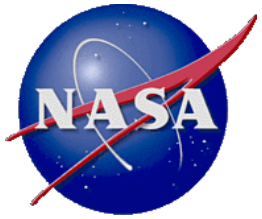


National Aeronautics & Space Administration

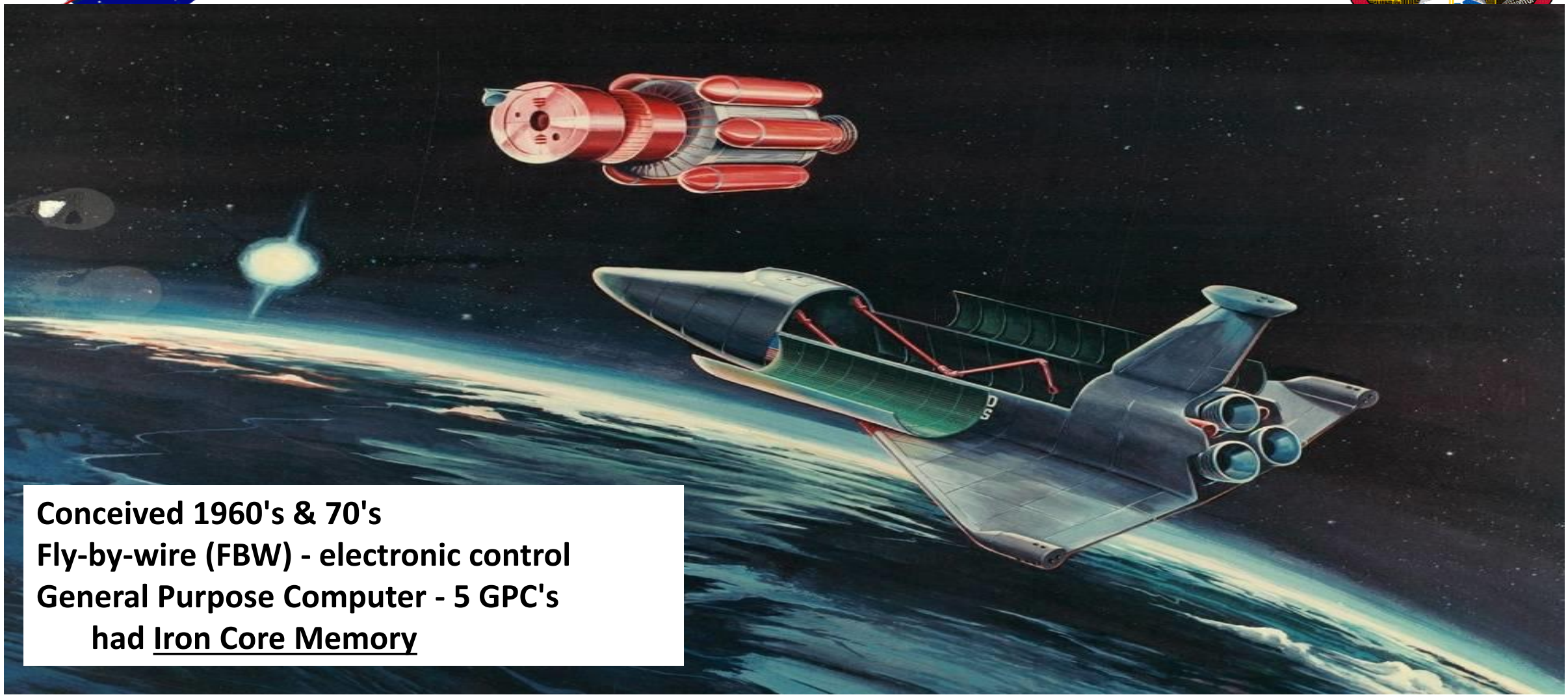
Johnson Space Center

Radiation Testing of Avionics Low Earth Orbit Human Spacecraft

Pat O'Neill
NASA JSC
Engineering, Avionic Systems Division
Electronic Design & Manufacturing

Technology Collaboration Center of Houston
Houston, Texas
September 21, 2015

Space Shuttle 1981 - 2011



Conceived 1960's & 70's
Fly-by-wire (FBW) - electronic control
General Purpose Computer - 5 GPC's
had Iron Core Memory

Original Shuttle - IRON CORE MEMORIES

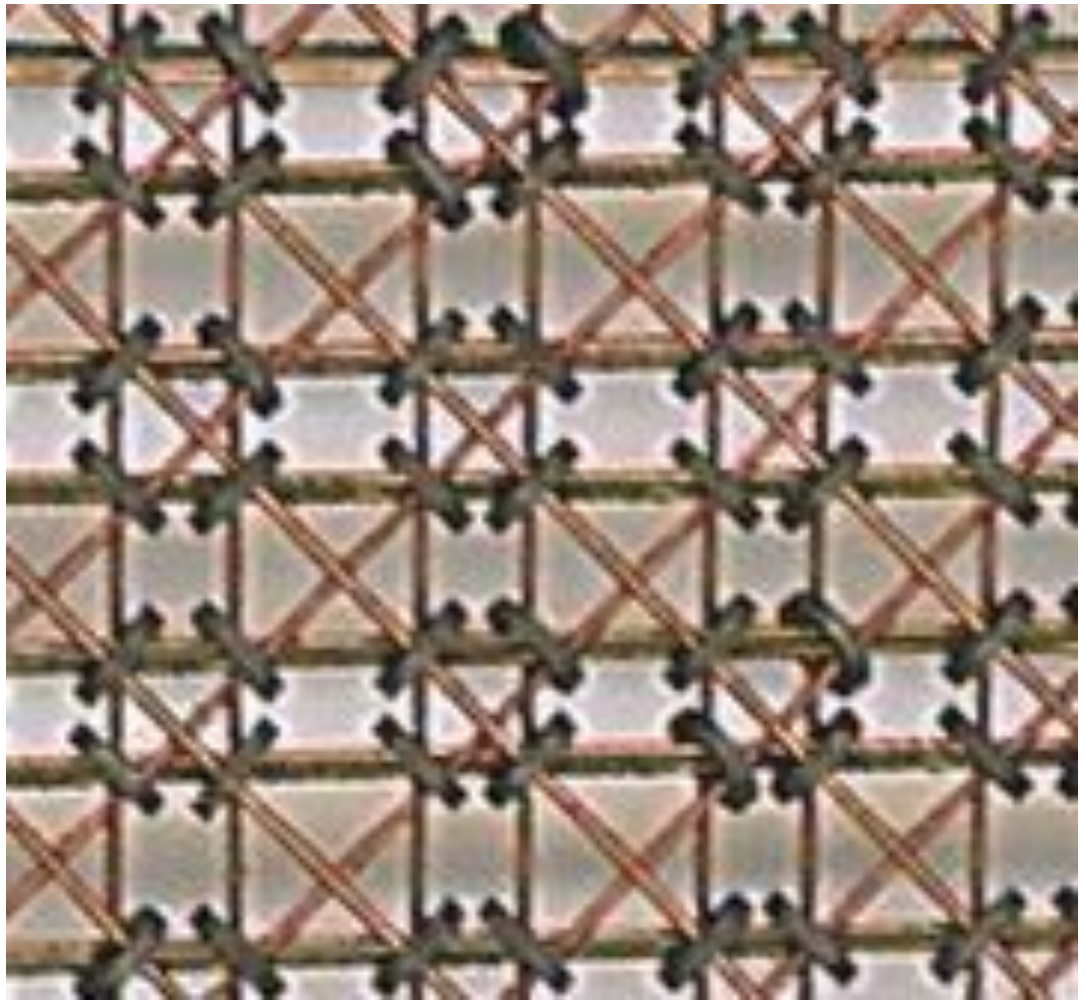
Ferrite ceramic core "donuts"

