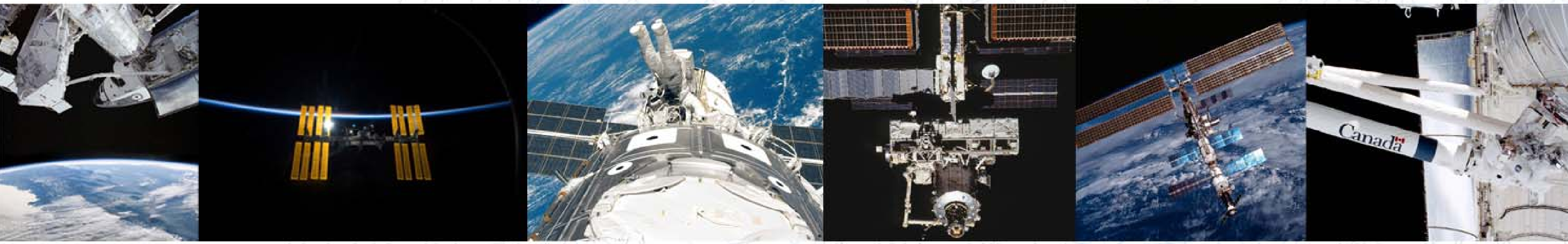
Space Exploration | International Space Station

Automation Conference



Advantages and Challenges of Using COTS Industrial Networking Technology on the International Space Station

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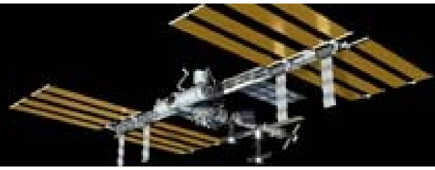
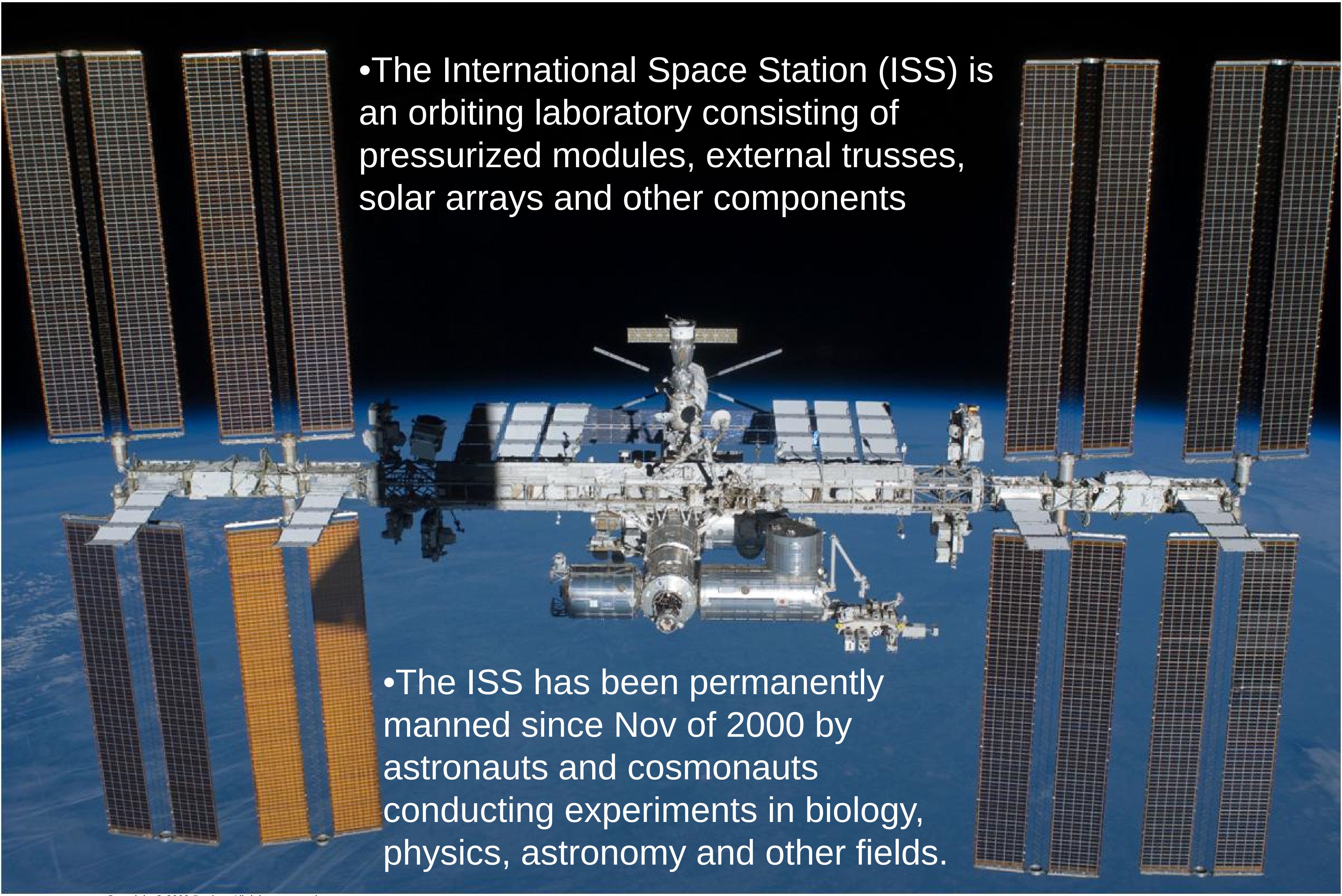
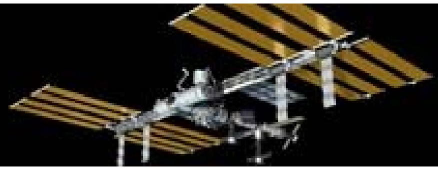


