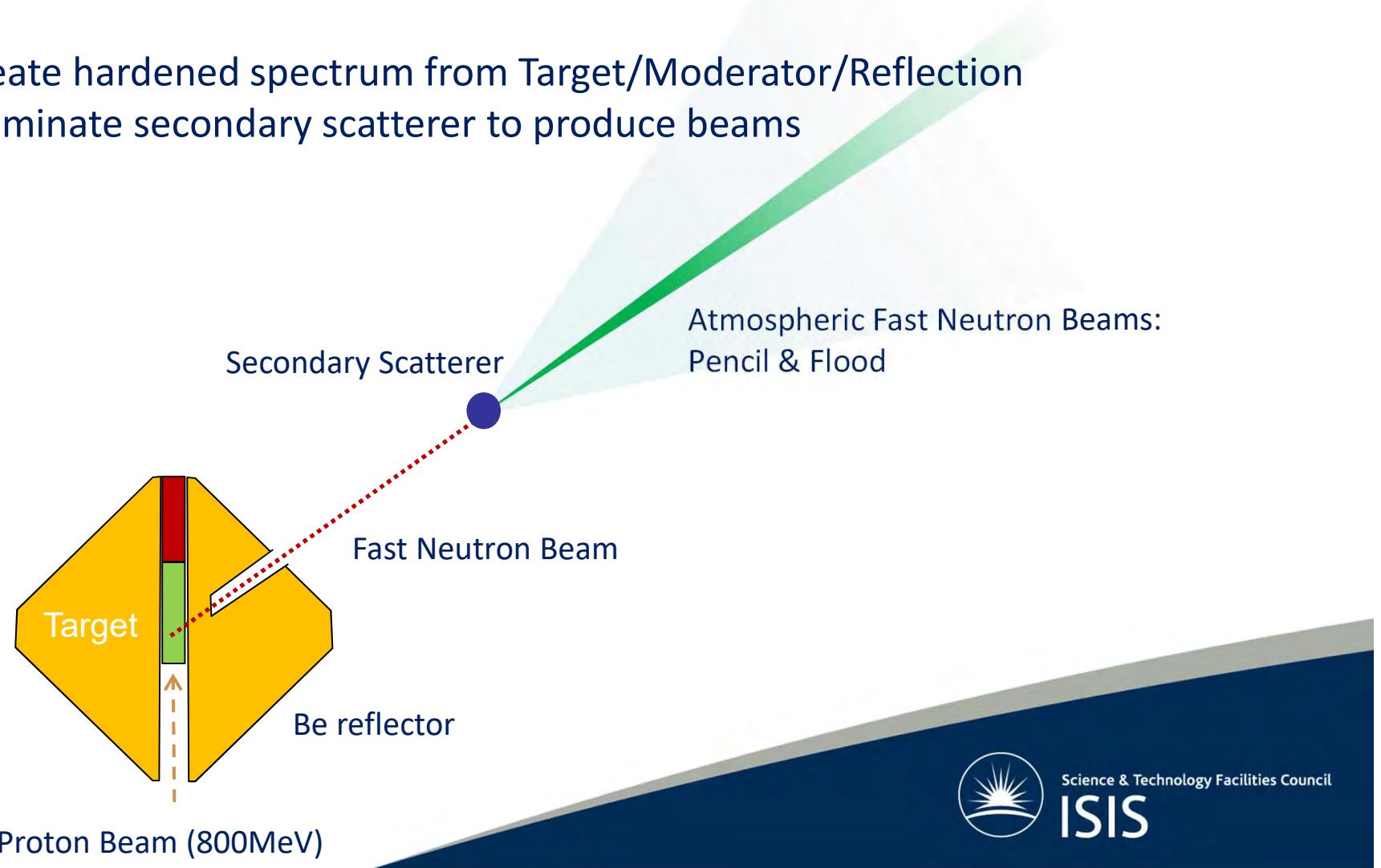
Problem: target complex optimised for thermal neutron beamlines;
no 'good' direct view of target



Beamline for the Accelerated Testing of Electronics

Solution: Use fast neutron flux from ISIS source in two stage process:-

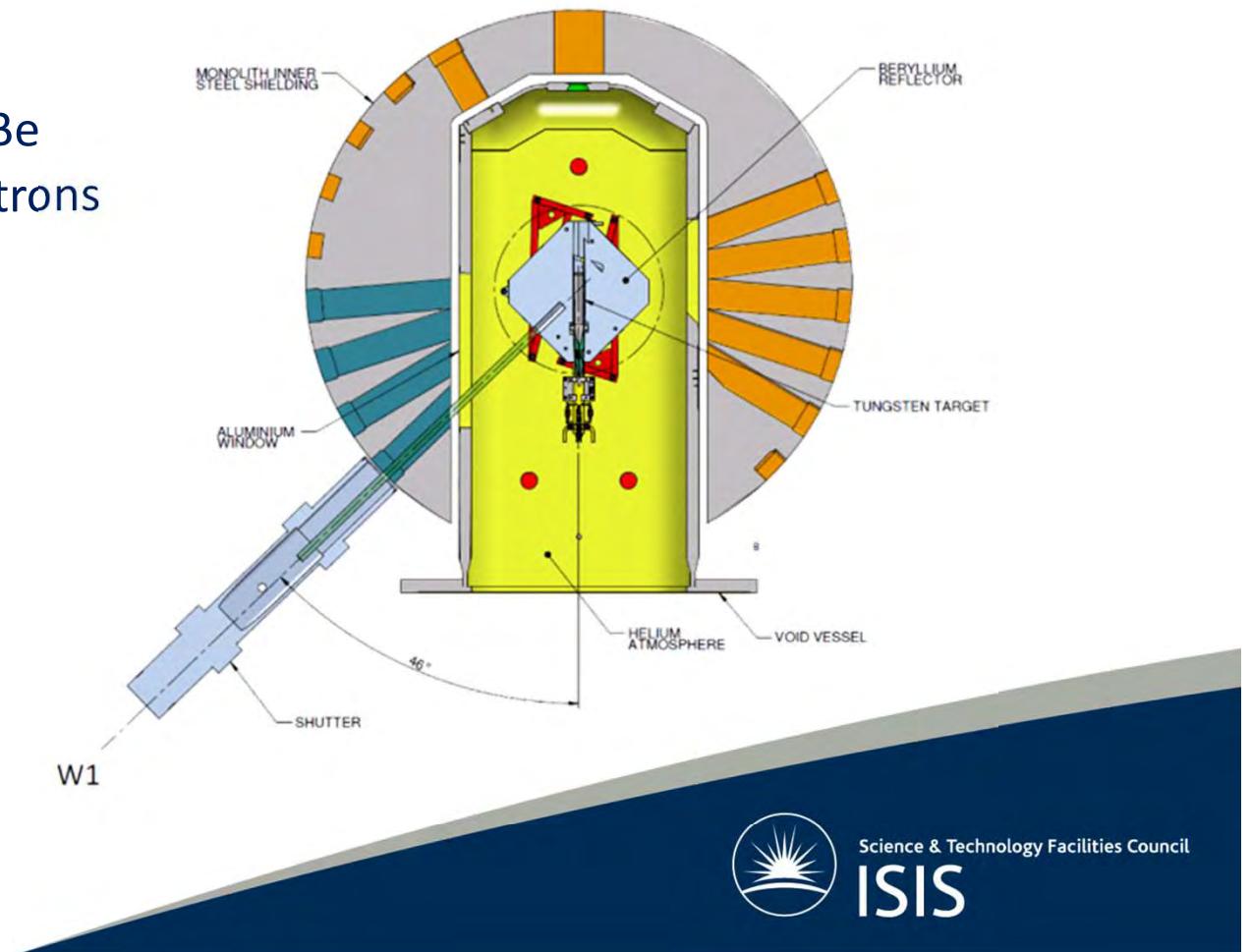
- 1 – Create hardened spectrum from Target/Moderator/Reflection
- 2 – Illuminate secondary scatterer to produce beams



Beamline for the Accelerated Testing of Electronics

Reality: Detailed design using Monte-Carlo to optimise spectrum to match the atmospheric neutron spectrum and maximise flux

Stage 1: Channel cut in Be reflector to extra fast neutrons

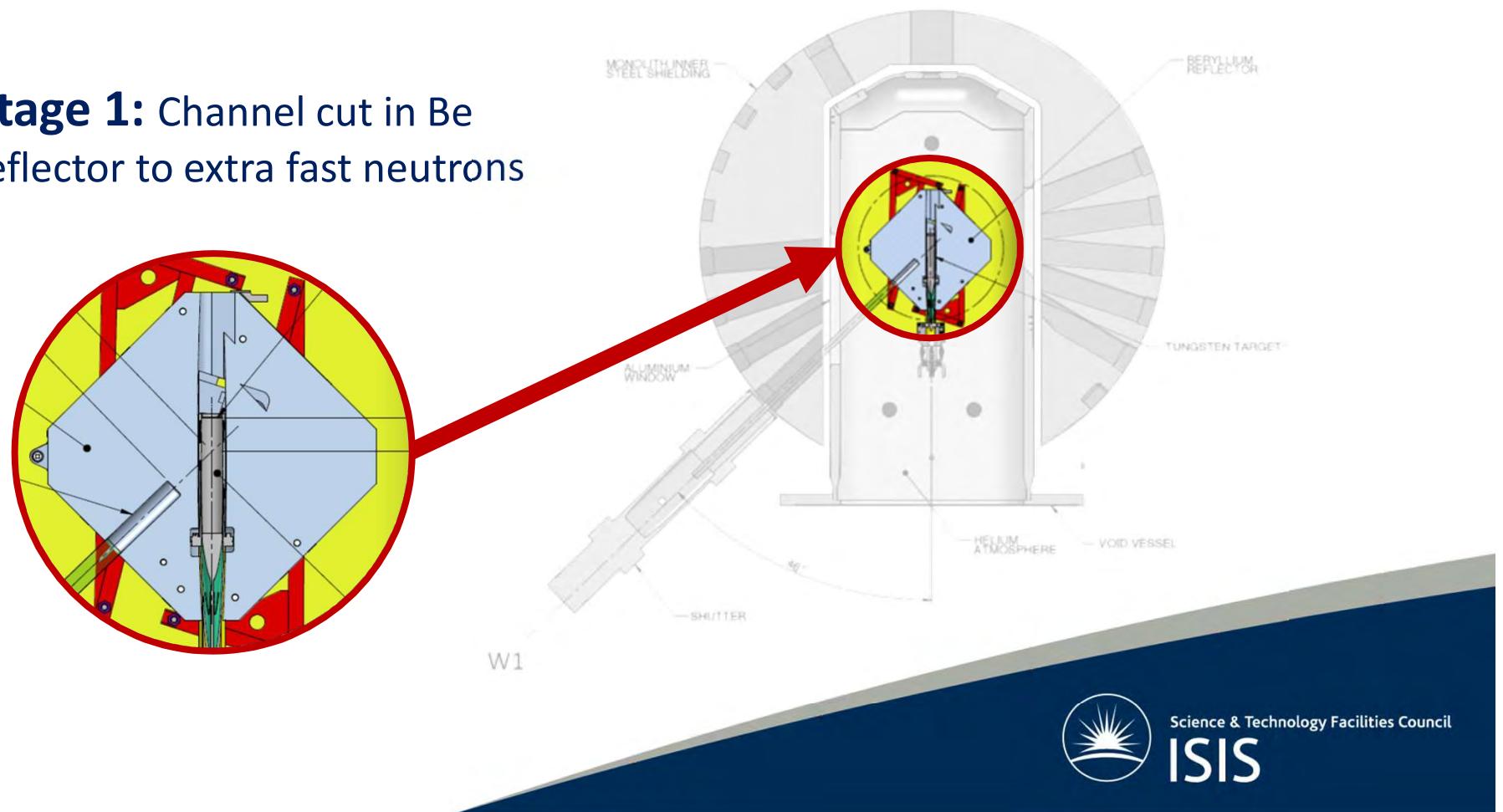


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ISIS

Beamline for the Accelerated Testing of Electronics

Reality: Detailed design using Monte-Carlo to optimise spectrum to match the atmospheric neutron spectrum and maximise flux

Stage 1: Channel cut in Be reflector to extra fast neutrons

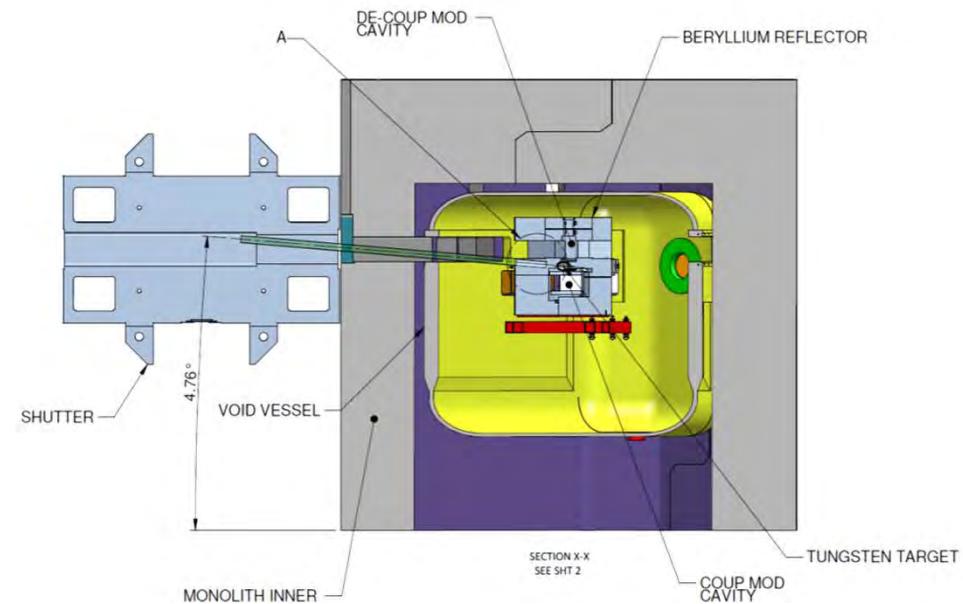
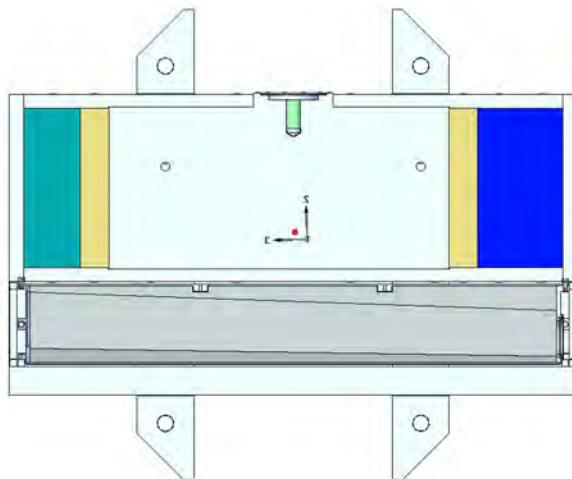


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Beamline for the Accelerated Testing of Electronics

Reality: Detailed design using Monte-Carlo to optimise spectrum to match the atmospheric neutron spectrum and maximise flux

Stage 2: Shutter inset acts as secondary scatterer illuminated by channel in reflector

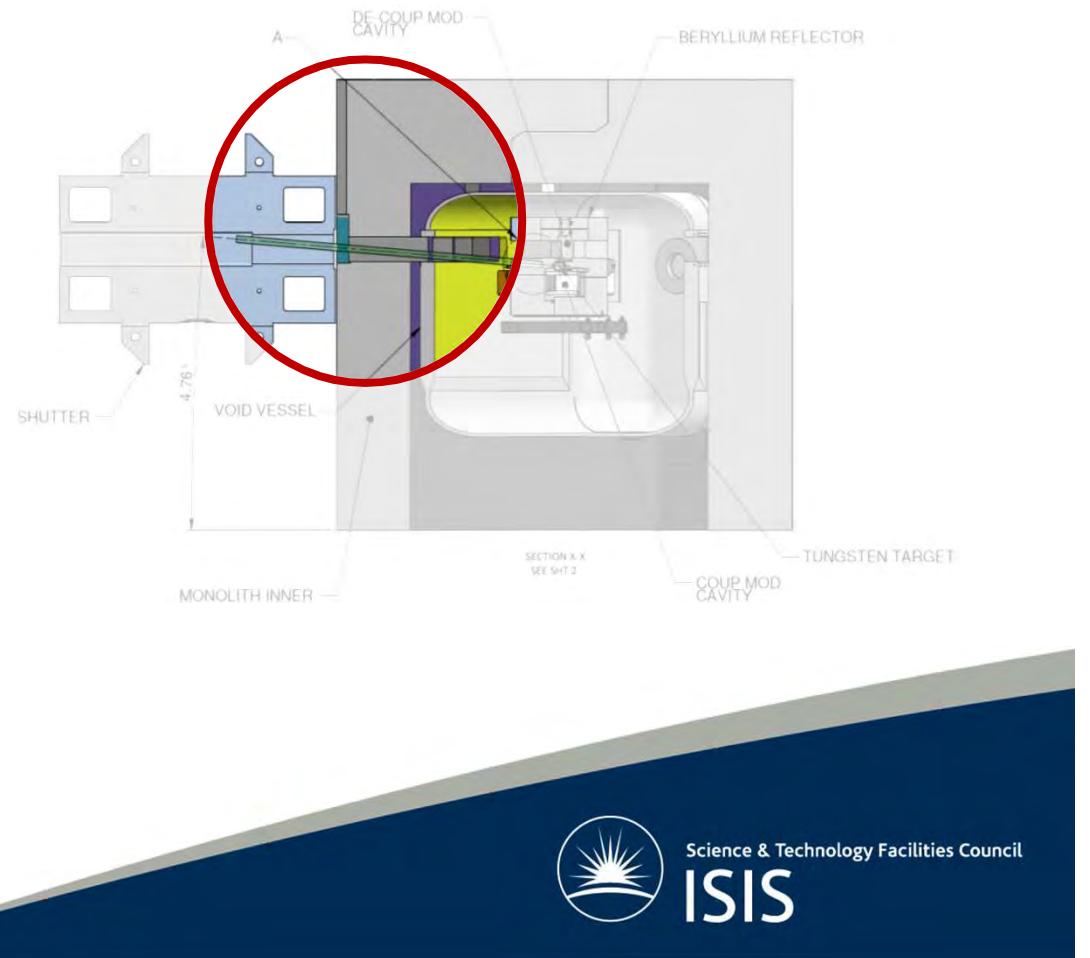
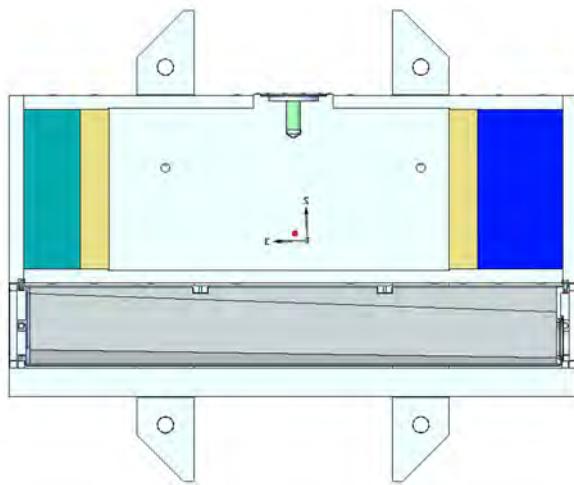