Retained memory with no power

Immune to ionizing radiation

Military aircraft, Mercury, Gemini, Apollo, Skylab (16k word),

Apple II, Commodore 64, …

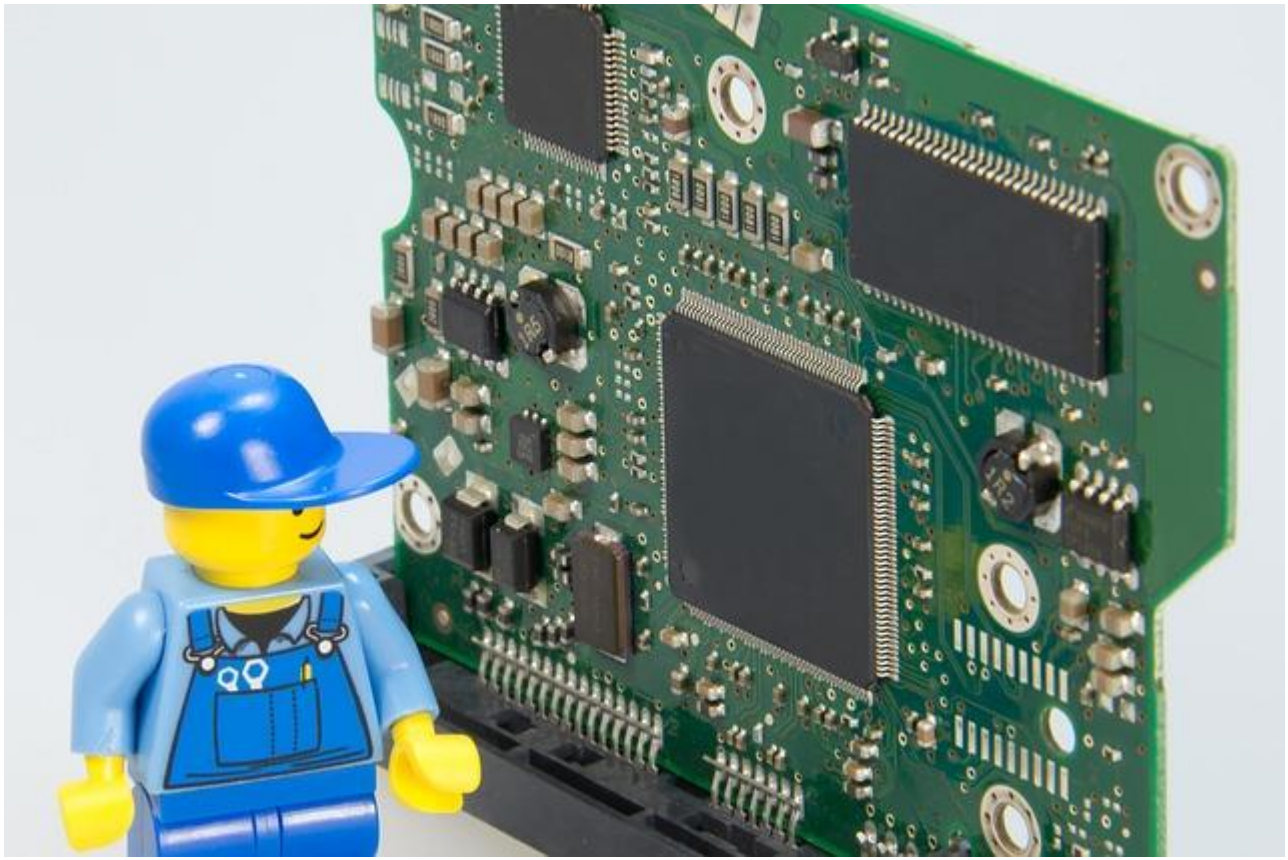


Shuttle Upgrade (1992) - STS 37
Static RAM Memory

Modern Computers have many microelectronic components - "chips"

- Memory, logic, & power control "chips"