What is ISS?



- The International Space Station (ISS) is an orbiting laboratory consisting of pressurized modules, external trusses, solar arrays and other components

- The ISS has been permanently manned since Nov of 2000 by astronauts and cosmonauts conducting experiments in biology, physics, astronomy and other fields.



ISS Fun Facts

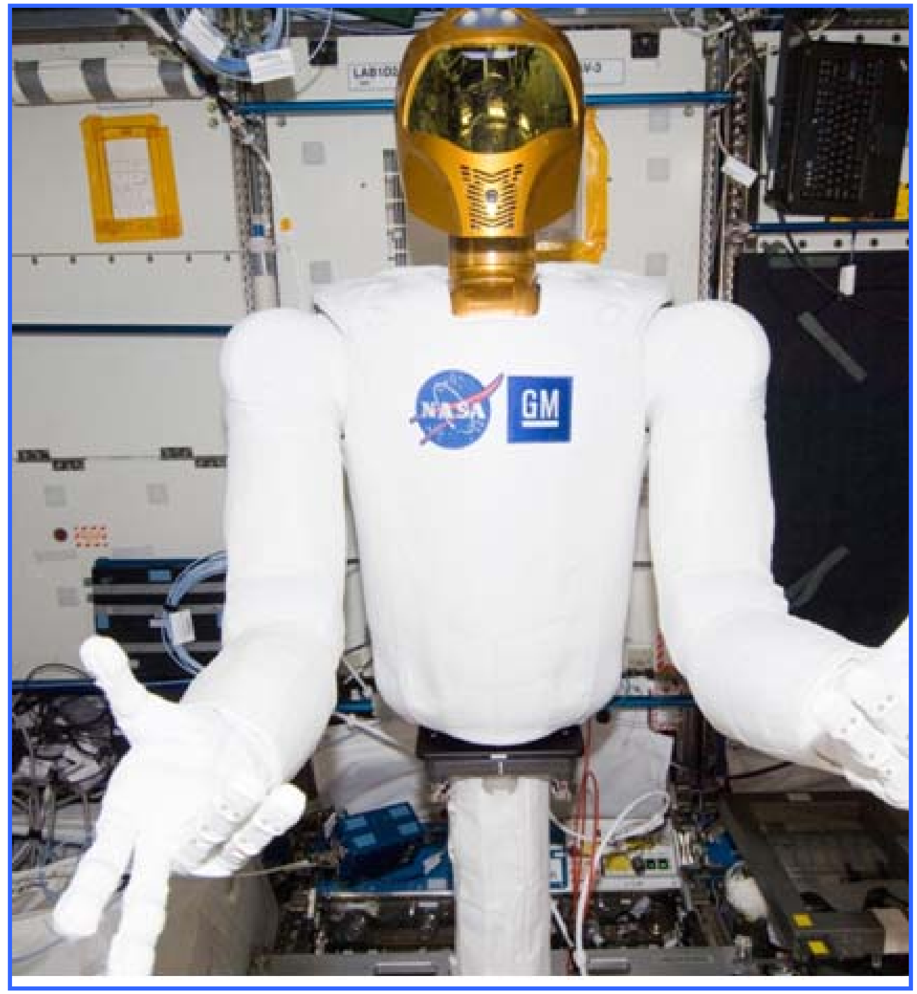
- **The ISS is now the largest artificial body in orbit. It is 357 ft (109 m) in length, making the space station's area span about the size of a football field.**
- **The ISS maintains an orbit with an altitude of between 330 and 435 km (205 and 270 mi)**
- **The space station weighs nearly 925,000 pounds (419,500 kg's).**
- **The ISS has 2 bathrooms, a gym and more room than a 6 bedroom house.**
- **The space station is nearly 4 times bigger than the Russian space station Mir and about 5 times as large as the U.S. Skylab.**
- **On average the ISS travels at 27,724 kilometers (17,227 mi) per hour.**
- **The space station completes 15.5 orbits a day, which means the crew members on board the station experience a sunrise or sunset every 92 minutes.**
- **The ISS program is a joint project that involves 5 space agencies. NASA of USA, Roskosmos of Russia, JAXA of Japan, CSA of Canada and ESA made up of several agencies from Europe.**
- **Over eight miles of wire connects the electrical power system on the ISS.**