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Beamline for the Accelerated Testing of Electronics

Reality: Detailed design using Monte-Carlo to optimise spectrum to match the atmospheric neutron spectrum and maximise flux

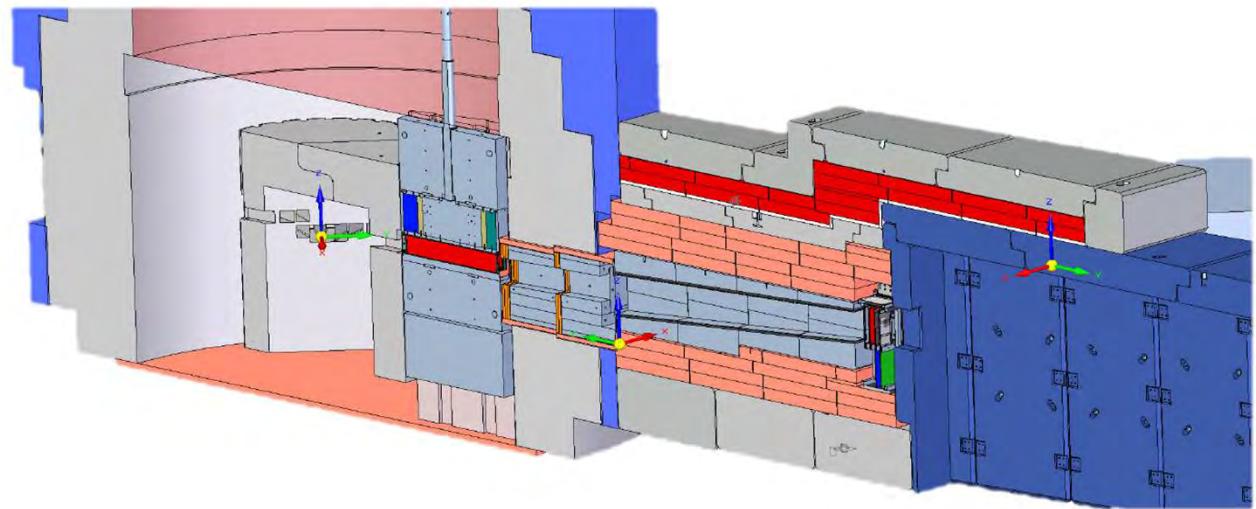
Stage 2: Shutter inset acts as secondary scatterer illuminated by channel in reflector



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Beamline for the Accelerated Testing of Electronics

Reality: Detailed design using Monte-Carlo to optimise spectrum to match the atmospheric neutron spectrum and maximise flux

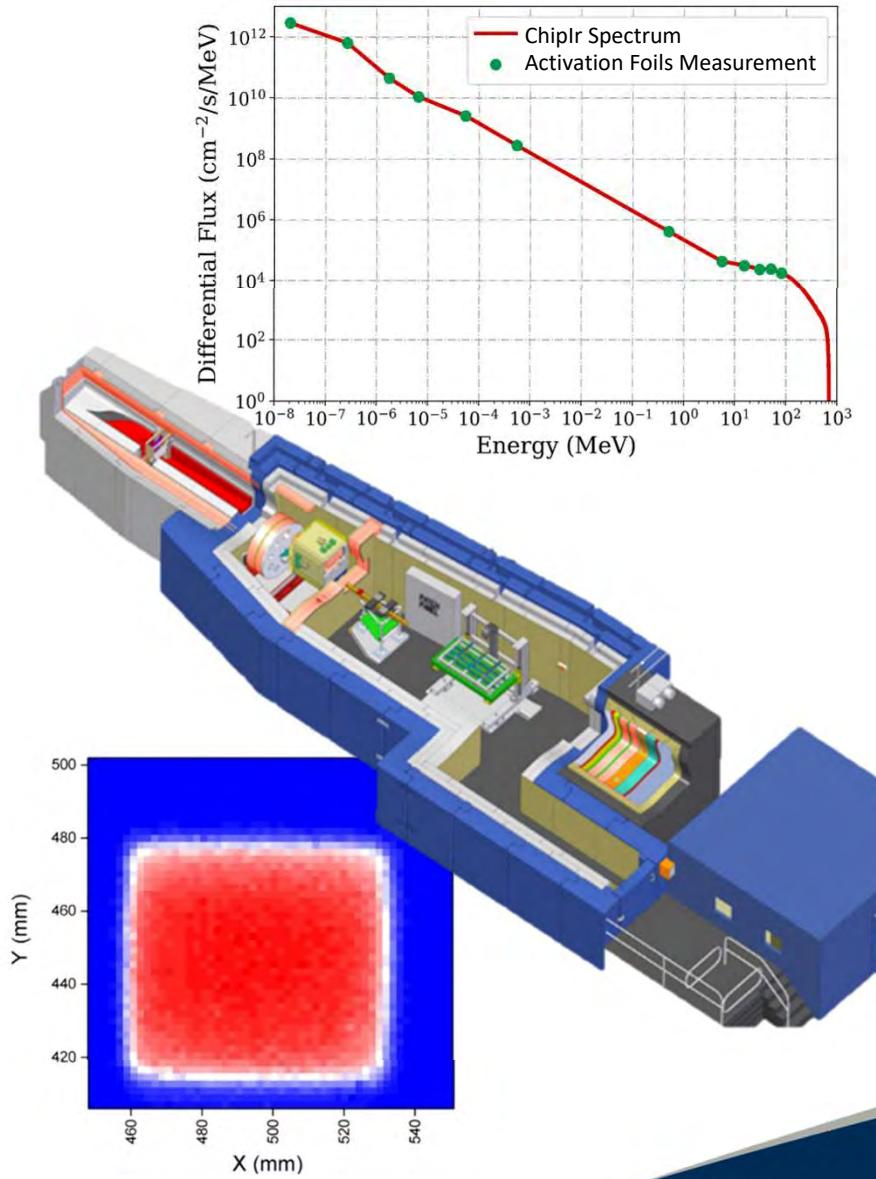


Stage 2+: Transport fast neutron flux to 'blockhouse'



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Beamline for the Accelerated Testing of Electronics

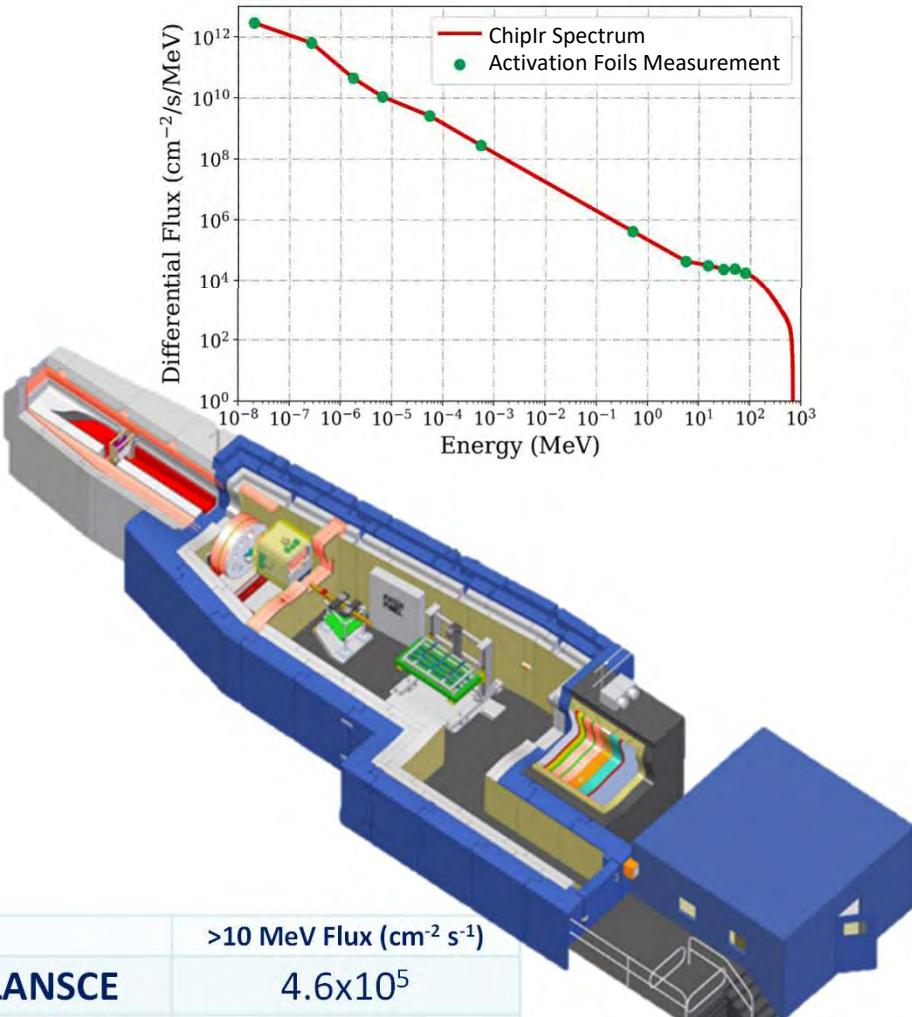


Currently Commissioning:
Flux, Spectrum & Beam Profiles



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Beamline for the Accelerated Testing of Electronics

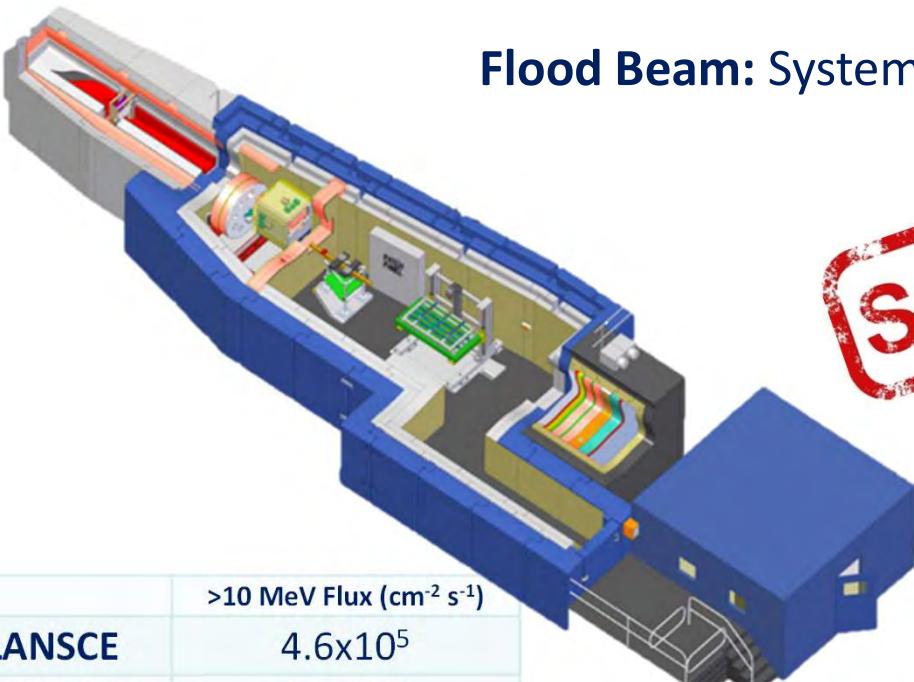


Currently Commissioning:
Flux, Spectrum & Beam Profiles

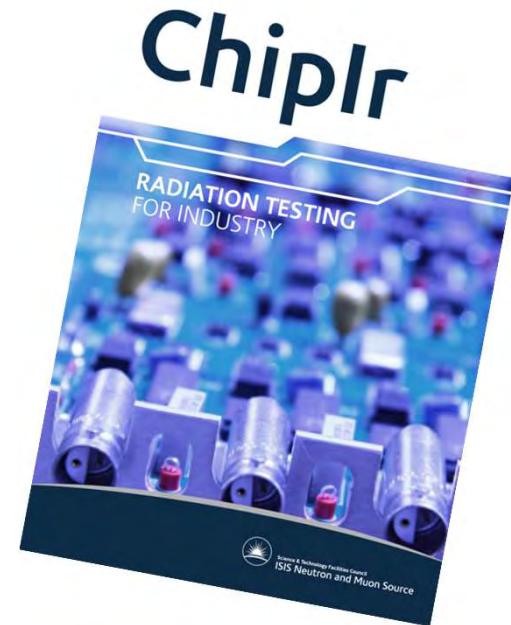
	>10 MeV Flux (cm ⁻² s ⁻¹)
LANSCE	4.6×10^5
TRIUMF	2.6×10^6
ChipIR	5.4×10^6