- Many "chips" have >> millions of transistors



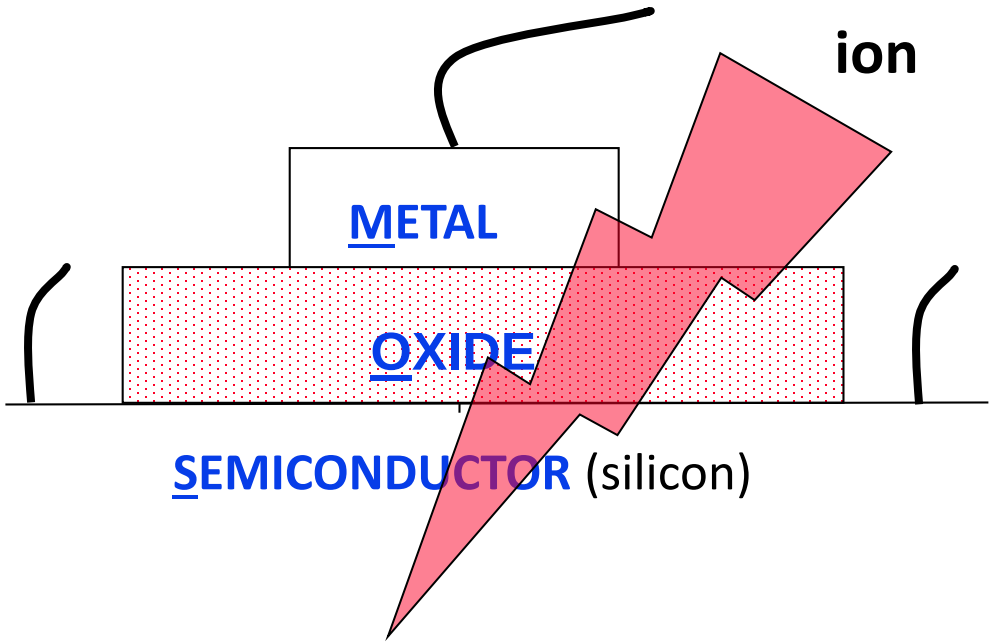
SEU OCCURS INSTANTLY and 1 ION CAUSES IT

Free electrons created in depletion region (channel) by ion

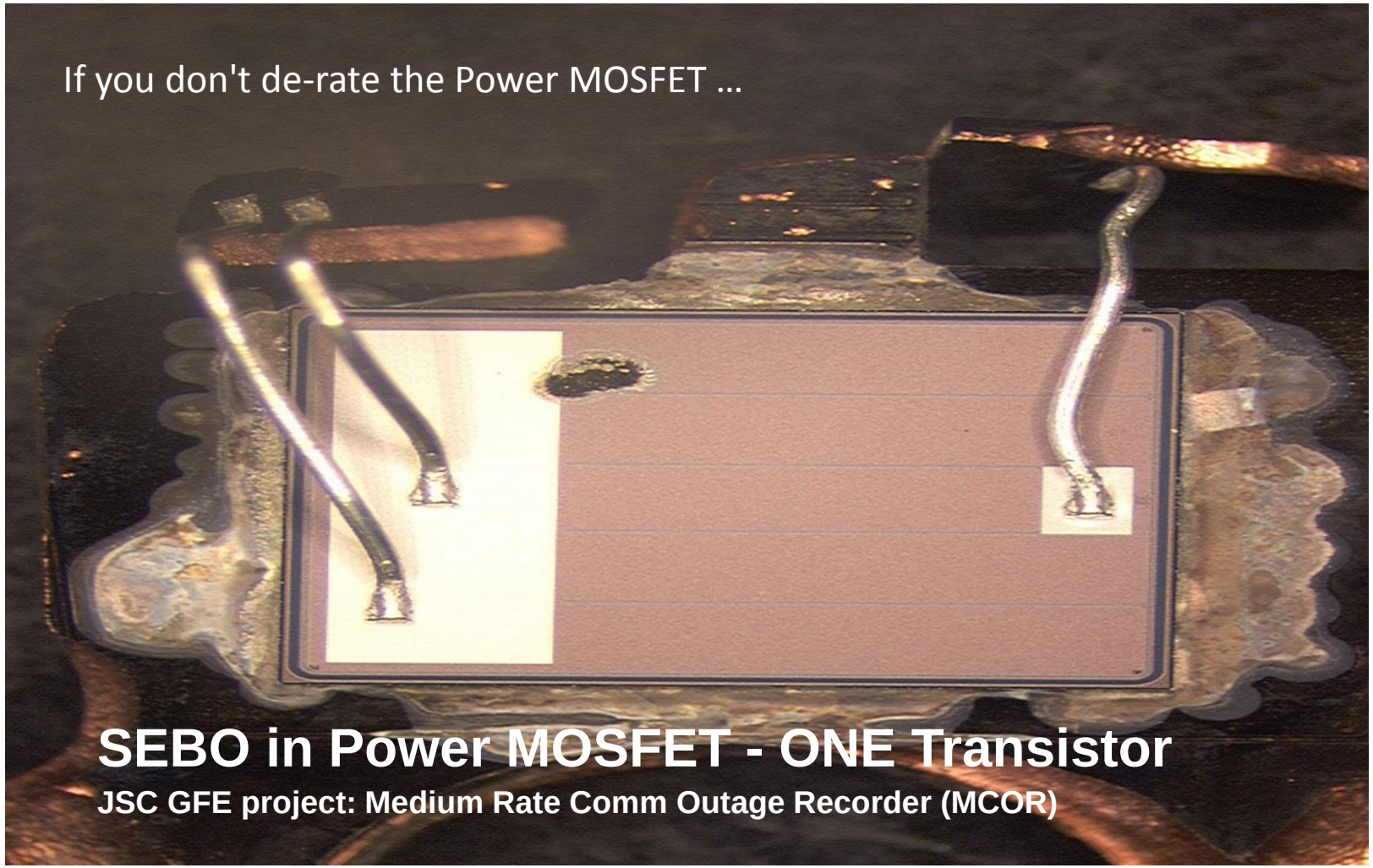
Current flows (source to drain)

A bit gets reset, a logic device outputs wrong state, etc.