Use of Industrial COTS on ISS

- **Use of Commercial Off The Shelf (COTS) electronics have been growing on ISS since the IBM laptop computers were first flown in 2000**
- **The adoption of COTS was driven by a need to lower integration costs for ISS payloads and to deploy newer technology as fast as possible**
- **The use of COTS for non-critical systems was a shift in the mindset of traditional aerospace providers which engineer for extremely high reliability and long service life**
- **The COTS philosophy is to continually upgrade, replacing obsolete technology with the newest available in planned intervals**
- **Use of industrial COTS on ISS is attractive since it's ruggedized, designed for high reliability applications, and has wide temperature ranges**

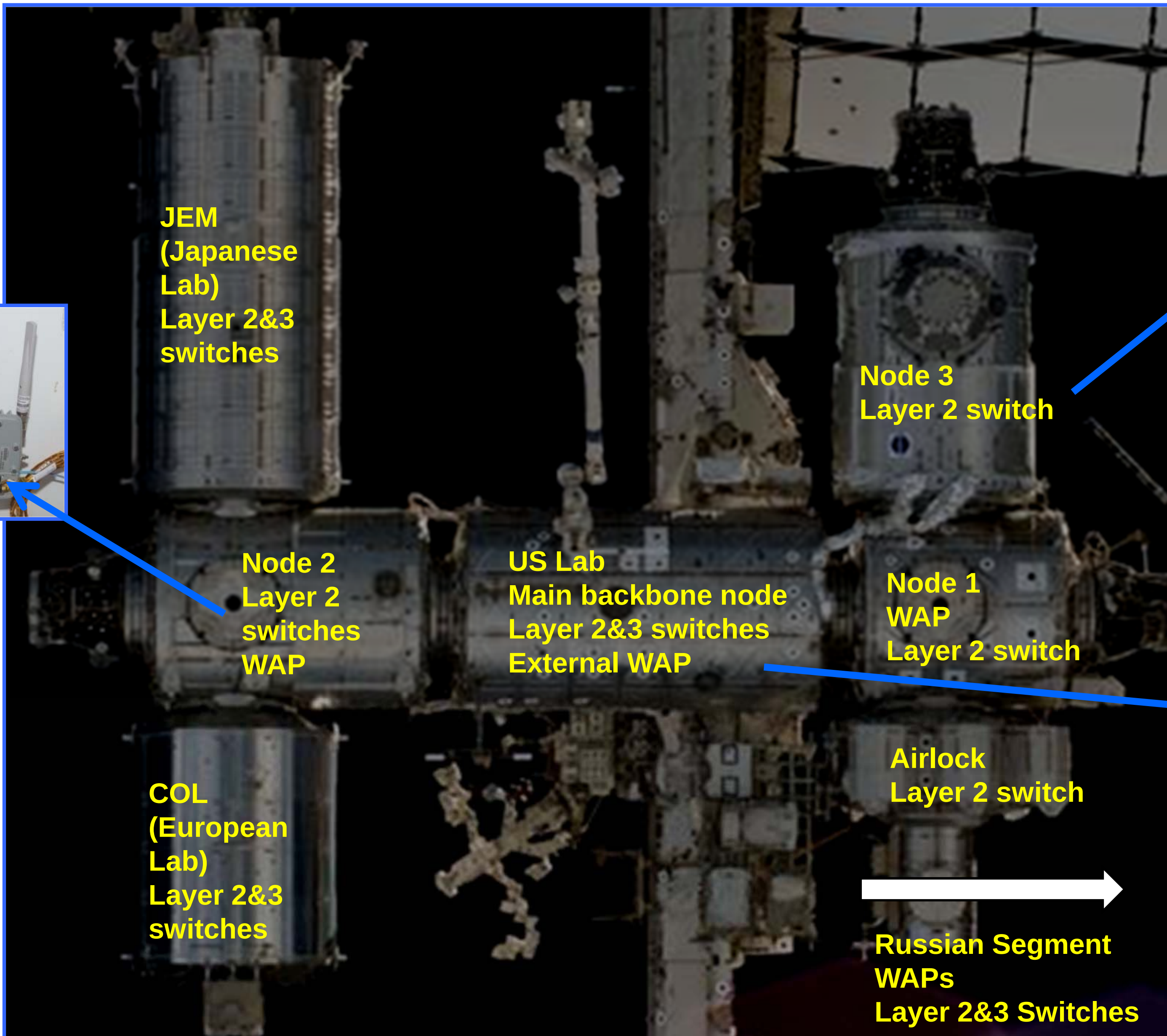
Industrial Automation on ISS

- **Data rate demands from payloads and experiments are driving the use of Industrial Automation on ISS**