Beamline for the Accelerated Testing of Electronics

Unique and innovative design
attracting commercial users



Flood Beam: System testing

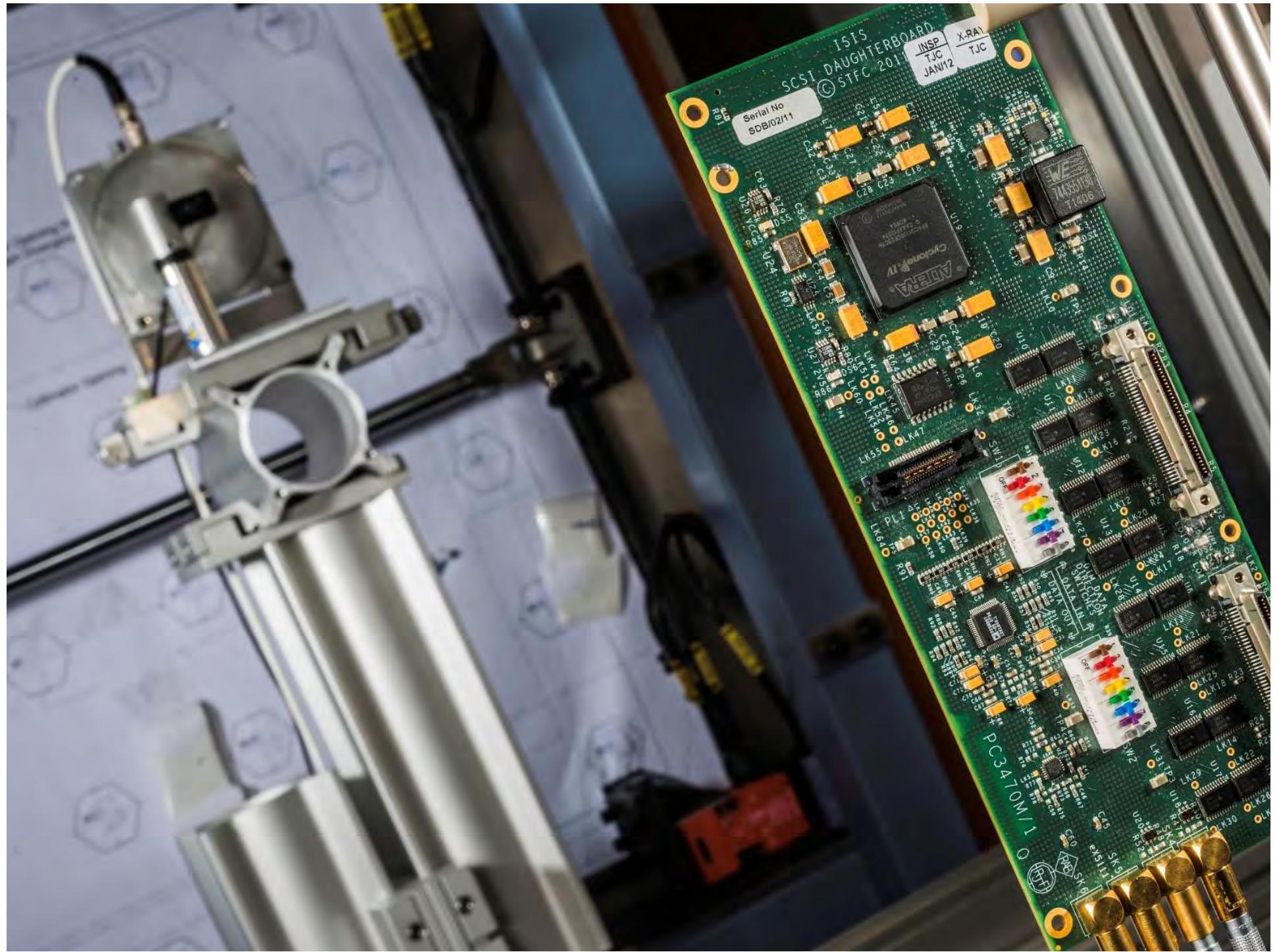


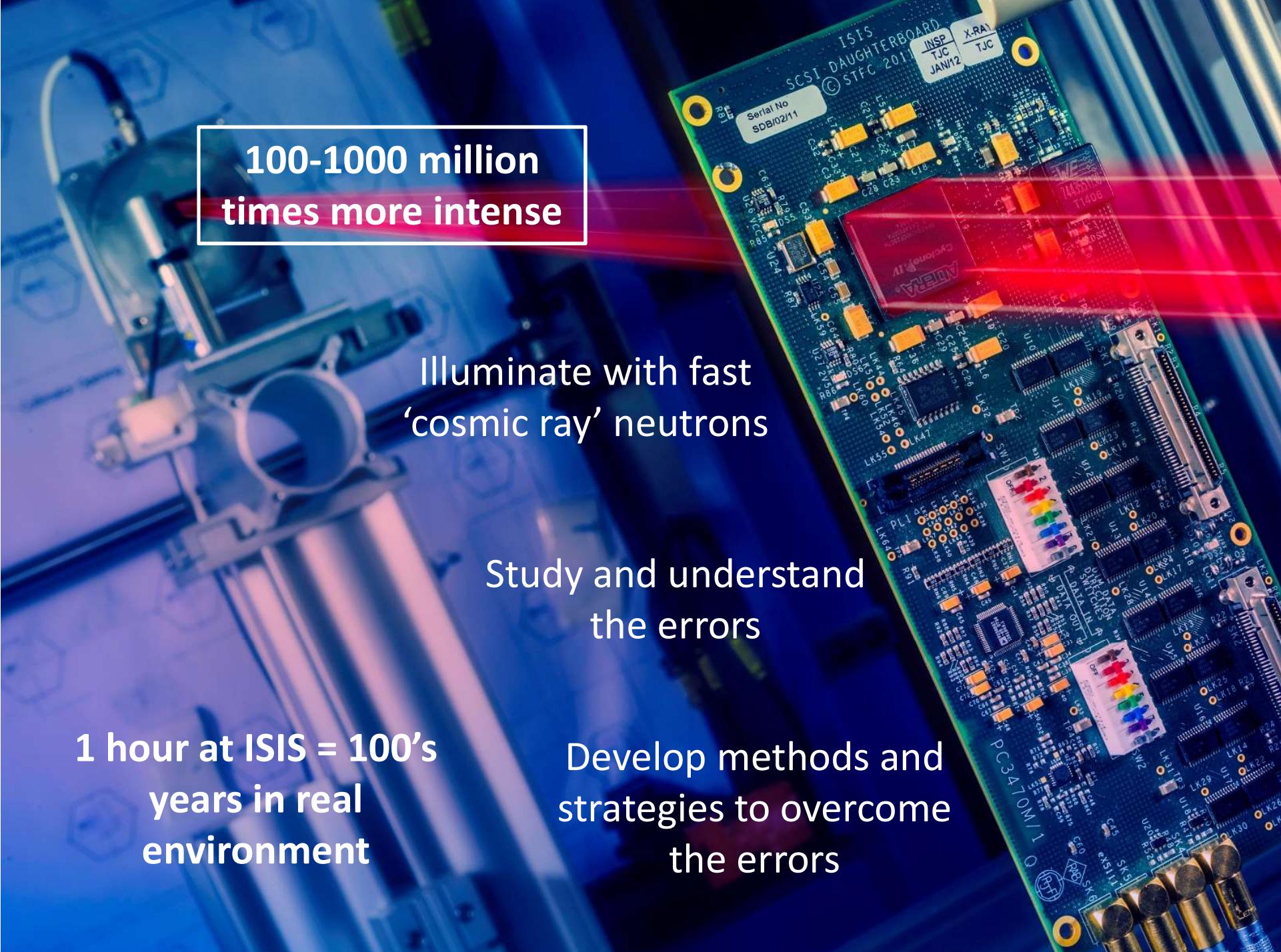
Collimated Beam: Device testing

	>10 MeV Flux ($\text{cm}^{-2} \text{s}^{-1}$)
LANSCE	4.6×10^5
TRIUMF	2.6×10^6
ChipIR	5.4×10^6



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**100-1000 million
times more intense**

Illuminate with fast
'cosmic ray' neutrons

Study and understand
the errors

**1 hour at ISIS = 100's
years in real
environment**

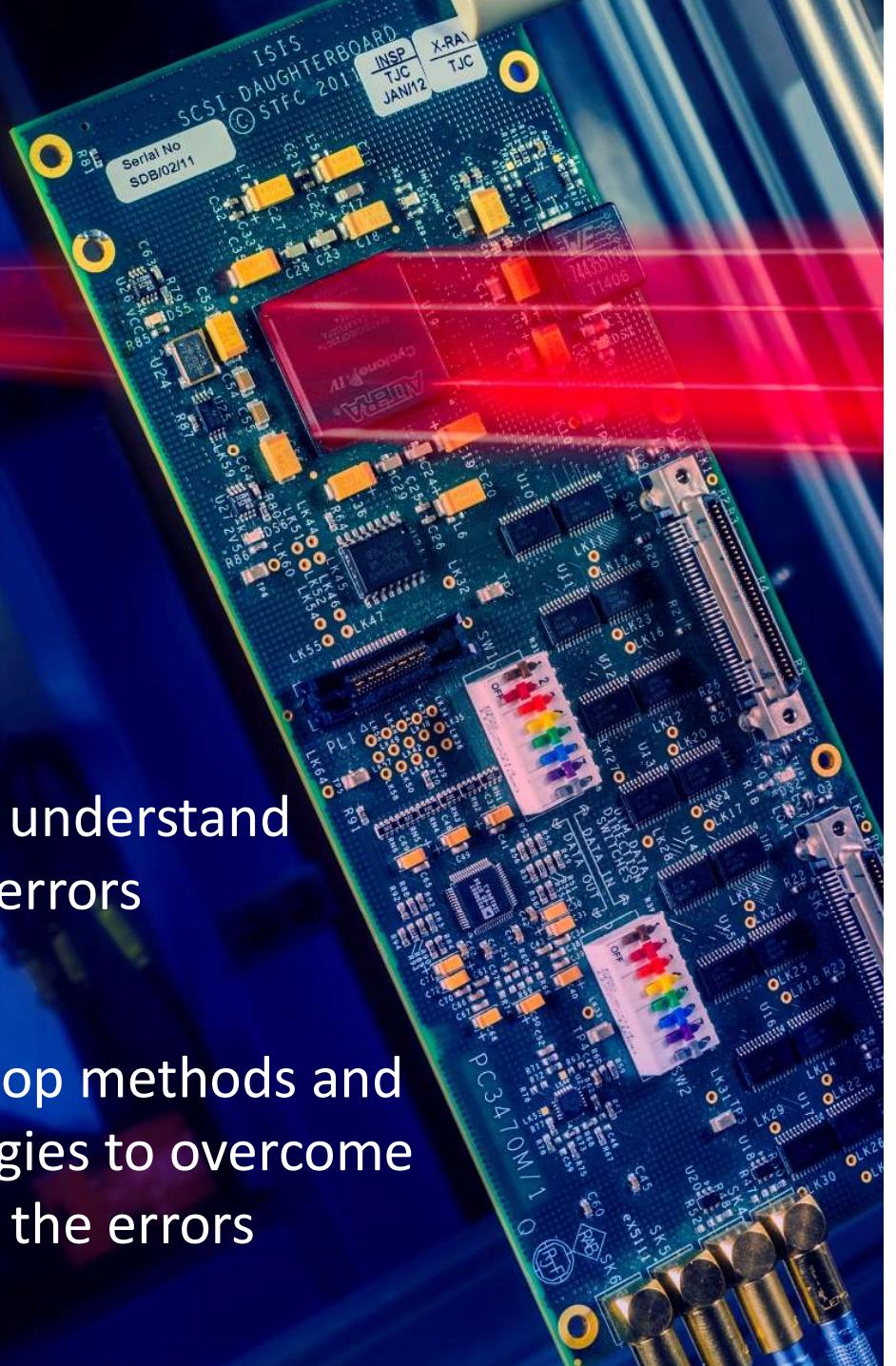
Develop methods and
strategies to overcome
the errors

Future Trends

Commercial Off The Shelf

Study and understand the errors

Develop methods and strategies to overcome the errors



**Commercial
Off
The
Shelf**



Designed for Performance



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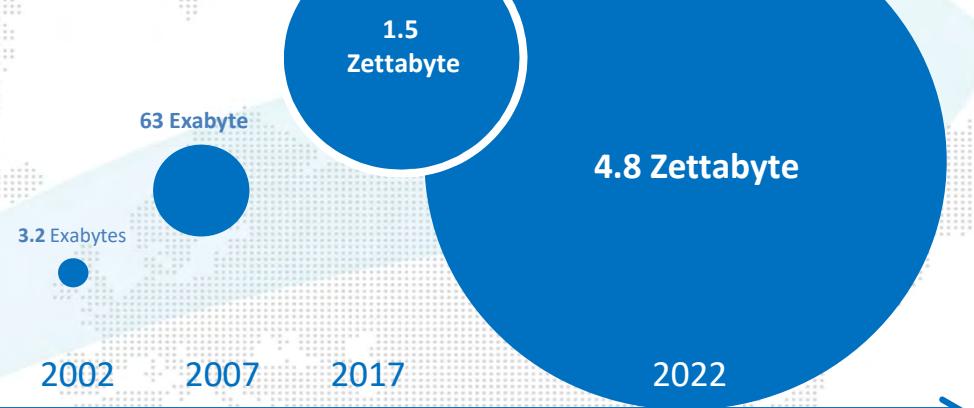
Commercial Off The Shelf



Designed for Performance

INTERNET Traffic

*Global Yearly
Internet Traffic*



1 Zettabyte =
1,000,000,000,000,000,000 bytes

"In 2017 the digital equivalent of every movie ever made will cross the global network every 3 minutes"

CISCO VNI Forecast

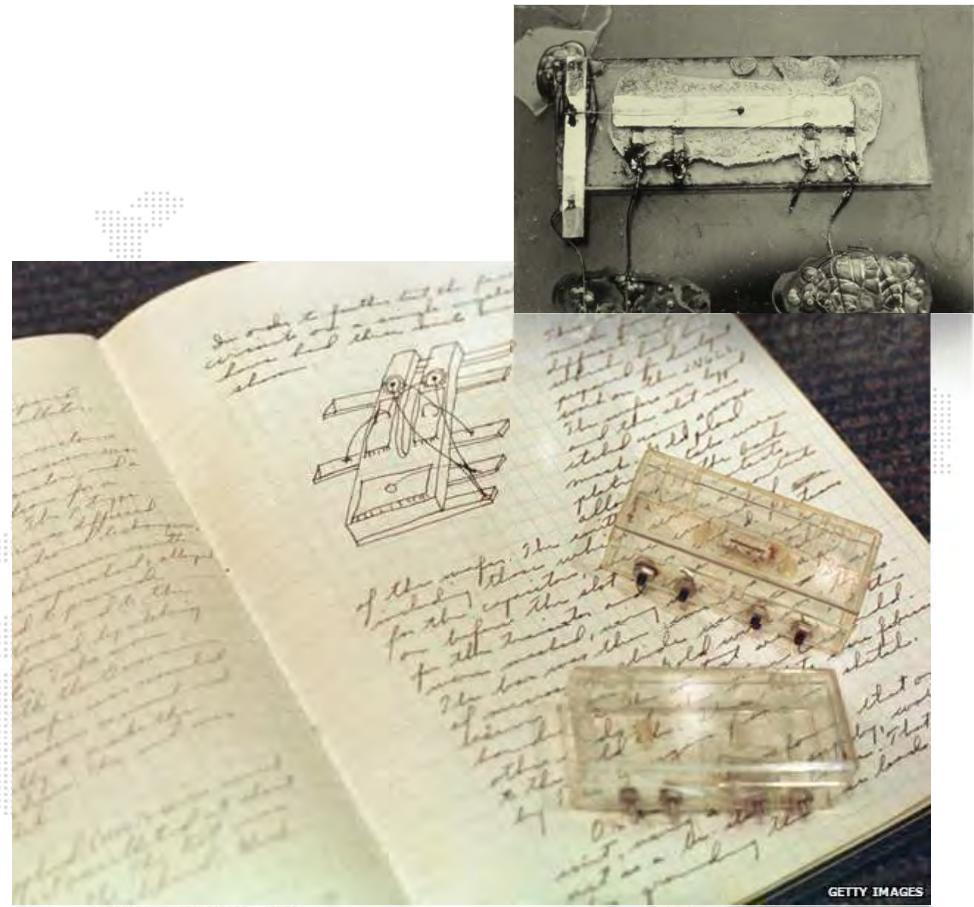


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Functionality



The first integrated circuit invented by
Jack Kirby at Texas Instruments on 12 September
1958



Scale

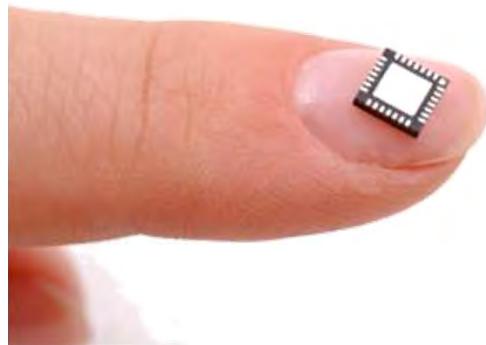


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Functionality



Scale



Martin Cooper
Invented mobile phone and made the first call in 1973

20.62
billion

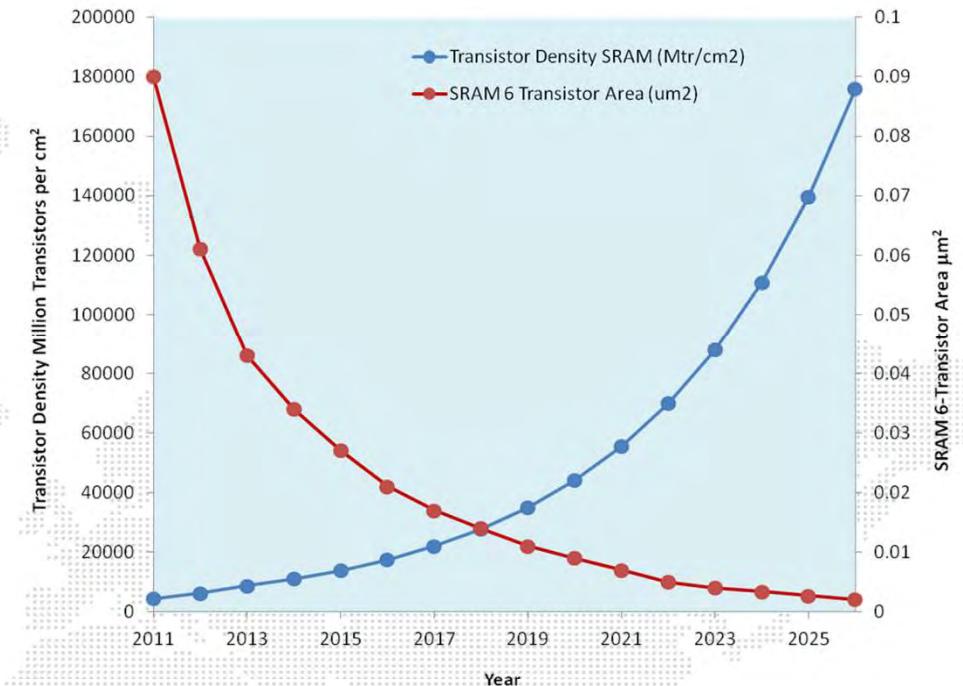
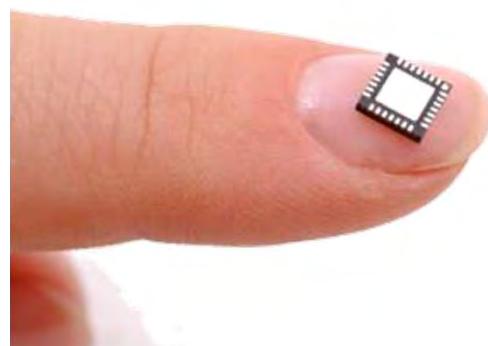