No permanent damage

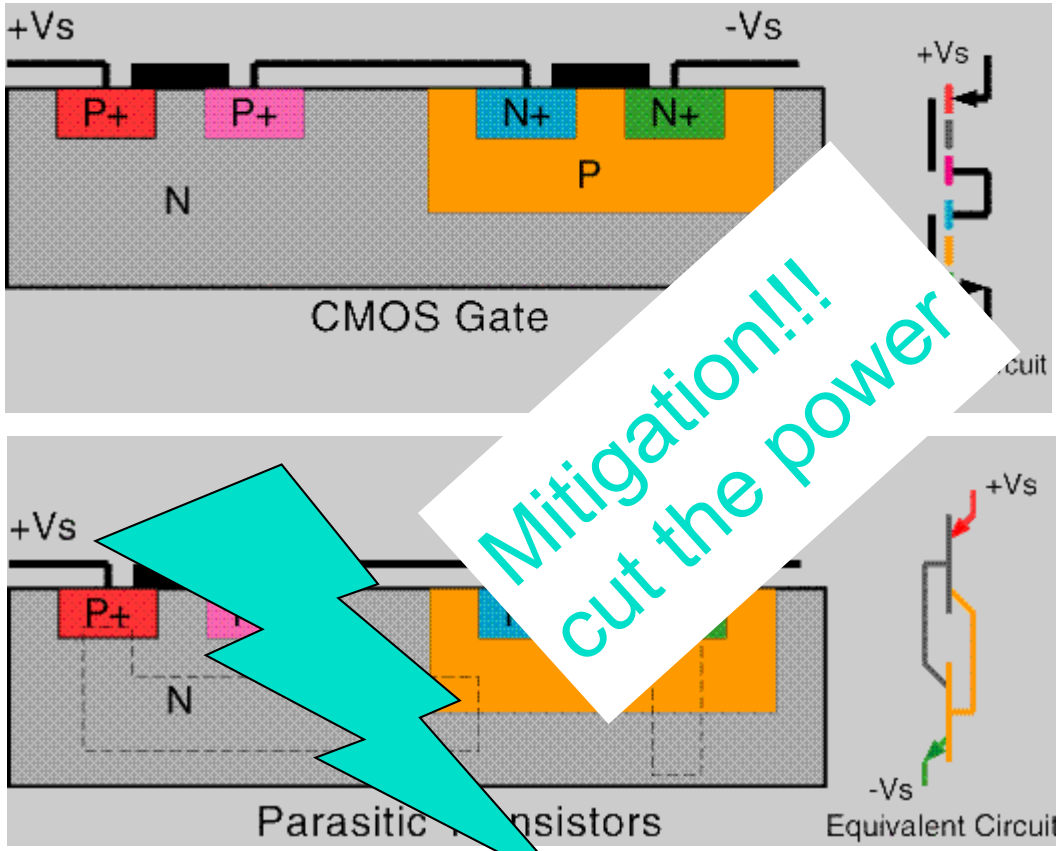


BURNOUT (SEB) & GATE RUPTURE (SEGR)


If you don't de-rate the Power MOSFET …
SEBO in Power MOSFET - ONE Transistor
JSC GFE project: Medium Rate Comm Outage Recorder (MCOR)

SEU's can be a problem - but not a hard failure
what is a LATCH-UP (SEL)?

>



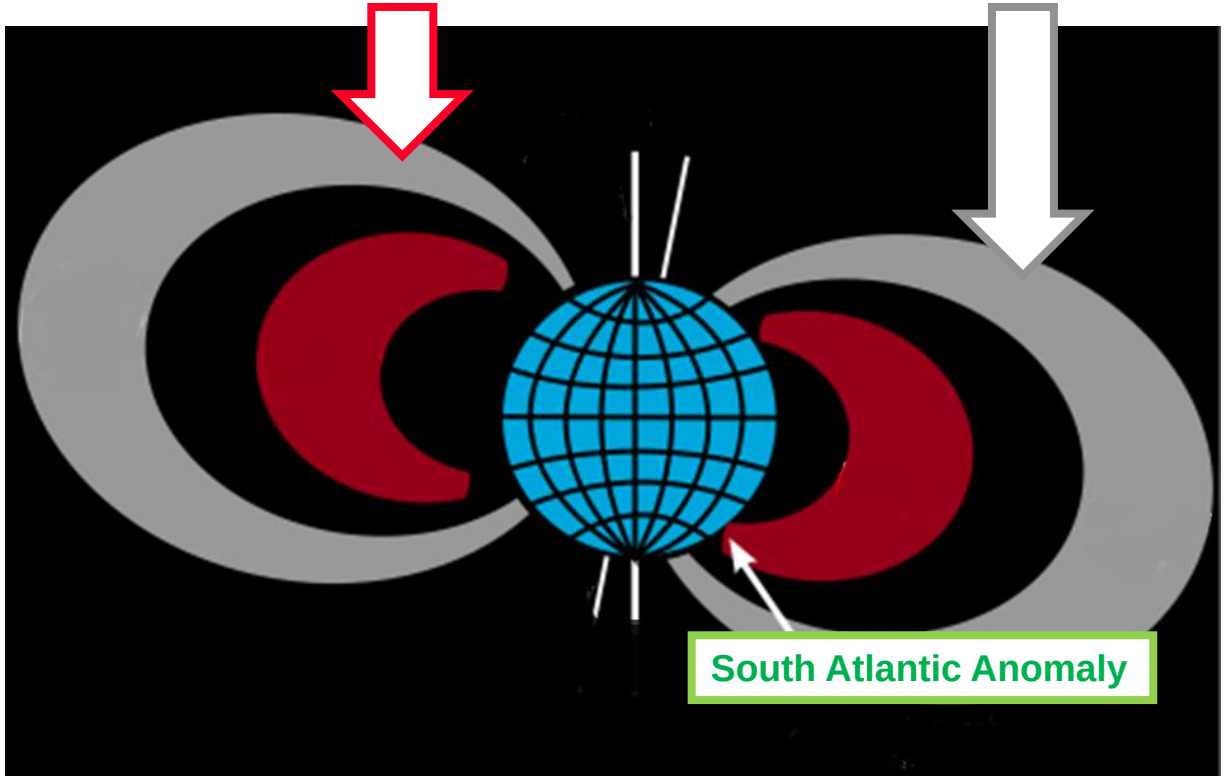
reverse biased p-n
junction in the substrate

ion makes p-n junction conducting **HIGH CURRENT**

Natural Space Ionizing Radiation (*External*)