- **In particular industrial Ethernet switches and wireless access points have been deployed in several modules to support data demands**
- **One prime example of automation technology transfer is the Robonaut**
- **NASA and General Motors collaborated on the Robonaut in part based on General Motors expertise in assembly line automation**
- **When fully operation the Robonaut will be able to perform tasks outside the space station using the wireless network**

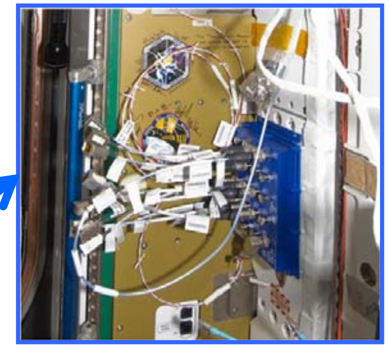


Overview of ISS Network

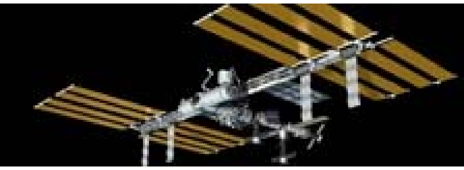
Node 2
Wireless
Access Point
(WAP)



Node 3
Layer 2 Switch



USL Main
Backbone
Router



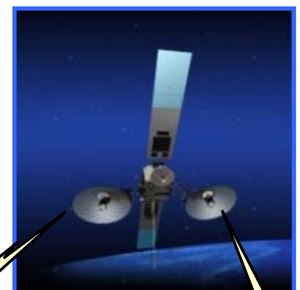
Network Connectivity to ISS

- **The network on ISS works like any other office or factory network**
- **The data does go through a few hops on the way from ISS to the ground but it is seamless to the network**
- **Once data is received at the WSTF (White Sands Test Facility) it can be sent anywhere in the world**