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Functionality



Scale

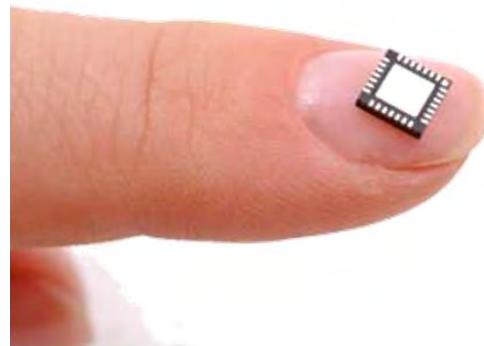


Reproduced from data in ITRS Roadmap 2011

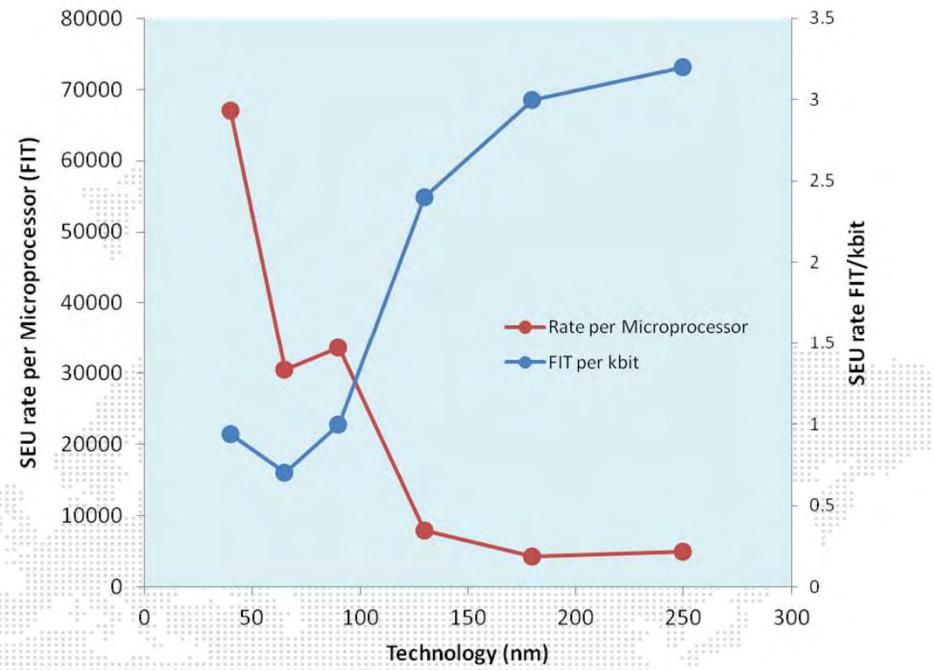


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Functionality



Scale



Date from IRPS11: The Impact of New Technology
on Soft Error Rates Anand Dixit and Alan Wood
Oracle Corporation Santa Clara, CA USA

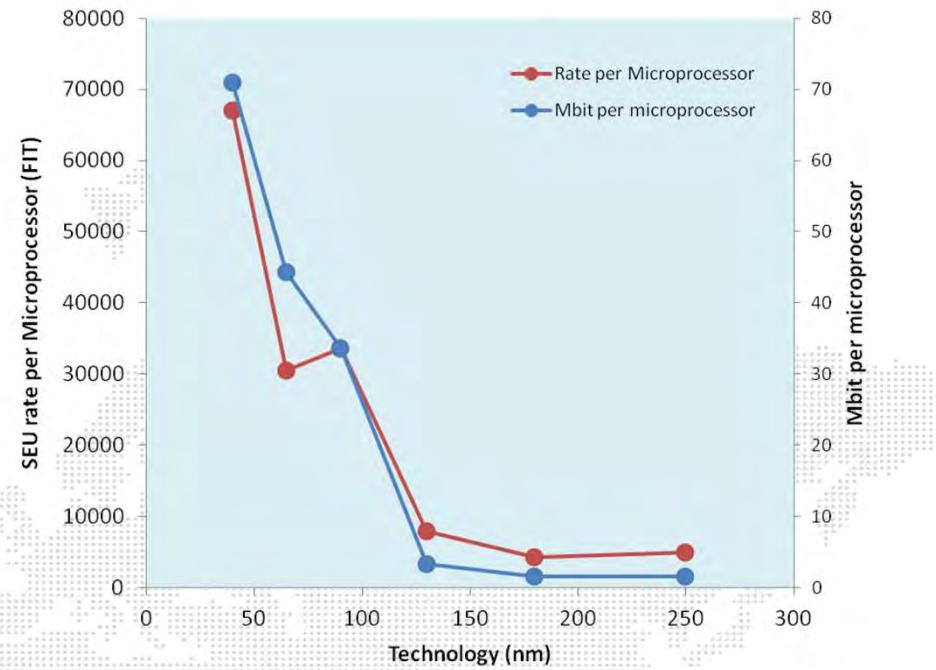
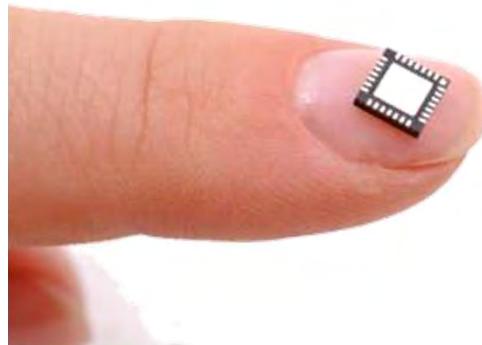


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Functionality



Scale



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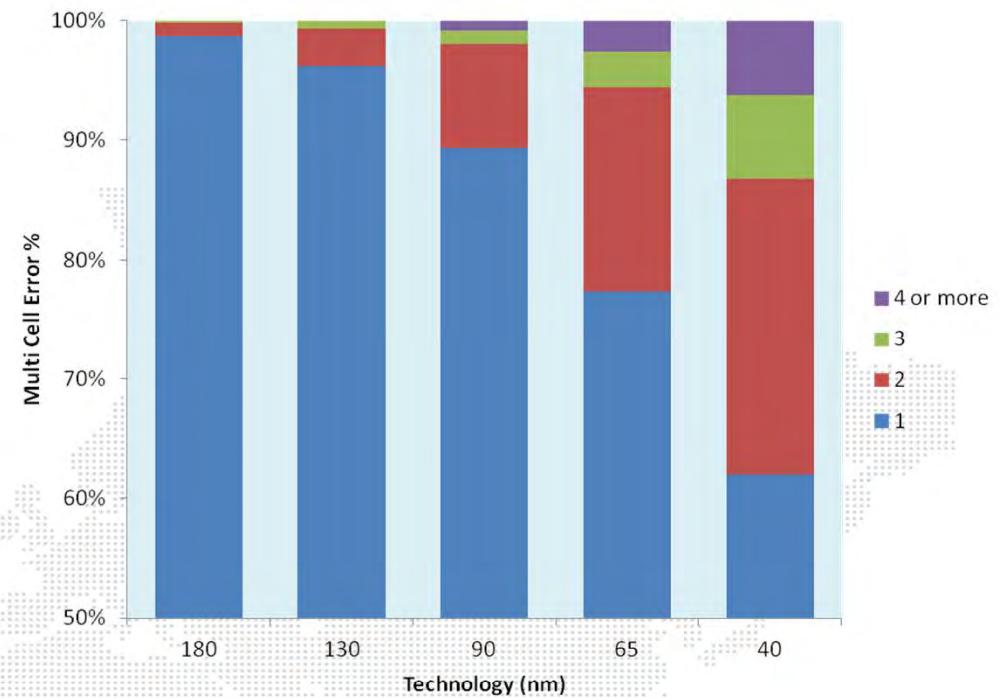
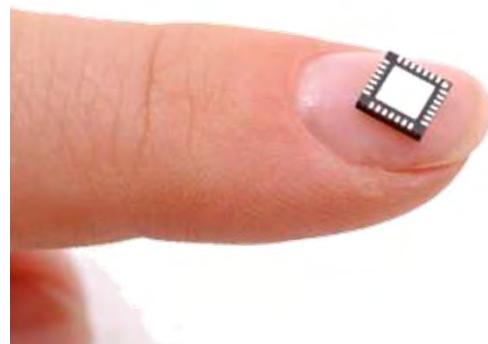


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Functionality



Scale

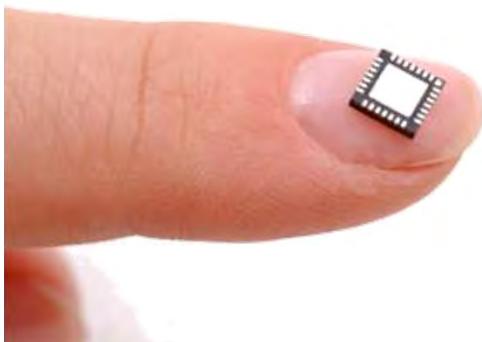


Date from IRPS11: The Impact of New Technology
on Soft Error Rates Anand Dixit and Alan Wood
Oracle Corporation Santa Clara, CA USA

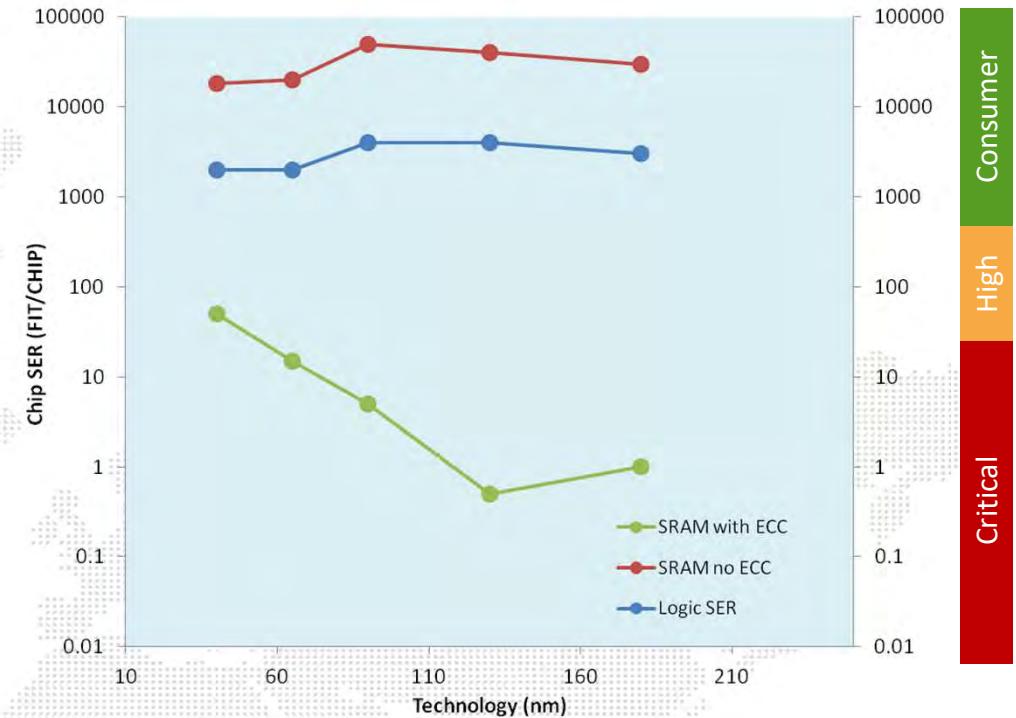


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Functionality



Scale



Data reproduced from R C Baumann, Neutron and Alpha Particle Effects in Electronics, RADECS 2012



ISIS

INTERNET

Traffic

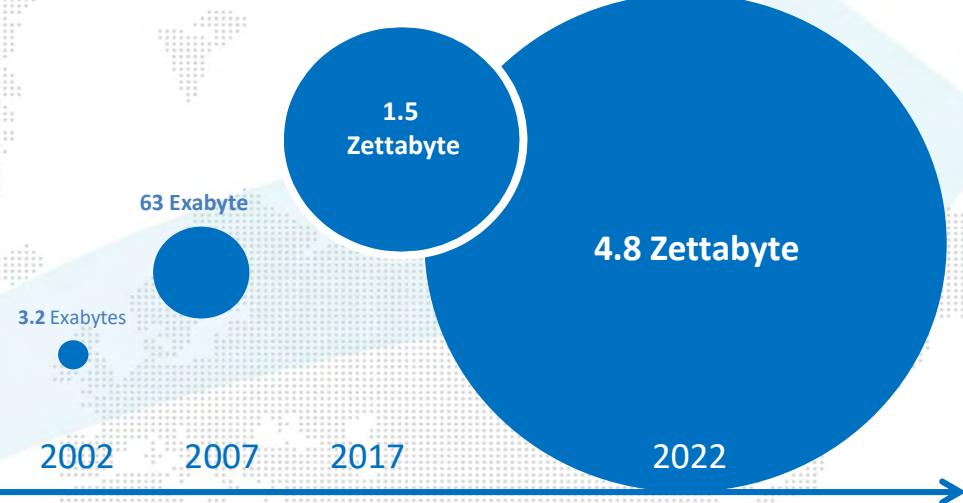
*Global Yearly
Internet Traffic*

Functionality



Scale

CISCO VNI Forecast



60%
Population using
internet

85Gb
Internet traffic per
month per user

3.6
Devices and
connections per
person



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Internet Infrastructure: Huge growth in internet in last three decades

Cosmic ray neutrons a significant problem in routers since 2000s

Ongoing neutron testing at **system level** required – **large beams**



The screenshot shows a blog post titled "Cisco says router bug could be result of 'cosmic radiation' ... Seriously?" by David Litzman. The post discusses how cosmic rays can cause errors in router memory, leading to bugs like the one found in the Cisco 3600 series. It includes a sidebar for "loopup" and a "Comments" section.

Cisco says router bug could be result of 'cosmic radiation' ... Seriously?

UPDATED: See Cisco's further explanation below

Comments

loopup

Who just joined?

Source: NetworkWorld; CISCO

Driverless Cars: Highly complex systems being deployed in cars



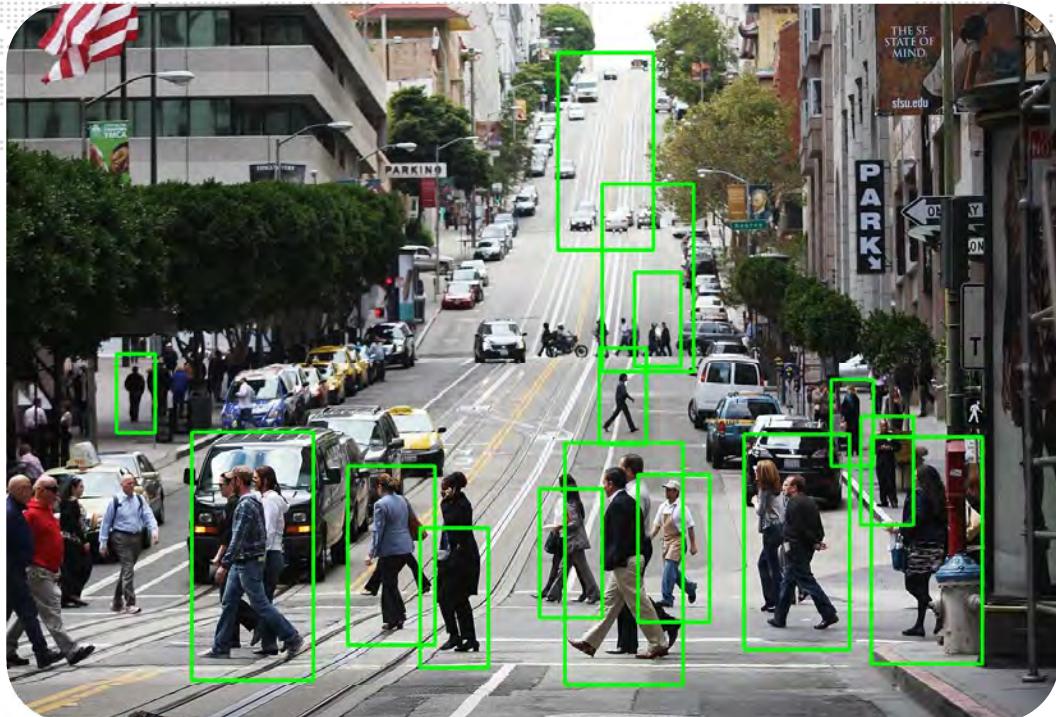
Underpinning technologies known to have susceptibility to neutrons



Driverless Cars: Highly complex systems being deployed in cars



Graphics Processor Units [GPU] – Key Technology



Detection and classification of **static** (signs, lanes, boundaries, etc.) and **dynamic** objects (pedestrians, cyclists, collision-free space, hazards, etc.)