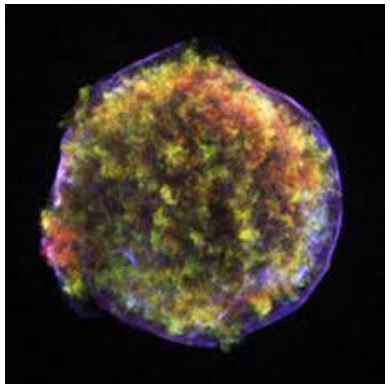
Van Allen Belts

Inner belt protons Outer belt electrons



Ions (protons to iron) attenuated by earth's magnetosphere for LEO

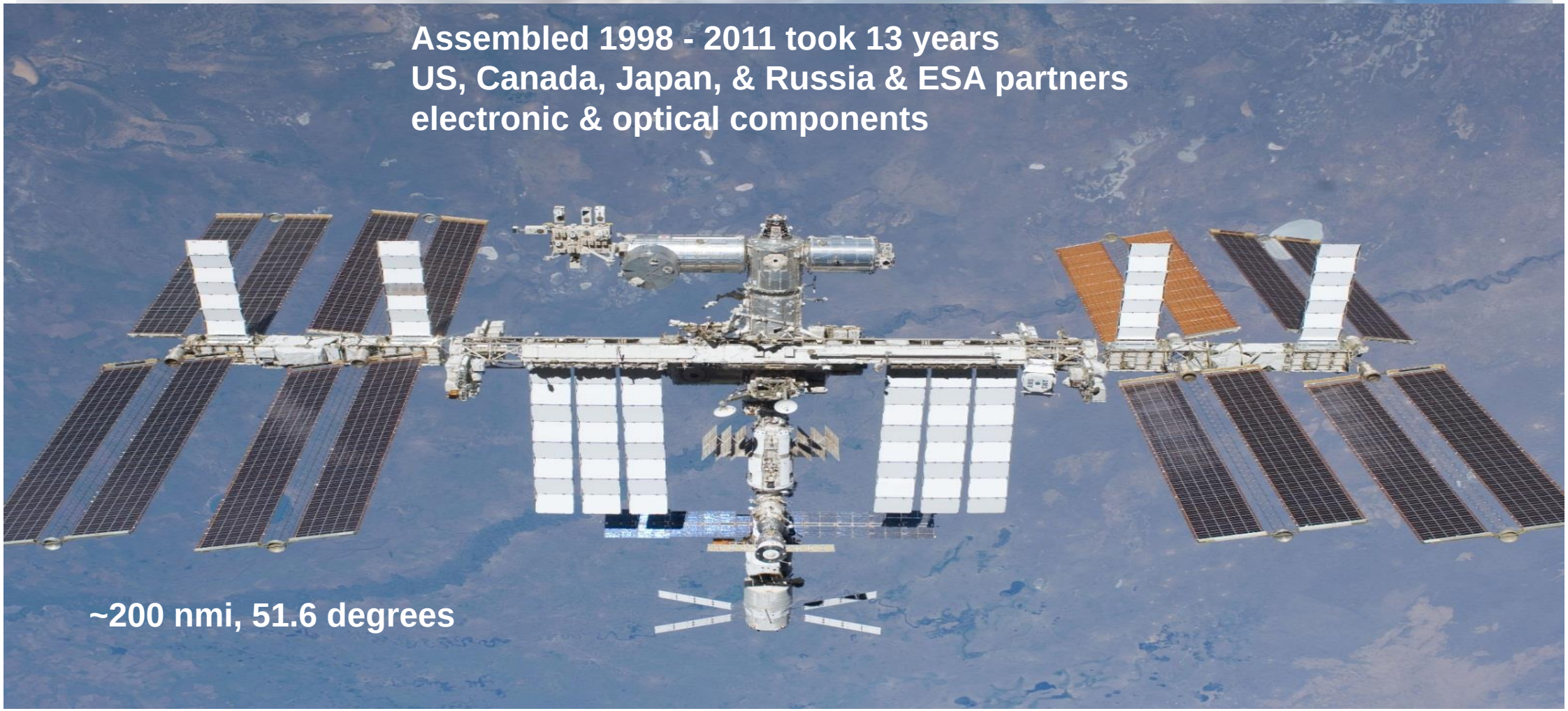
Galactic Cosmic Rays (GCR)



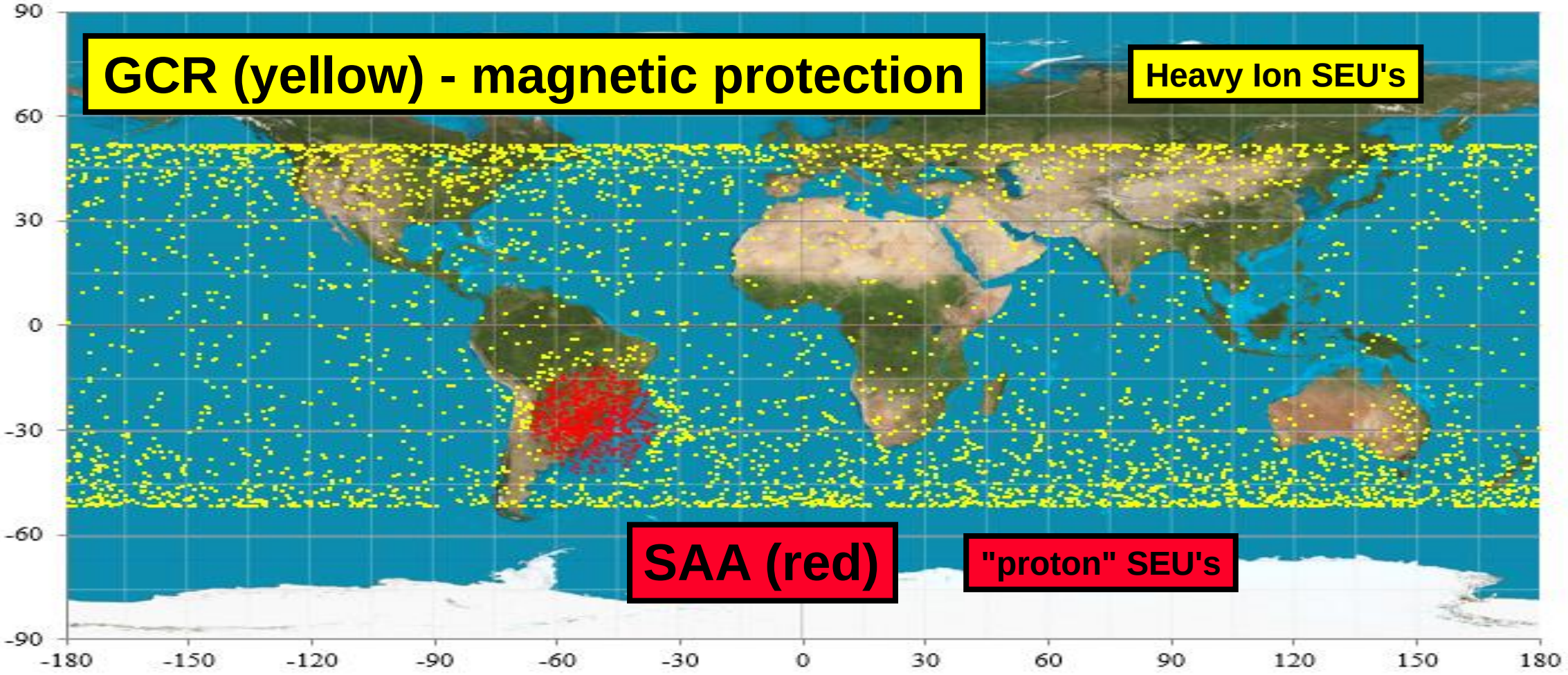
Solar Particle Events (SPE)