ISS Network

Custom Avionics combines frames and packets with other ISS data and sends to the Ku Band System

Data relayed to a TDRS satellite



Data down linked to WSTF

TDRS to WSTF

Land Lines

Payload Operations and Integration Center (POIC) Huntsville, Al

Mission Control Center (MCC) Houston, TX

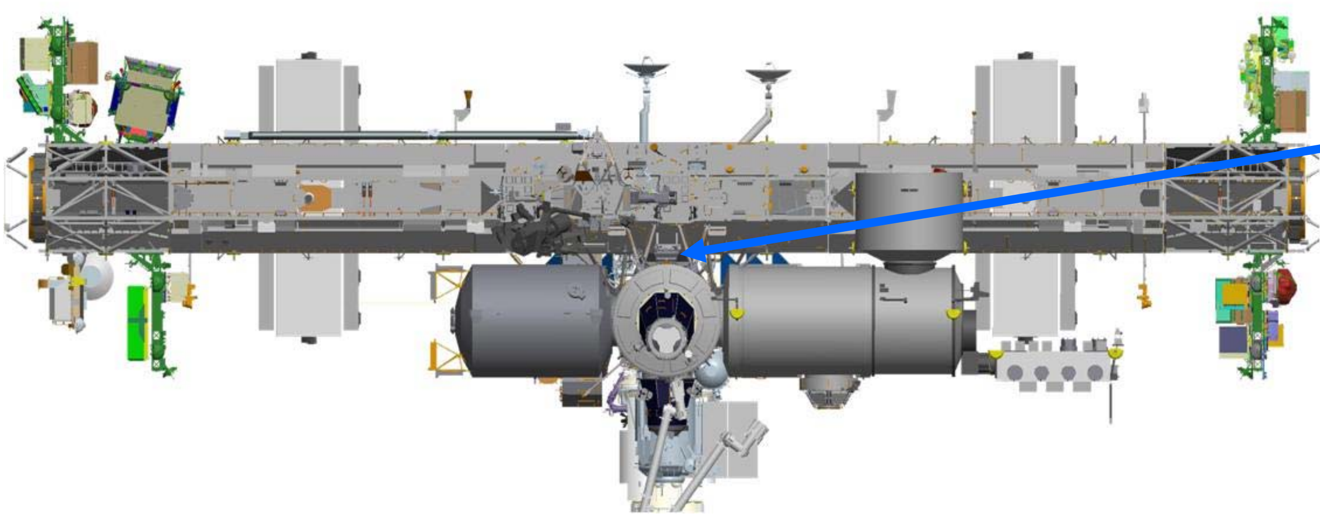
Network Operations

- **Flight controllers in Houston and Huntsville control and configure the by logging into the devices on orbit, similar to any ground network**
- **Payload use of the network is similar to industrial use where custom automated experiments are being controlled via the network**
- **Crew use of the network is similar to an office environment**

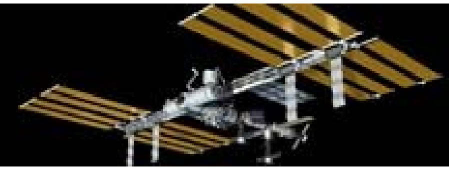
- Crew has access to the internet and email
- ISS has VOIP so the crew can make phone calls to the ground
- ISS LAN supports video conferences with family, flight surgeon, and public affairs events

External Wireless Communication System

- **EWC provides 802.11n communications outside the space station using two WAPs internally connected to external antennas**
- **The first users of the External Wireless Comm (EWC) system are about to be deployed on ISS**
- **This will mark the first major use of COTS electronics outside the ISS**
- **Industrial COTS wireless devices in client mode will be integrated with payloads and other devices using the system**