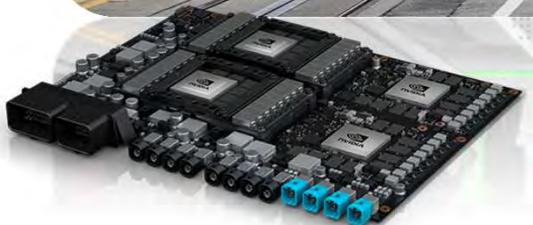


Image: Paolo Rech from
UFRGS University, Brazil

NVIDIA – Self Driving Safety Report

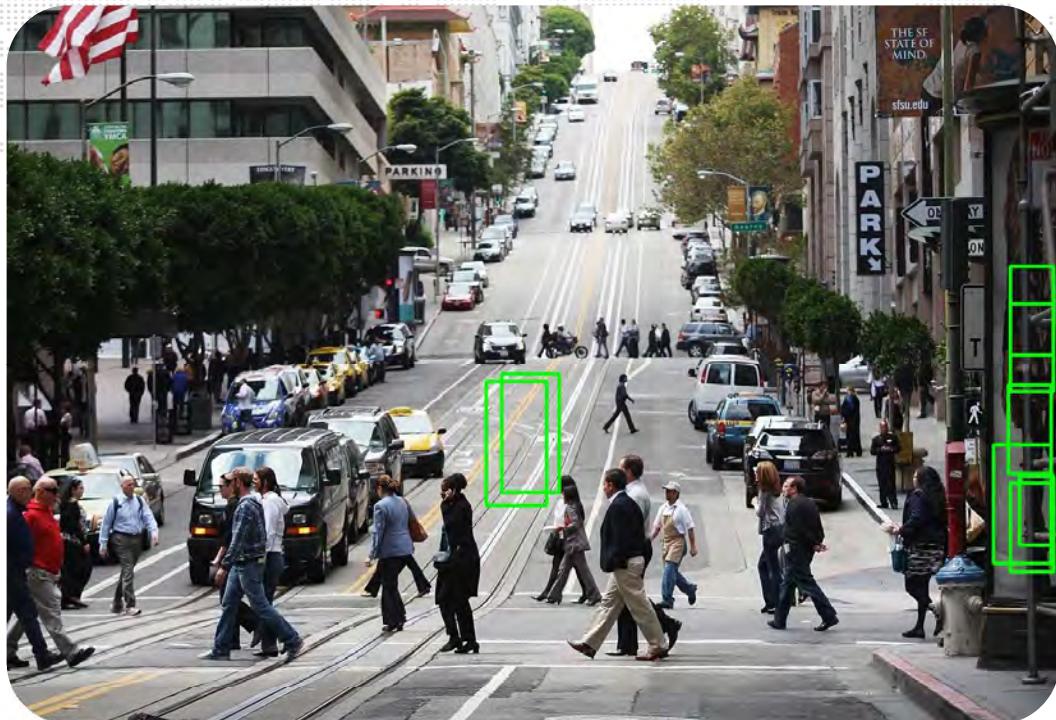


Science & Technology Facilities Council
ISIS

Driverless Cars: Highly complex systems being deployed in cars



Automotive Safety Integrity Level D - Possibility of Fatal Injury



Very stringent failure levels
being set 10 errors in 1
billion hours – 10 **FIT**
(much better than humans)

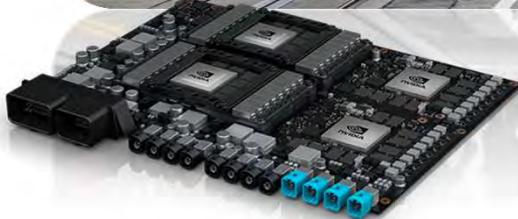


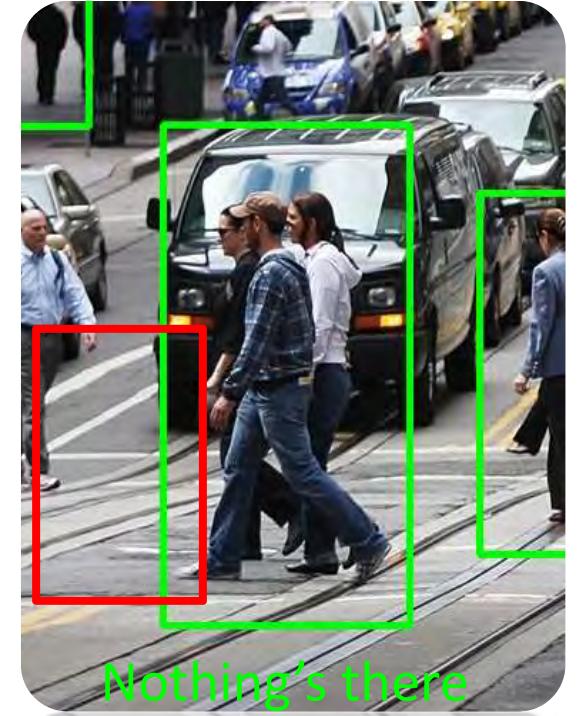
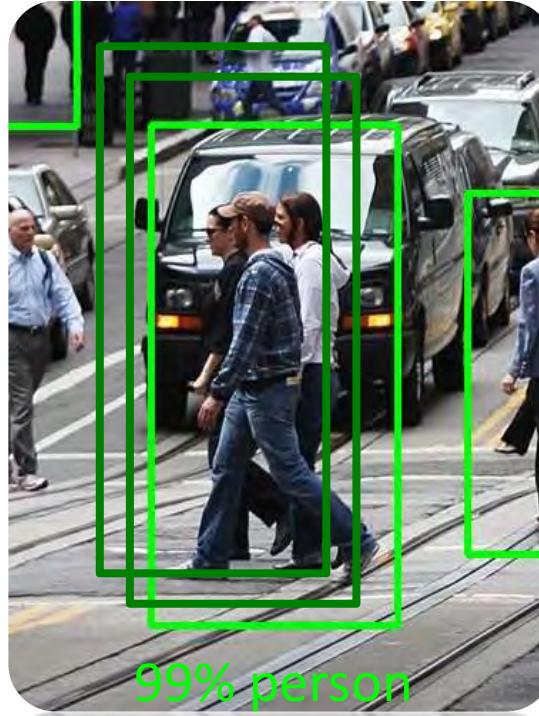
Image: Paolo Rech from
UFRGS University, Brazil

NVIDIA – Self Driving Safety Report



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Examples of observed errors



Driverless Cars: Highly complex systems being deployed in cars



Typical test: matrix multiplication $A \bullet B = M$

2048 x 2048 double precision arrays

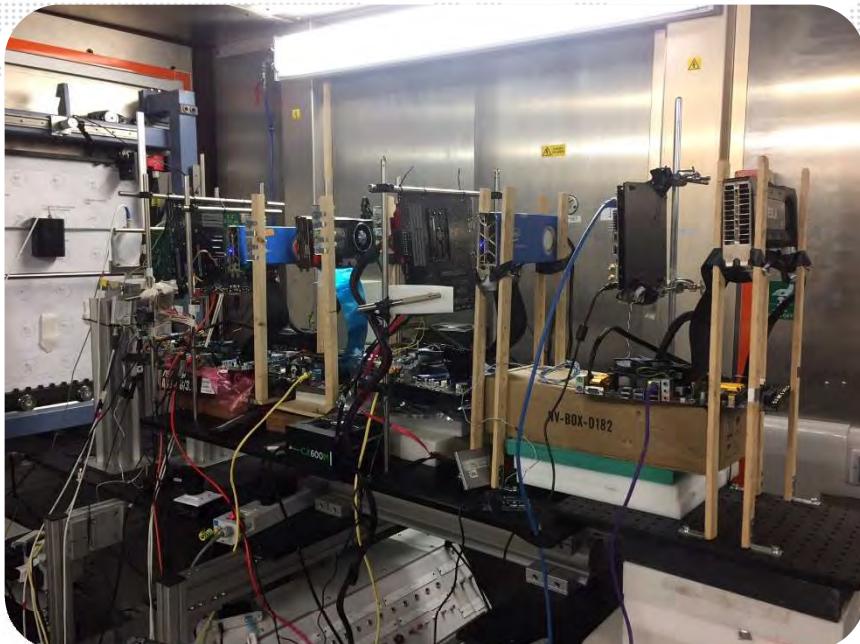
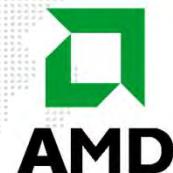


Image: Paolo Rech from
UFRGS University, Brazil

Paolo Rech



Driverless Cars: Highly complex systems being deployed in cars



$$\text{‘Cross Section’} \times \text{flux (@sea level)} = \text{Error Rate}$$

From accelerated testing on ChipIR

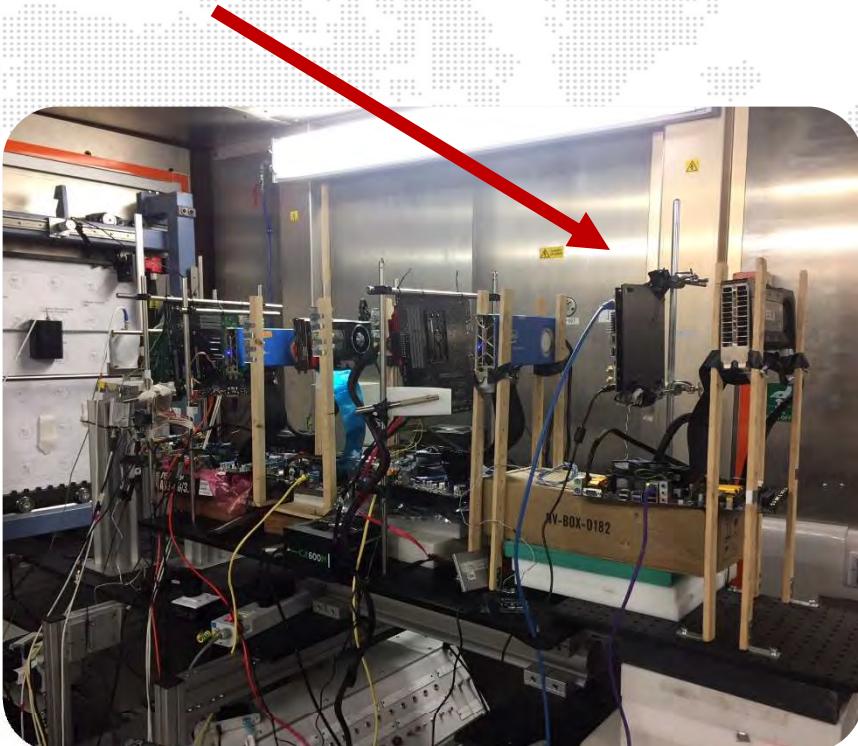
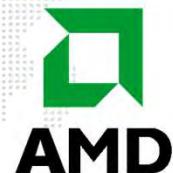


Image: Paolo Rech from
UFRGS University, Brazil

Paolo Rech



Driverless Cars: Highly complex systems being deployed in cars



$$2.66 \times 10^{-6} \text{ cm}^2 \times 13 \text{ n/cm}^2/\text{h} = 3.46 \times 10^4 \text{ FIT}$$

From accelerated testing on ChipIR

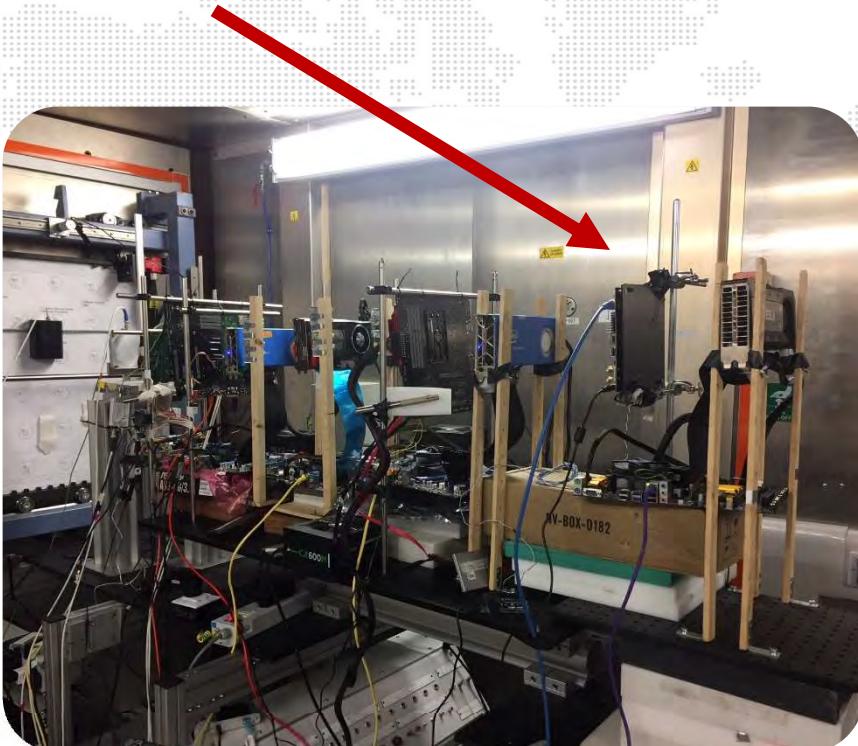


Image: Paolo Rech from
UFRGS University, Brazil

Paolo Rech



Driverless Cars: Highly complex systems being deployed in cars



Error every 3.2 years...

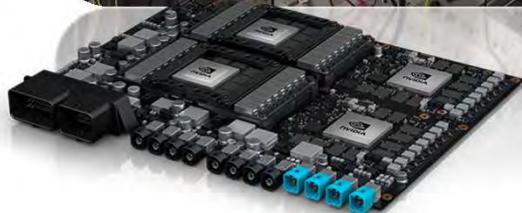
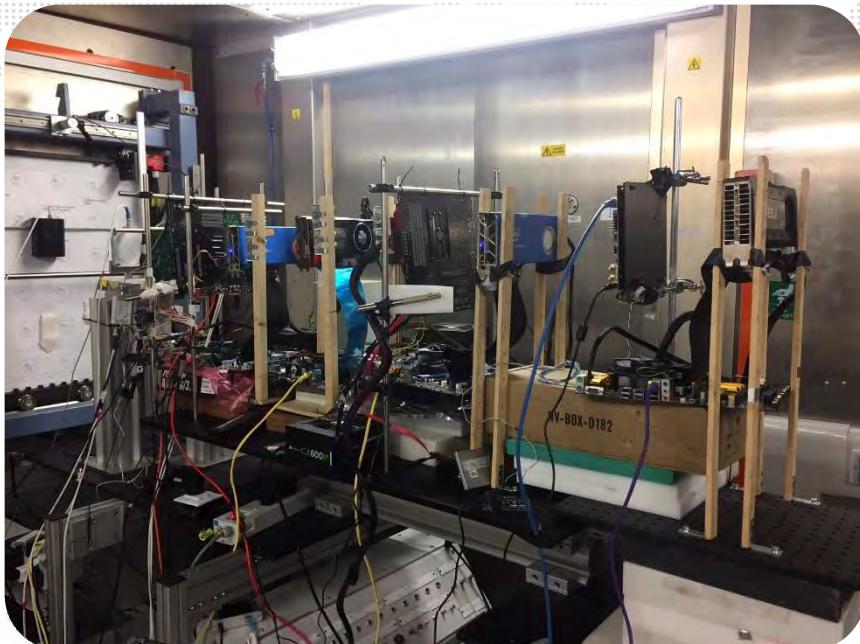


Image: Paolo Rech from
UFRGS University, Brazil

Paolo Rech

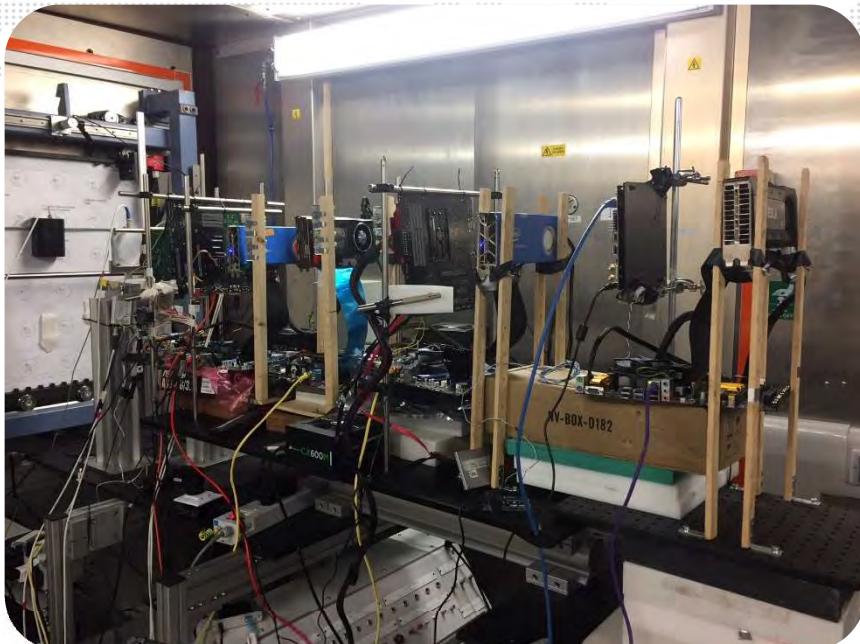


Driverless Cars: Highly complex systems being deployed in cars



Error every 3.2 years...