International Space Station (ISS)

Endeavour (STS-134) undocked on May 29, 2011



Single Event Upsets Observed*
US LAB MDM Memory (2009 - 2014)



*Paul Boeder - Boeing Houston

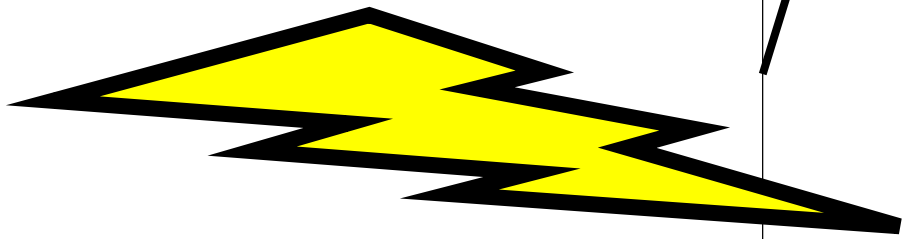
* Error Detection & Correction (EDAC)

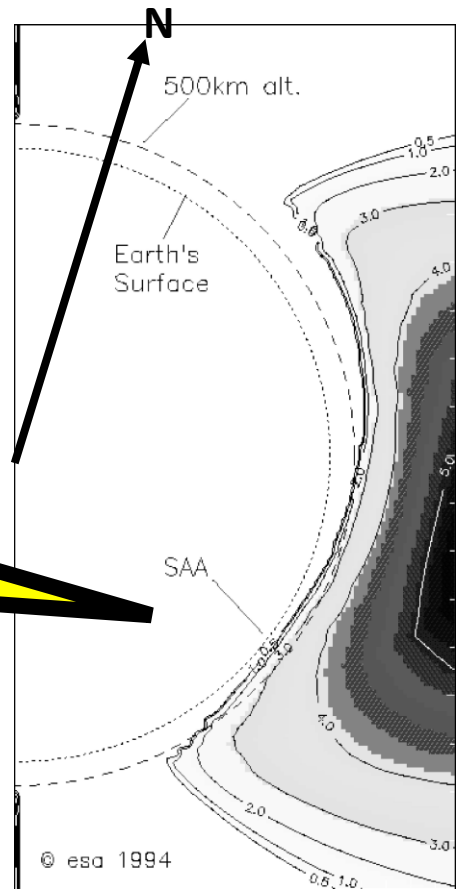
Magnetic Field causes SOUTH ATLANTIC ANOMALY (SAA)

TILTED ~ 10 Degrees (from rotation axis)
- magnetic North is in Greenland

FIELD DISPLACED ~ 500 km from center of earth
- toward the Pacific Ocean

(protons "trapped" in mag field)