Wireless Antennas

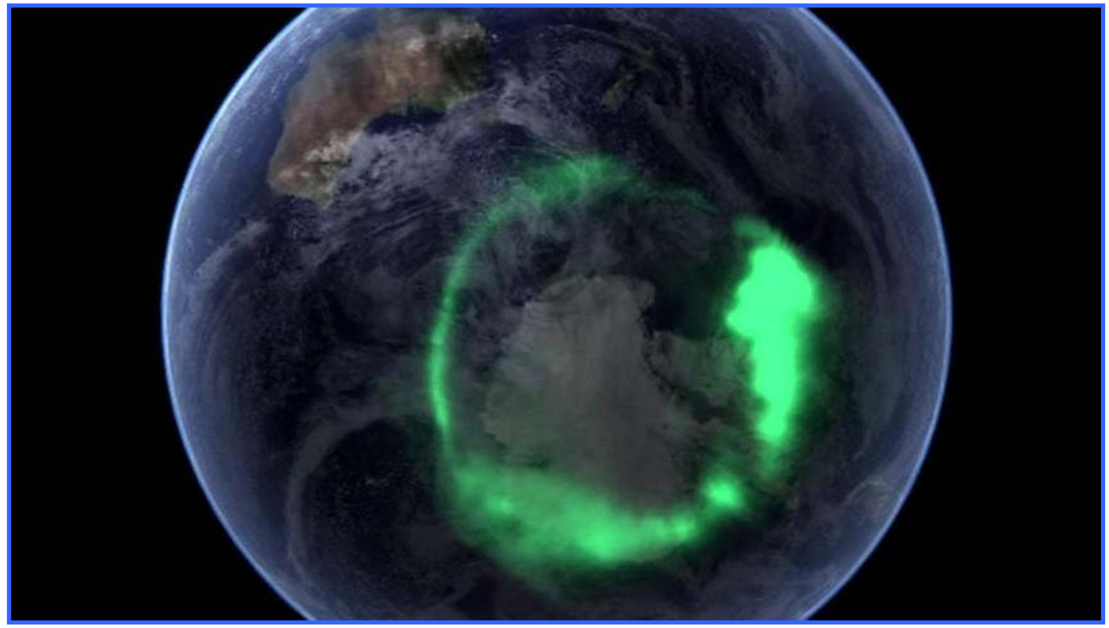


Challenges of COTS in Space Environment

- **The use of COTS on ISS seems like it would be fairly easy but there are many factors to consider**
  - The radiation environment is much harsher at ISS altitudes
  - COTS material are generally do not meet aerospace standards
    - Use or tin plated components in electronics
    - Flammable or Toxic materials in cables
  - The thermal environment is much different on ISS
    - Convection cooling is much less efficient
    - External equipment can routinely experience large temperature changes over its 90 minute orbit.

Ionizing Radiation

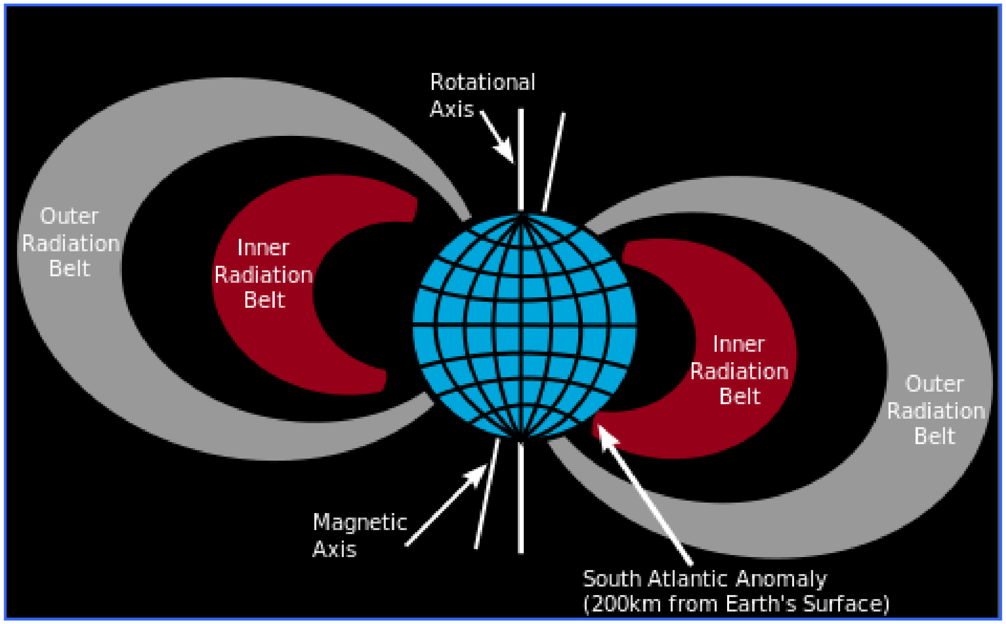
- **Ionizing radiation is radiation that carries enough energy to strip electrons from atoms or molecules**
- **On ISS, ionizing radiation is made up primarily of high energy protons from cosmic rays and solar wind**