...but 1.5 million cars on UK roads = error every minute



Paolo Rech

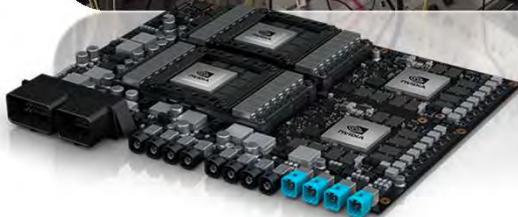
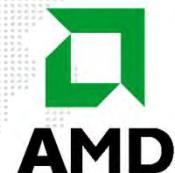


Image: Paolo Rech from
UFRGS University, Brazil

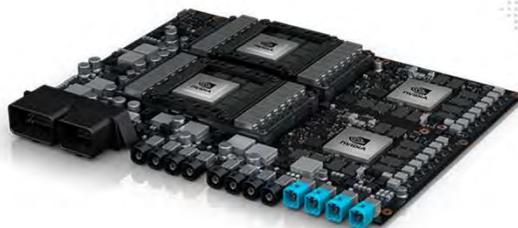
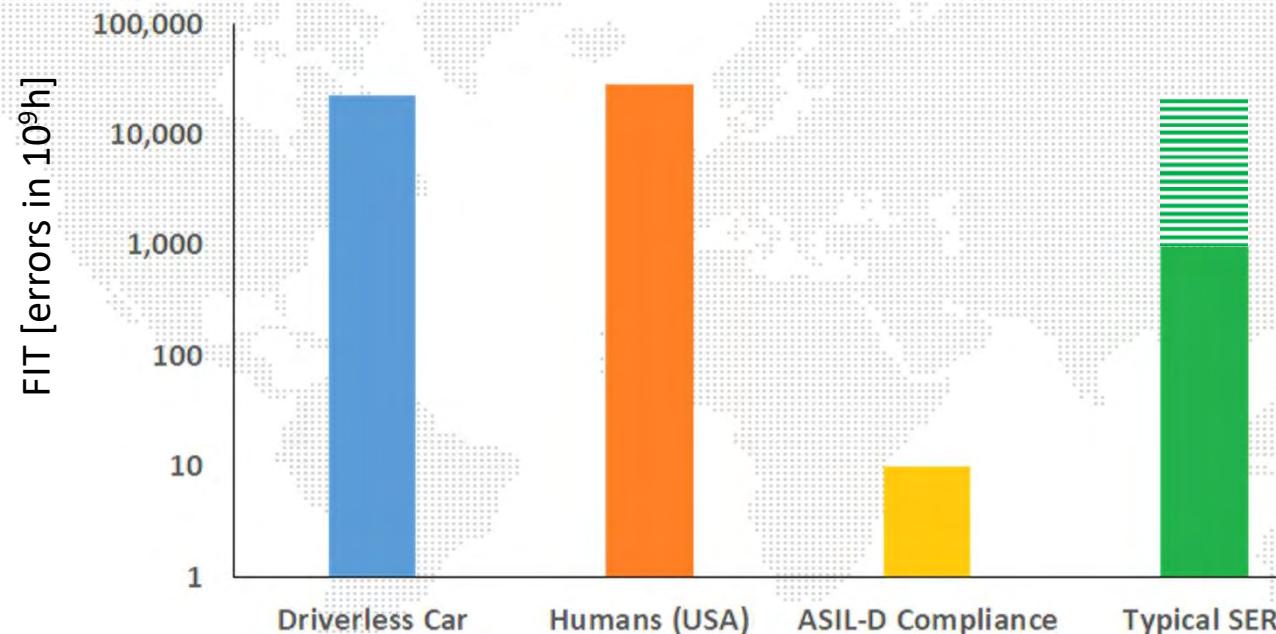


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Driverless Cars: Highly complex systems being deployed in cars



Automotive Safety Integrity Level D - Possibility of Fatal Injury



Nirmal R. Saxena.,SELSE 2016 Keynote,
Paolo Rech from UFRGS University, Brazil &
Oliveira et al.,Trans. Comp. 2016

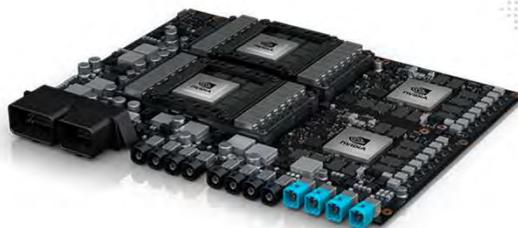
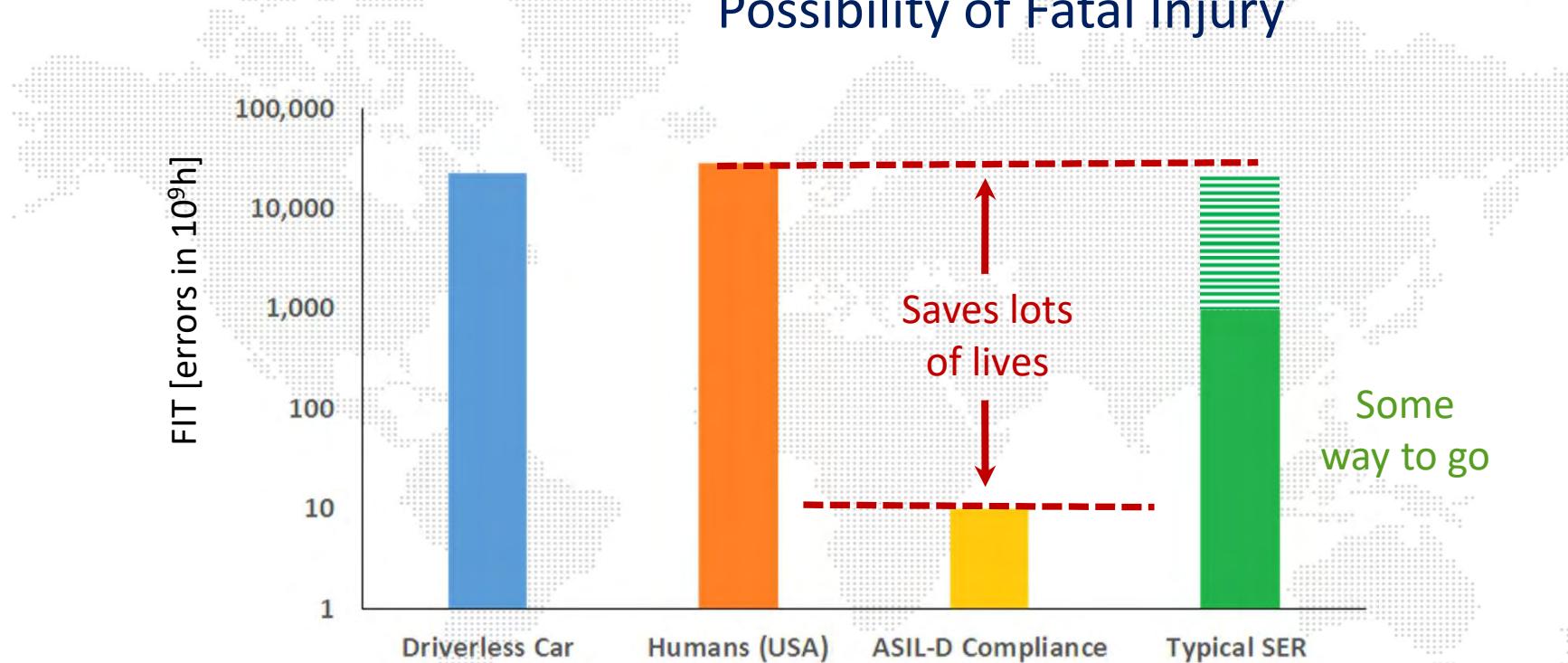


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Driverless Cars: Highly complex systems being deployed in cars



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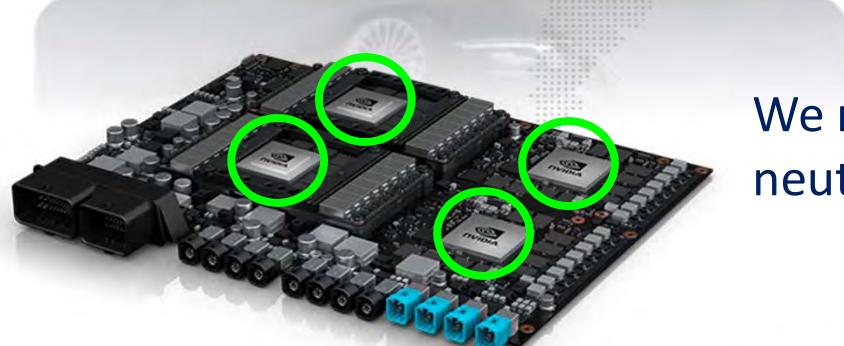
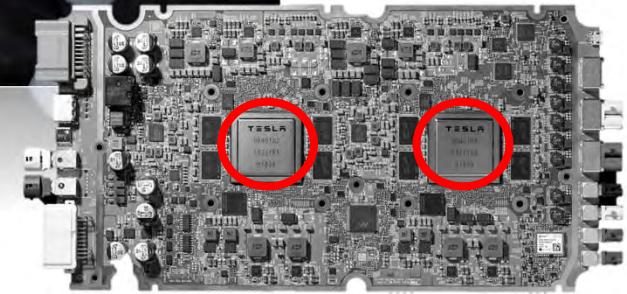


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Driverless Cars: Highly complex systems being deployed in cars



Count the Chips - Naïve (costly) solutions in today's self-driving cars



We need to find **smarter ways** to detect neutron-induced errors

Image Source: NVIDIA & TESLA



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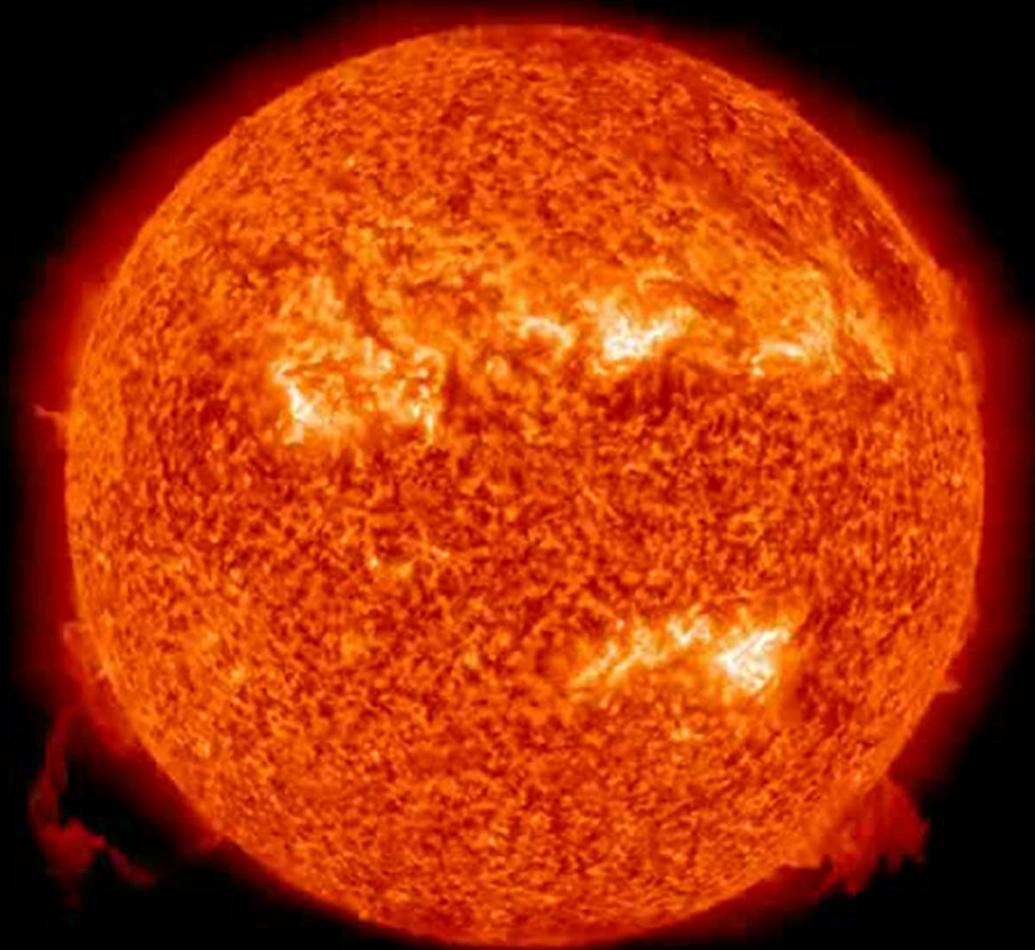


“For example an autopilot system was found to upset on average every 200 flight hours... if a major **Ground Level Event** had occurred before this problem was eventually fixed such an upset could have occurred every hour making safe flight very difficult.”

UK Parliament - Commons Select Committee:
Science and Technology
Inquiry in Scientific Advice and Evidence in
Emergencies: (iii) Solar Storms
Report HC 498



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SDO/AIA 304 2011-06-05 14:10:33 UT

Video: NASA/SDO

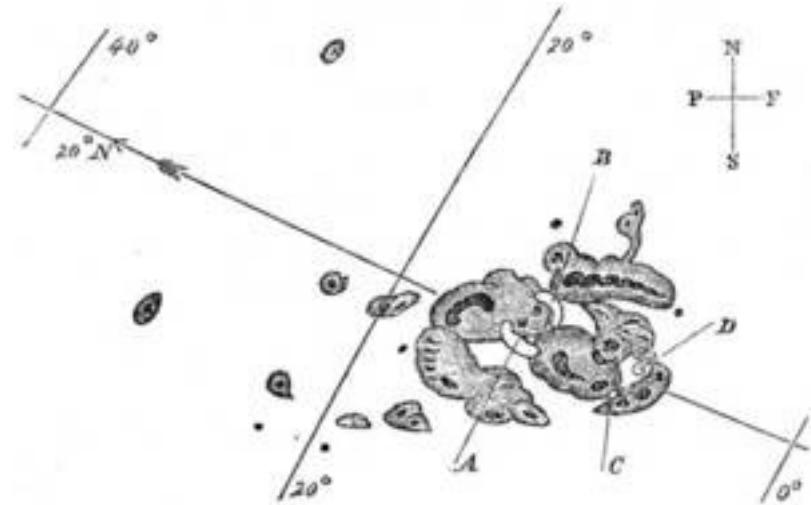
Space Weather: impact of extreme solar events on aerospace and ground based infrastructure

Extreme Space Weather's impact on modern infrastructure of increasing concern for Governments



Recent inclusion of Extreme Space Weather into IEC aerospace standards (TR 62396)



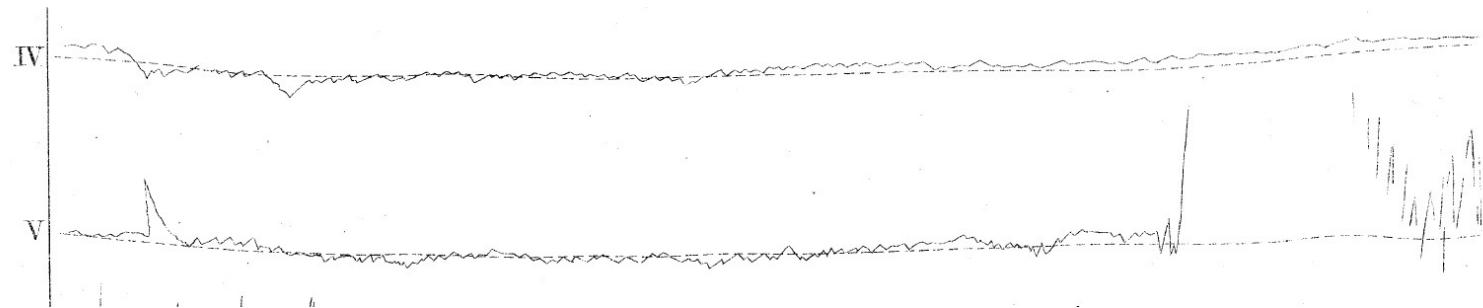


11:23am Sept 1st 1859

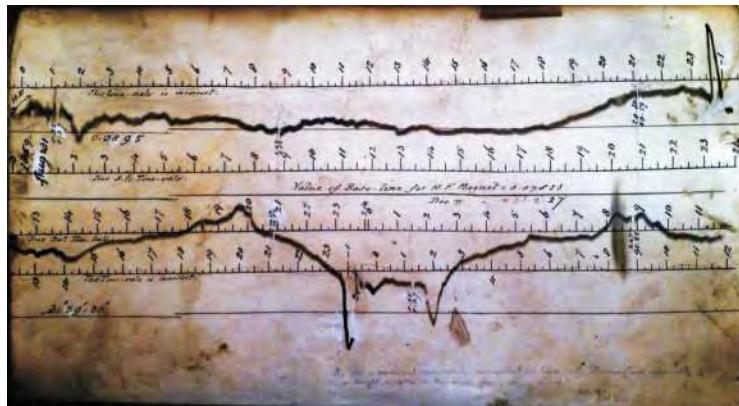
*Description of a Singular Appearance seen in the Sun on
September 1, 1859.* By R. C. Carrington, Esq.

While engaged in the forenoon of Thursday, Sept. 1, in taking my customary observation of the forms and positions of the solar spots, an appearance was witnessed which I believe to be exceedingly rare.

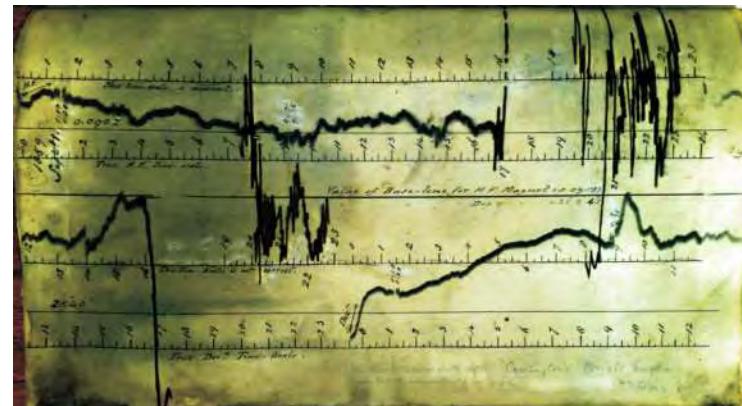
Source: Proc Royal Astronomical Society 1859



Earth's Horizontal Magnetic Field Kew Observatory: Balfour Stewart: Phil. Trans. R. Soc. Lon. 1861, 151, p423

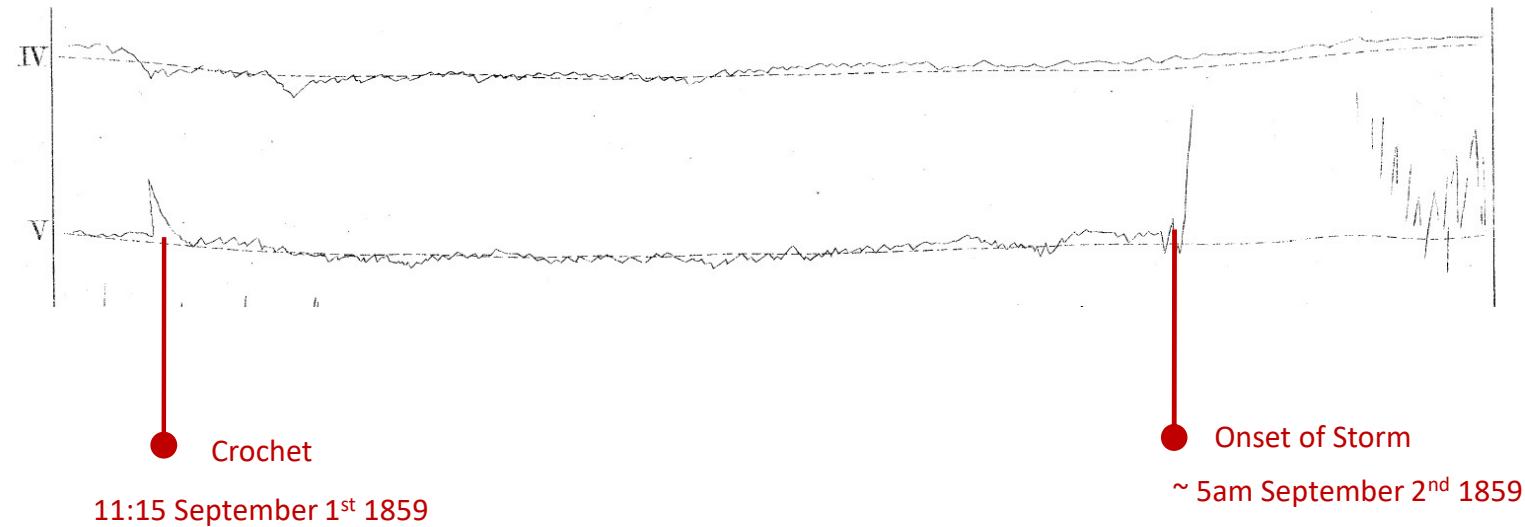


Greenwich Observatory



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Carrington Event - 1859



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Great Aurora of 1859.
ART. XLII.—The Great Auroral Exhibition of August 28th to September 4th, 1859.