RESULT IS a SPOT called the South Atlantic Anomaly

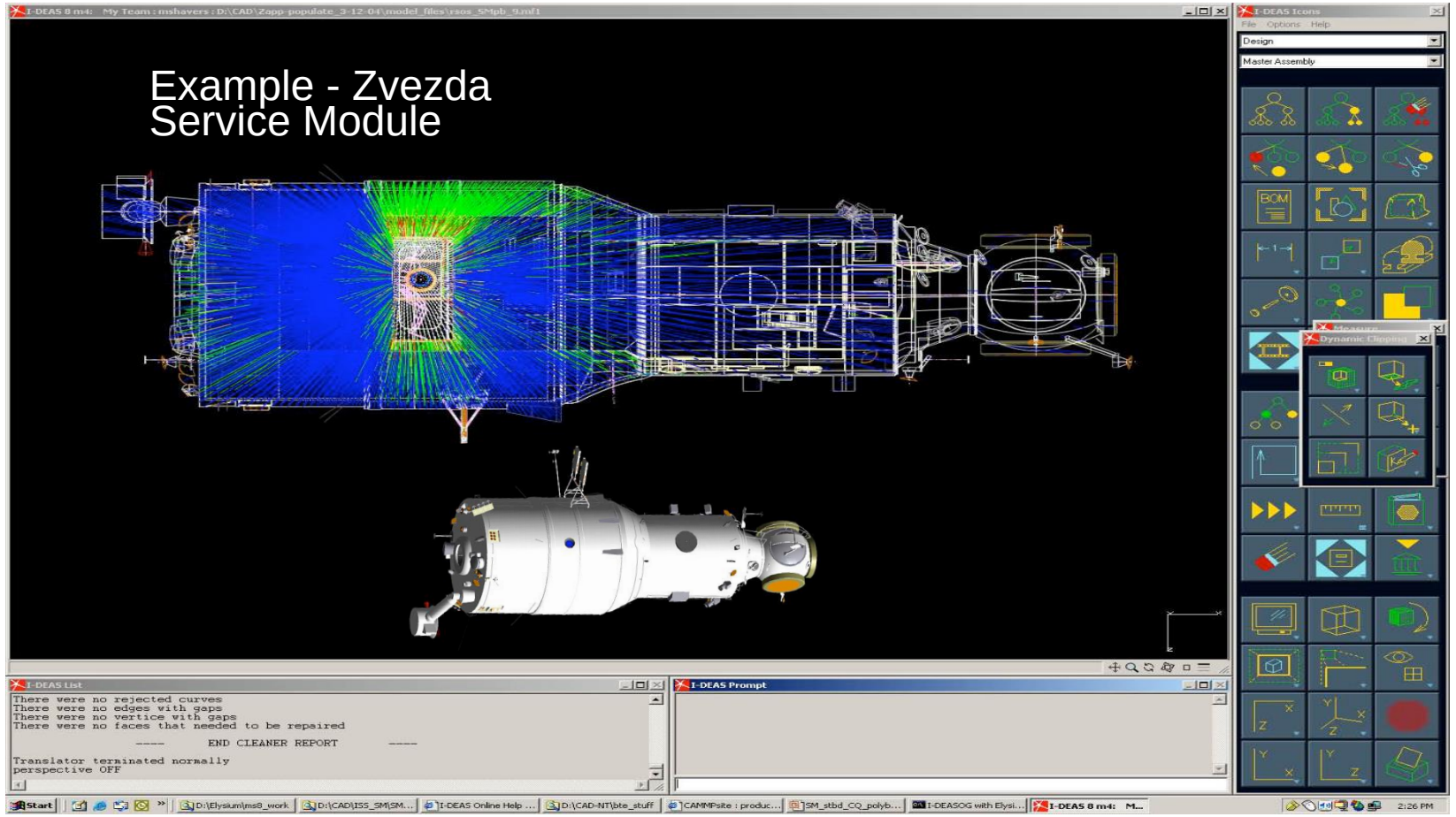
STRONG ALTITUDE DEPENDENCE

Analysis Tool
NASA JSC CAD Model - Ray Tracing

CAD model calculates mass thickness for 1000's rays from a point inside module

Average thickness into equal bins

Calculate flux (cosmic ray model) transported through each bin



Are CAMERAS Important?

Brownie (Eastman, 1900), Instamatic, SLR's, slides, 8 mm home movies, ... Film

Cell Phone, cars, security, ... Digital Memory

NASA CAMERAS

- Orbiter Boom Sensor System (OBSS) to **inspect Orbiter's tiles upon arrival at ISS** or Skylab star tracker, … **Critical?**

- **live TV** broadcast around the world of NASA astronauts & rovers …moon, Mars **Important?**

- **Scientific** (SOHO Halloween Storms, CHANDRA CCD's, …) **Data Cost $?**

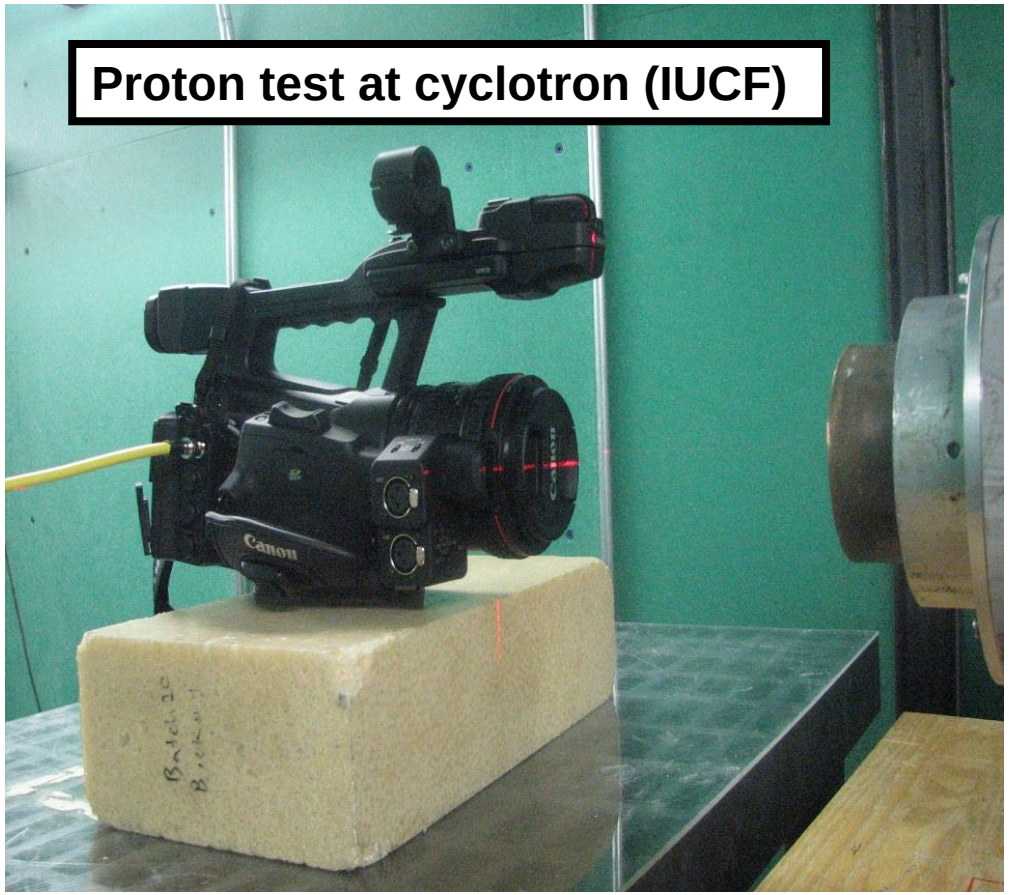
NASA CAMERAS do more than just ... "take pictures"