On the evening of August 28th, 1859, was commenced an exhibition of Auroral or Polar light which continued with varying intensity at different localities in North America, so far as is now known, up to September 4th. This auroral display is one of the most remarkable ever recorded in the United States; remarkable not only for the great extent of territory over which it was observed, but also for its duration, for the intensity of the illumination as well as the brilliancy of the colors, and the extreme rapidity of the changes. It was also equally remarkable for the magnetic disturbances which accompanied it, especially on the 2d and 3d of September. These electrical perturbations were recorded not only by the usual magnetic instruments, but over the whole system of telegraphic wires, especially in New England and the Canadas, the magnetic induction either greatly interfered with or prevented the working of the lines by the usual voltaic current, while in more than one case the north and south lines were worked during the daytime of September 3d solely by the atmospheric influence! This remarkable and novel phenomenon deserves and will receive special attention hereafter.

It appears from our own correspondence, and from the daily Journals, that the late display of the Aurora was witnessed from Cuba and Jamaica on the south, to an unknown distance beyond the Canadas on the north, and from Central Europe on the east, to California on the west. Doubtless we may expect to hear that it was seen over the entire northern hemisphere, and in some places as far south as lat. 20° .

Since the laws of this phenomenon are as yet but imperfectly understood, it is regarded as very important that the facts respecting the late grand exhibition should be carefully collected and placed on record, in the expectation that at some future day they may afford the basis for a complete and satisfactory theory of this meteor.

We now publish such original observations on this Aurora as have reached us in an authentic form, and we hope in future numbers of this Journal to present many other important data of the same description from different and distant parts of this and the other continent. We intend to present in the first place the *facts* of this exhibition divested of all theoretical considerations; and when all the materials have been collected we shall give such explanation of them as we are able. At present we put on record observations of the aurora and its attendant phenomena made at Lewiston, Me.; at Toronto, Canada West; at New Haven, Conn.; at West Point, N. Y.; at Bloomington,

SECOND SERIES, VOL. XXVIII., NO. 61.—NOV., 1860.

49

ART. XLII.—*The Great Auroral Exhibition of August 28th to September 4th, 1859.*

display of the Aurora was witnessed from Cuba and Jamaica on the south,



Source: American Journal of Science and Arts vol 28,29,30 , (1860)



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Prof. E. Loomis on the Aurora of 1859.
 80° E. to N. 85° W., and its altitude at its center was 12°. Many of them reached the zenith but no corona was formed. The coruscations were mostly white.
 Sept. 3d. The evening was cloudy, but the aurora was sufficiently strong to illuminate the clouds.

17. *Observations at Newark, Ohio, (lat. 40° 4', long. 82° 23') by David W. Rice.*

Sept. 1st, about midnight the entire heavens except near the southern horizon were illuminated by a pale yellow light. In about ten minutes masses of red light appeared in the E. and W.; and as they faded away others appeared in the N. and S. Subsequently there was a beautiful emanation of red rays from a circular center near the zenith. The whole phenomenon lasted about two and a half hours. In the S. and S.W. lay a dark cloud rising about five degrees above the horizon.

18. *Observations at Baltimore, Maryland, (lat. 39° 18' long. 76° 57') by C. Wernicke, Telegraph Superintendent.*

On the morning of Sept. 2d, I found the telegraph wires charged to an extent far beyond the strength of our ordinary batteries. Upon disconnecting the batteries I got clear and distinct writing from Cumberland, distant 179 miles. When the current was at its maximum strength, the manipulations of the operator at Cumberland worked the armature of the relay magnet here with a force nearly equal to that which would be produced by a Grove battery of 50 cups on a short circuit. The intensity of the spark at the instant of breaking the circuit, was such as to set on fire the wood work of the switch board. The current however was variable, and at times no sensible effect could be observed.

19. *Observations at Aurora, Indiana, (lat. 39° 4' long. 84° 54') by George Scoville, M.D.*

Sept. 1st, about 10 P.M. a faint aurora was seen in the north; and about midnight the aurora extended over the whole heavens. In the north the light was of a pale color resembling the break of day, and a few faint streamers could be seen. About 1 A.M. the whole southern heavens presented a deep red appearance. At 1^h 30^m streamers were more frequently seen in the north, and occasionally a ray would appear in the S.E. and S.W. Between 2 and 3 A.M. streamers arose in all directions, but much paler in the north than in the south. The streamers converged to a point presenting the appearance of a vast and gorgeous tent. From 1 A.M. until the break of day, the most brilliant display was in the south.

Sept. 2d, about 8^h 15^m P.M. the aurora appeared again in the north. There were occasional flashes of light resembling distant lightning. It disappeared in a few hours.

ART. XXXI.—The Great Auroral Exhibition of Aug. 28th to Sept. 4th, 1859.—6TH ARTICLE; by Prof. ELIAS LOOMIS.

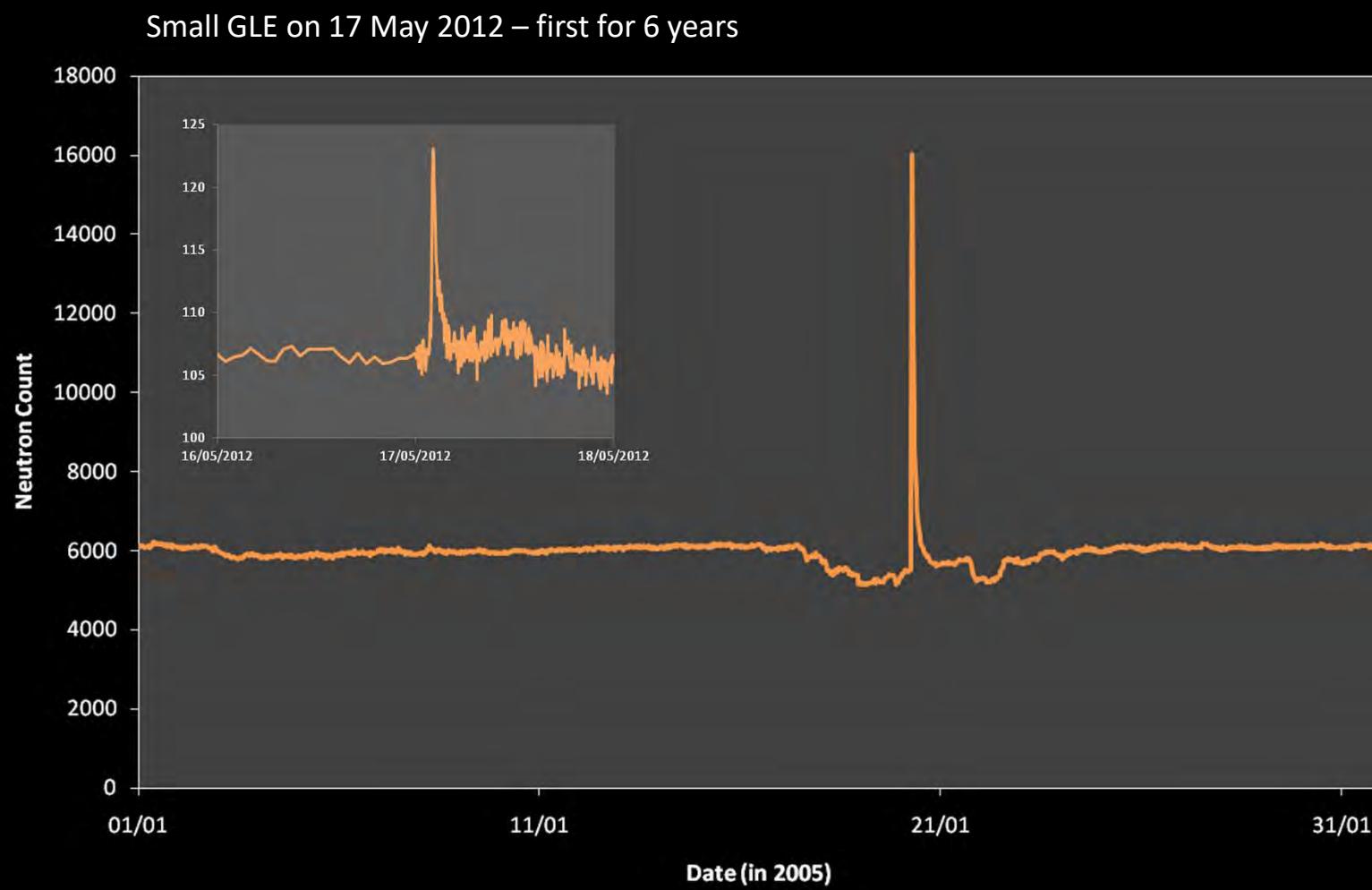
Upon disconnecting the batteries I got clear and distinct writing from Cumberland, distant 179 miles.

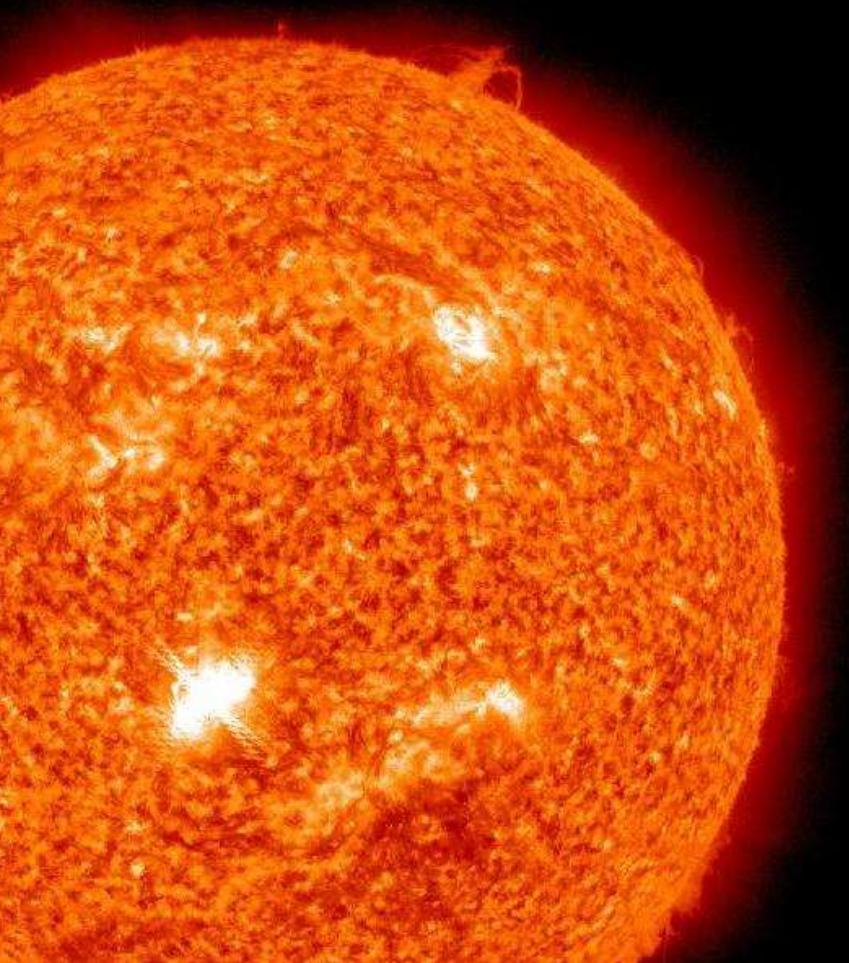
was such as to set on fire
the wood work of the switch board.

Source: American Journal of Science and Arts vols 28,29,30 , (1860)



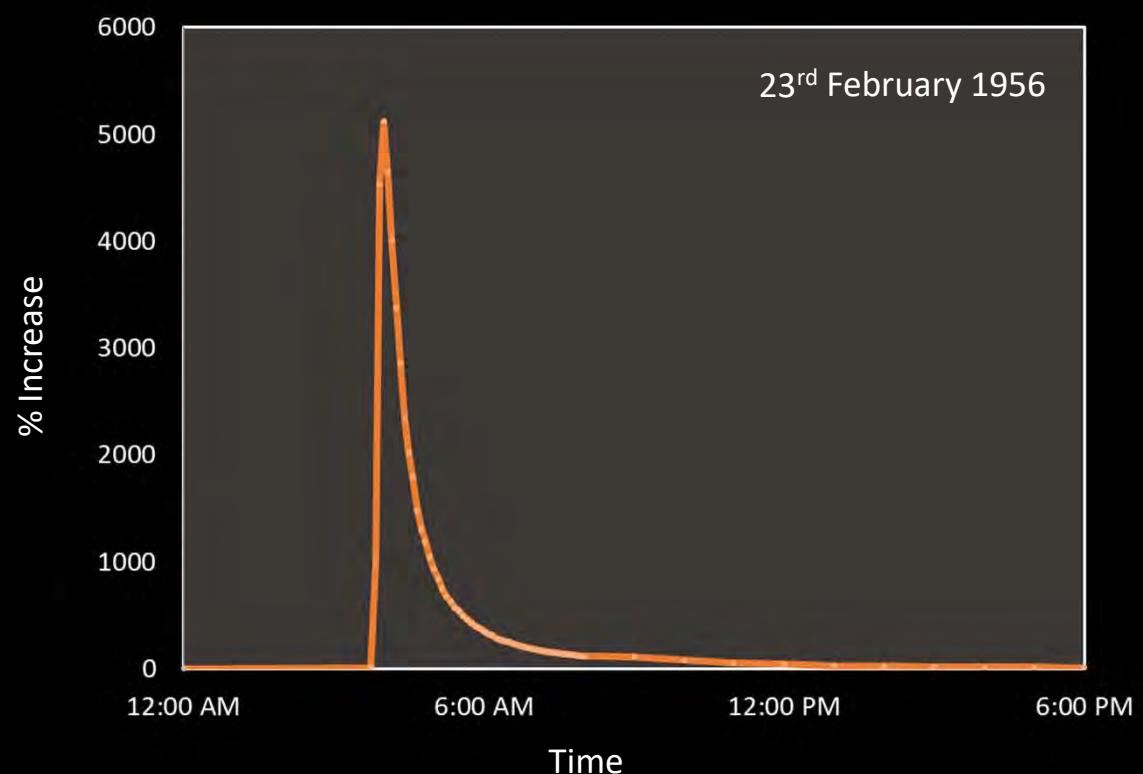
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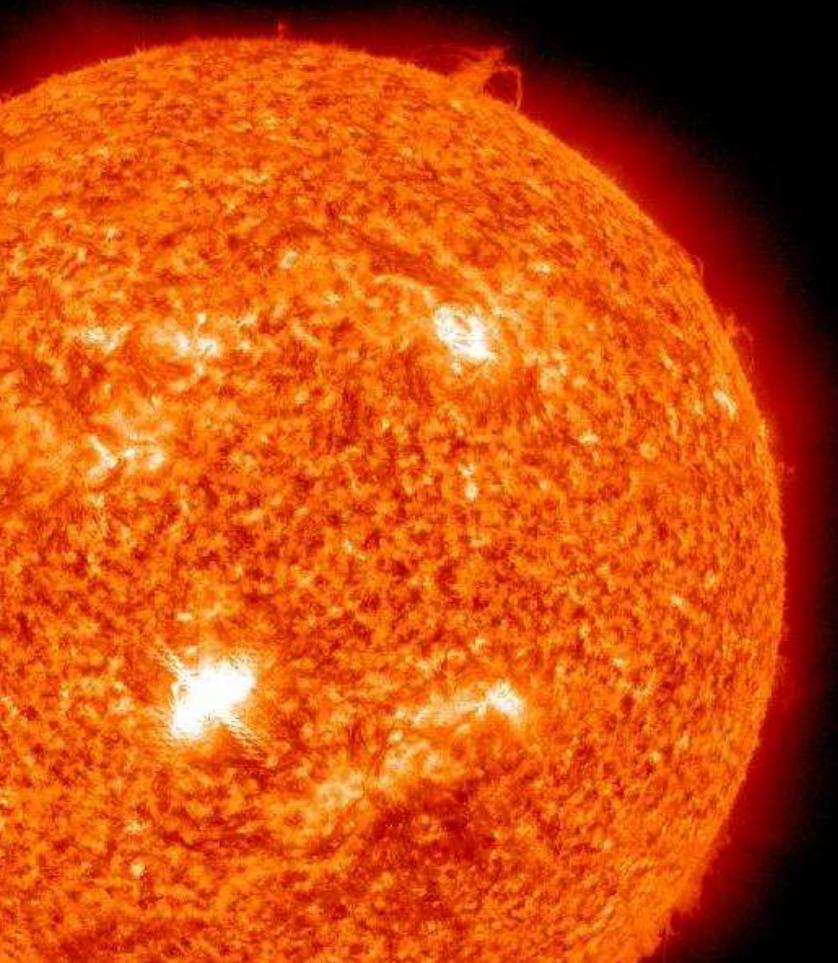


1859 ‘Carrington’ Event

Largest event in last
160 years



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1956 Event

Largest event in
electronics era

Yardstick for Space Weather

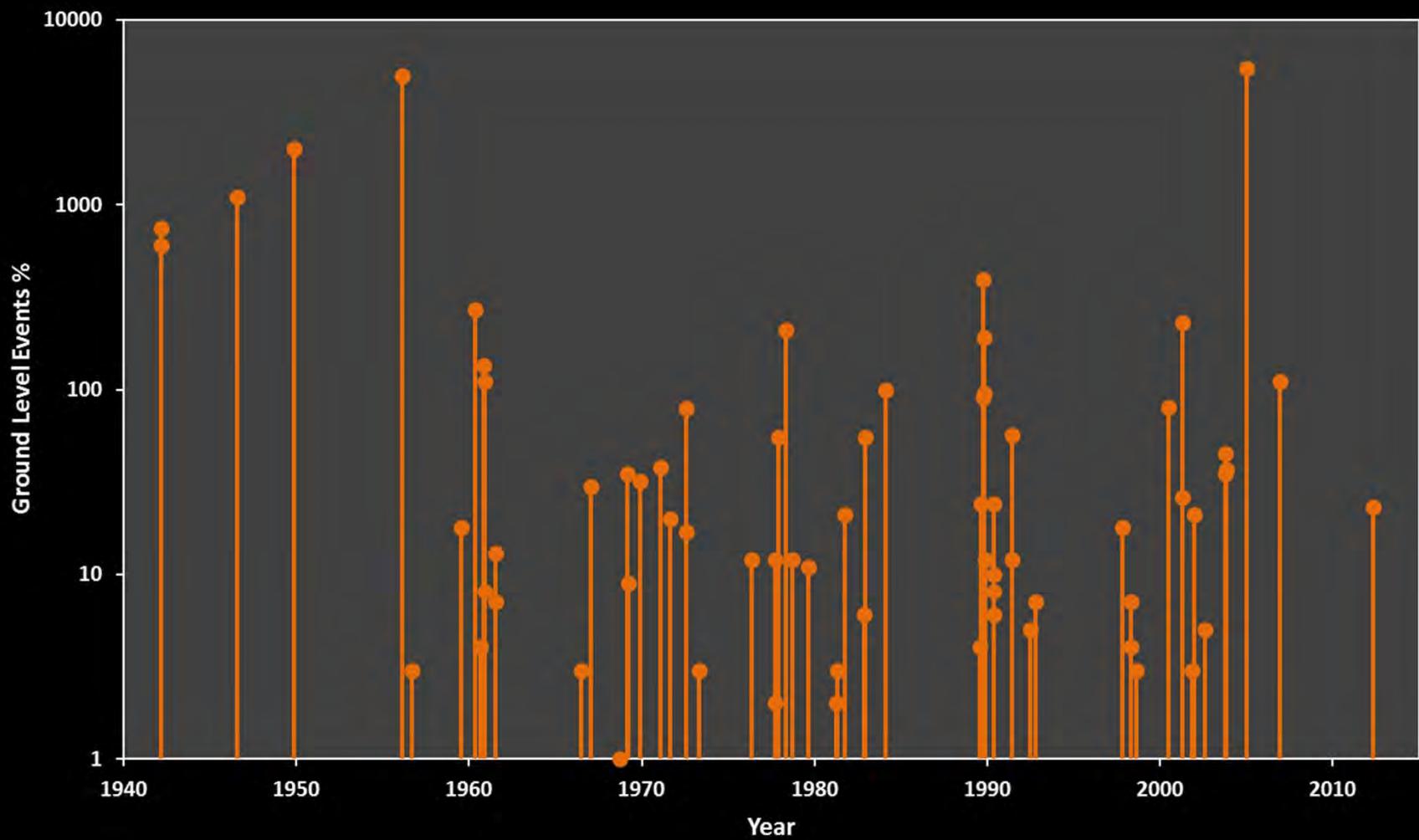
1000X the normal GCR at 12km

1-in-50 year event

30,000X the normal GCR at 12km

1-in-1000 year event

IEC TR 62396-6 Technical Report (2018)

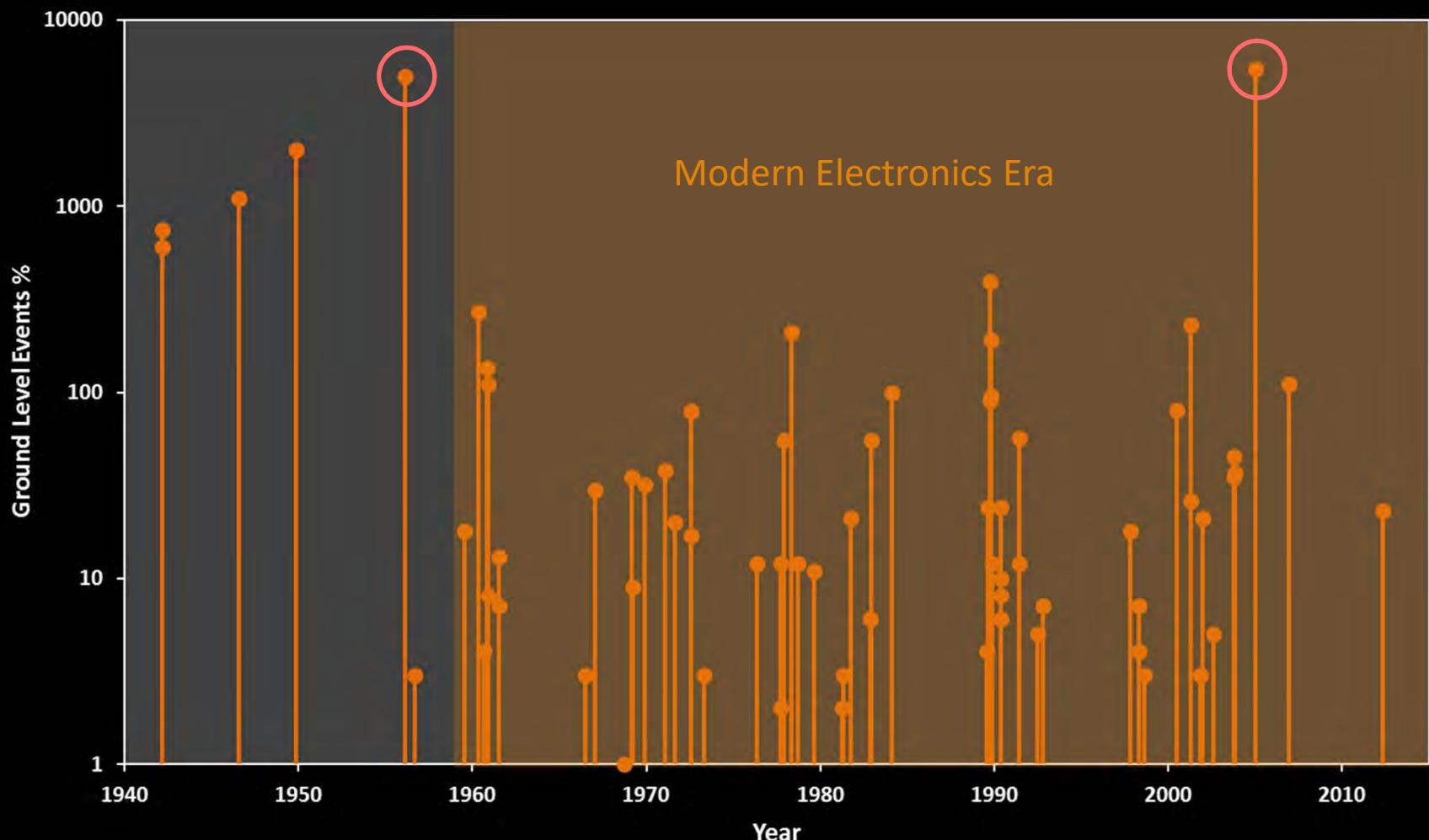


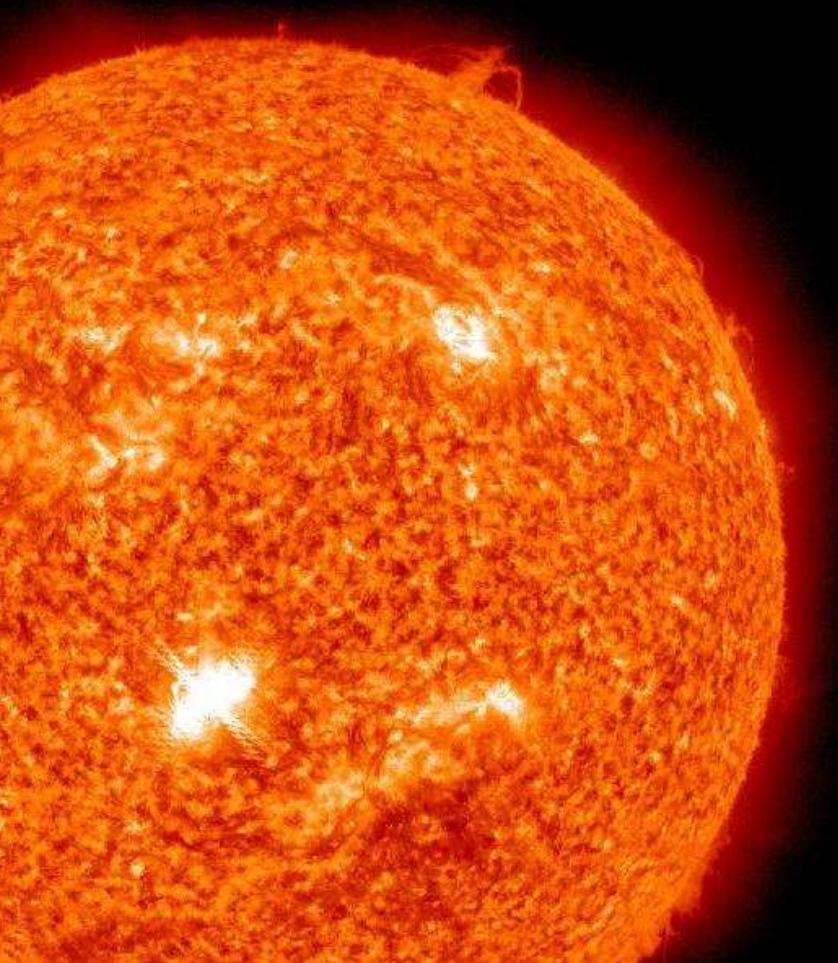
23rd February 1956

Leeds UK

20th January 2005

Antarctica; Northern Hemisphere /10





1956 Event

Largest event in
electronics era

Yardstick for Space Weather

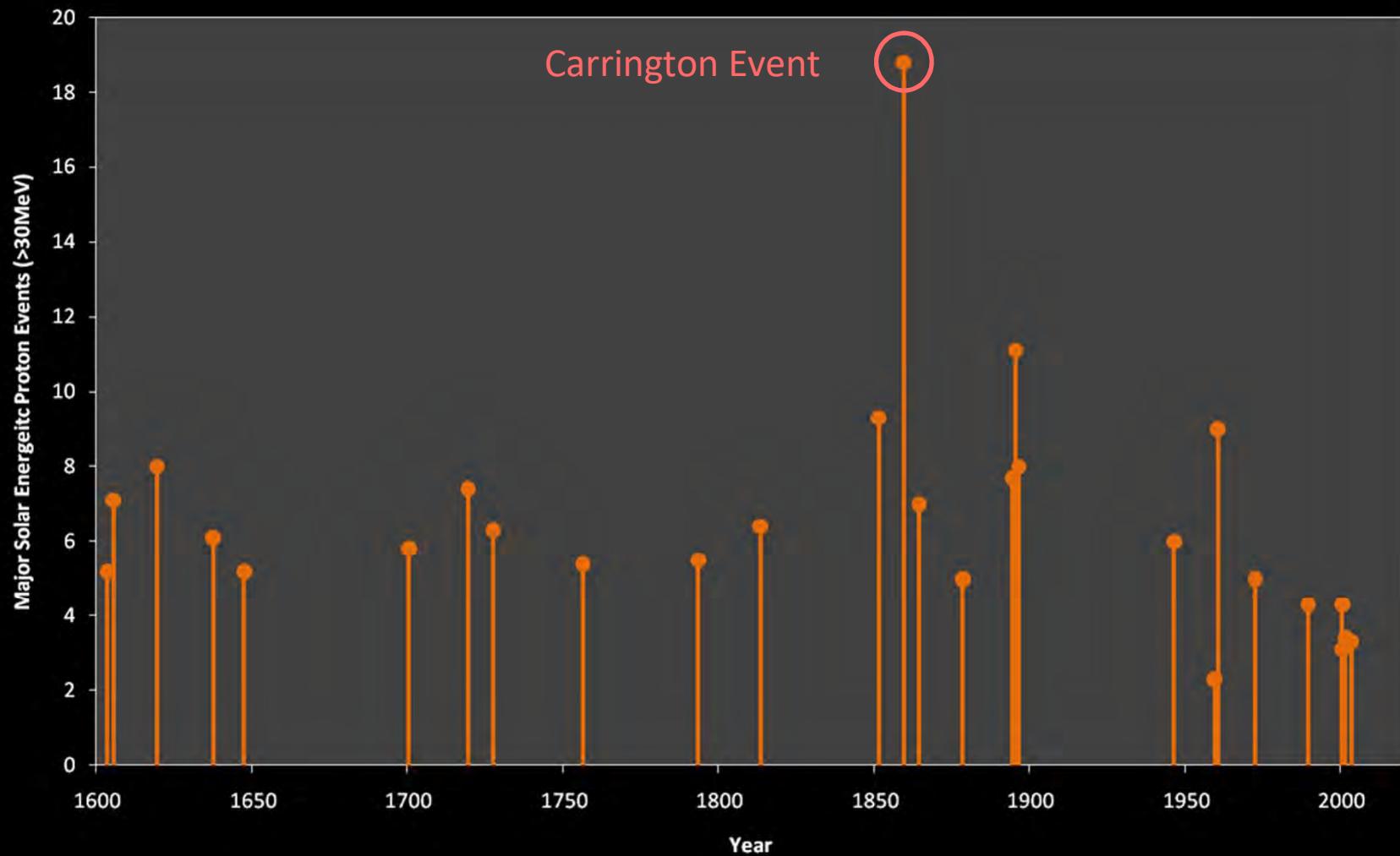
Upsets/hr in 1GB SRAM

2520

Burnout/hr in power device
(MOSFET)

1.8 – 7.5

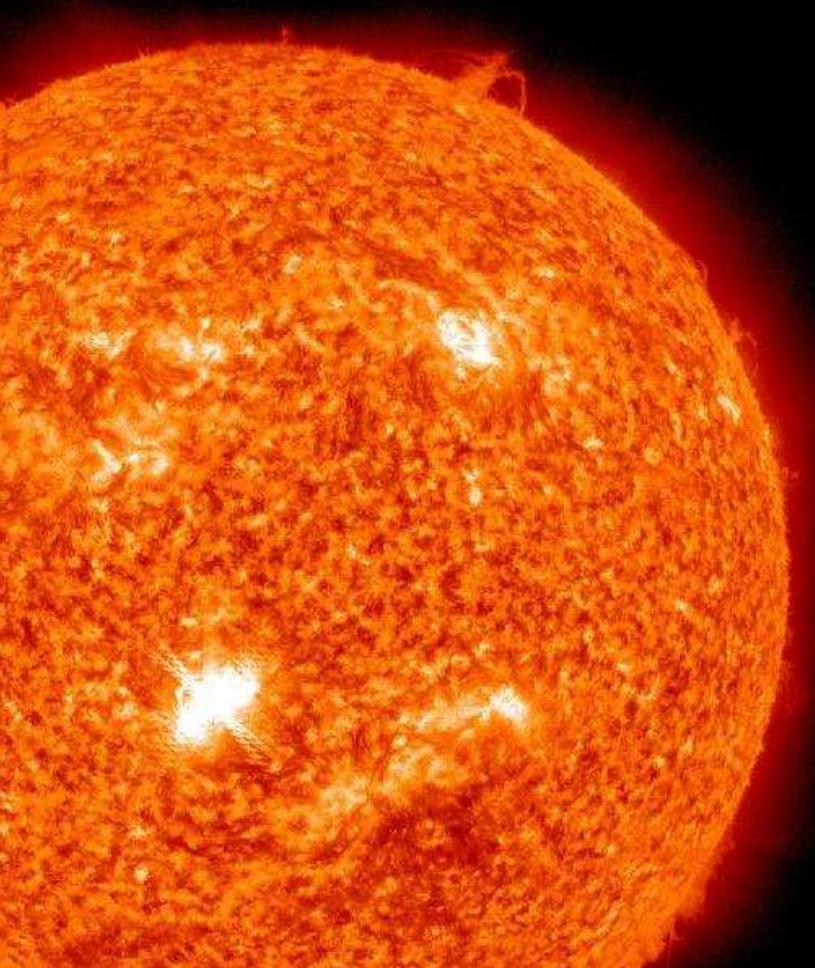
At 40,000ft - Clive Dyer et al NSREC 2017



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“This situation should improve in the next two years with the opening of a dedicated beamline (ChipIR) The ChipIR wide beam facility will enable complete powered and monitored equipment and systems to be irradiated at radiation levels equivalent or greater than a Carrington event to verify equipment SEE tolerance.”

Royal Academy of Engineering



Thank You



Driverless Cars

Paolo Rech
Caio Lunardi
Daniel Oliveira
Fernando Santos
Lucas Klein
Pedro Pimenta
Philippe Navaux
Luigi Carro



Space Weather

Alex Hands
Clive Dyer
Keith Ryden



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Carlo Cazzaniga
Goran Skoro
Steve Lilly
Stuart Ansell*
Kevin Jones



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