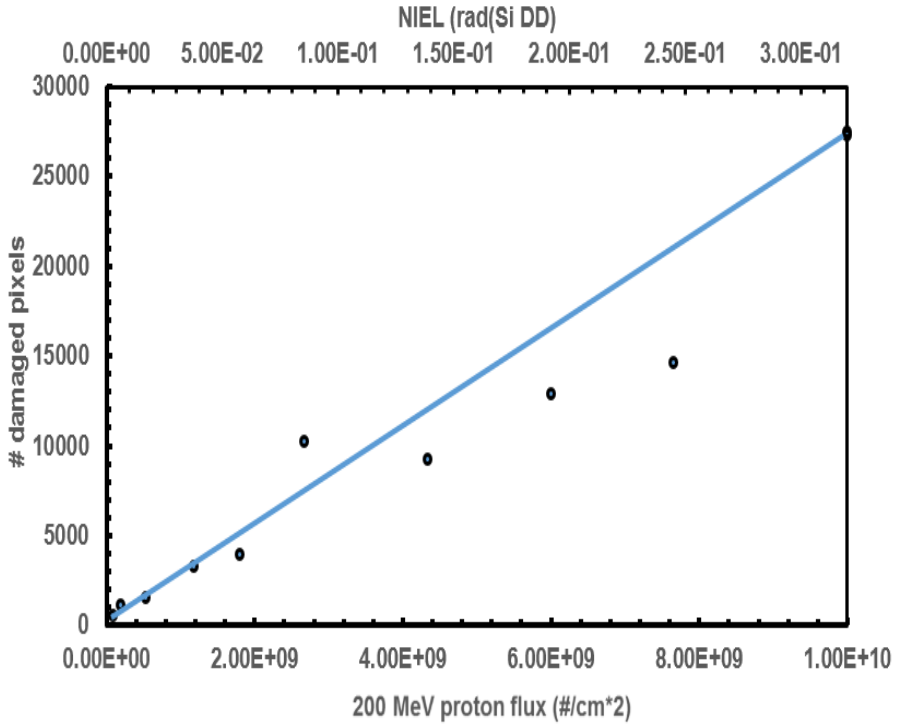
NASA ~ Johnson ~ Houston

PERMANENT BAD PIXELS

Imager degradation correlates with NIEL dose

New ISS High Definition Camera - Canon XF-305





Permanent Damage after annealing

SUMMARY & CONCLUSIONS

BEO - Beyond Earth's Magnetosphere (MEO and above)

CSDA shows SPE (Oct 89 WW) much worse (>2 OOM) than GCR's for low shielding (<2" al)

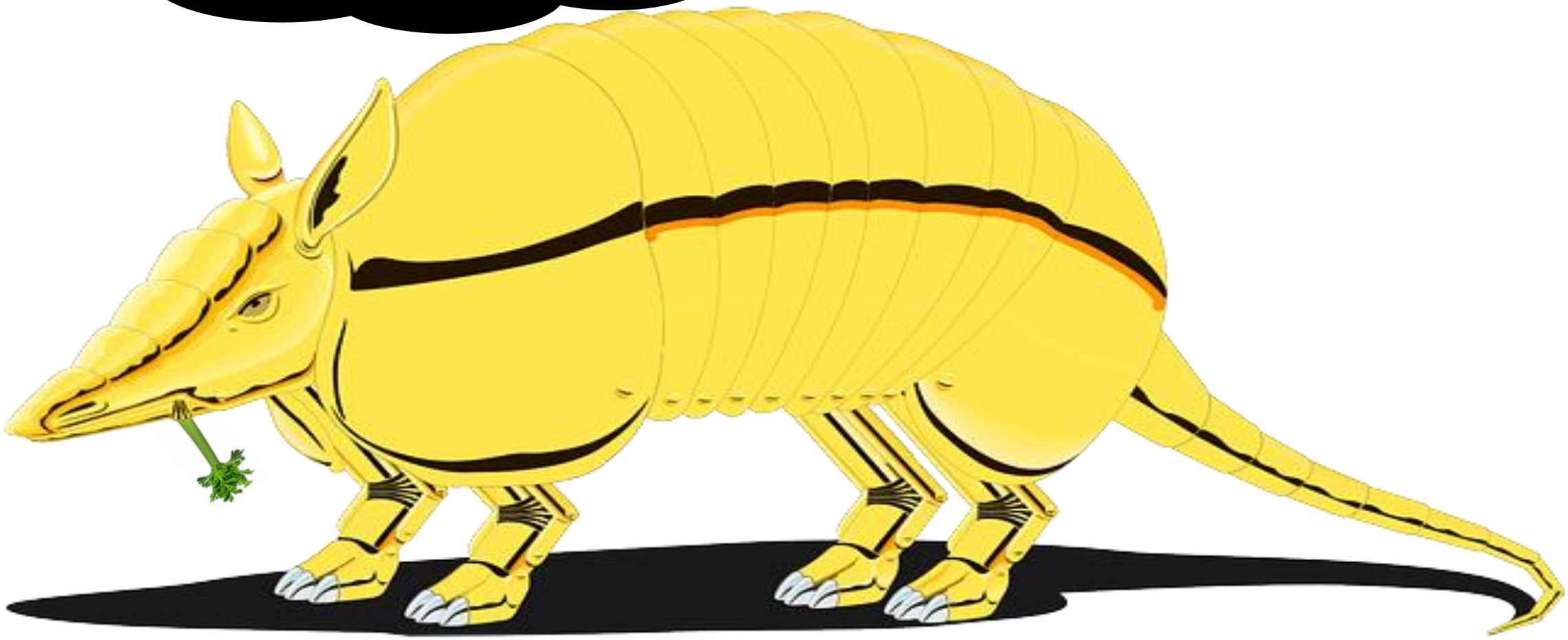
CSDA breaks down for thicker shielding (>4-6" al) for GCR's and SPE (Oct 89 WW)

Dose due to secondary p+n's from GCR's is much higher than for ISS & grows with shielding

TID - 200 rad(si) / yr (1 rad(si) / yr for LEO - ISS at 186 nmi)

DD - 10x's as much optical damage (13,000 vs 1500 pixel / yr)

~last slide


questions or comments?