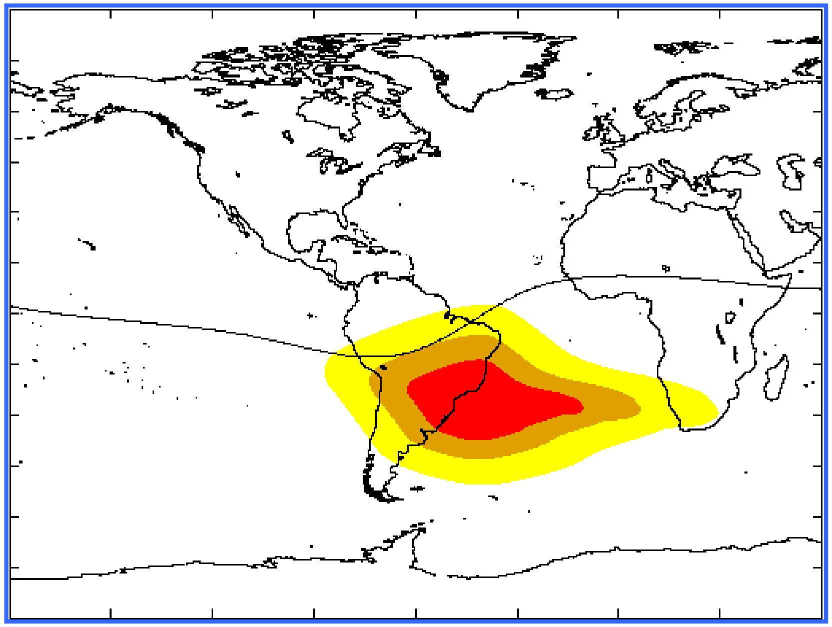


  - **These particles are normally absorbed by the Earth's atmosphere and when they interact with atmosphere in sufficient quantity they cause aurora**
  - **Without the protection of the Earth's atmosphere the ISS and crew are exposed to about 1 millisievert each day, which is about the same as someone at sea level would experience in a year**

South Atlantic Anomaly

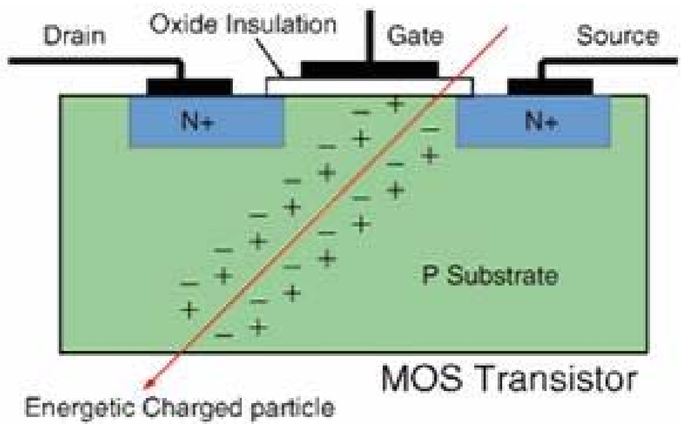
- The earth's radiation belts also have an impact on radiation dose
- South Atlantic Anomaly (SAA) is an area where the Earth's inner Van Allen radiation belt comes closest to the Earth's surface dipping down to an altitude of 200 km (124 mi)
- A majority of the radiation effects seen with COTS hardware on orbit happens in this region



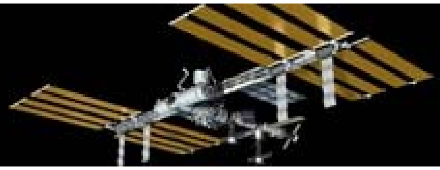


Radiation Effects on Electronics

- Radiation striking electronic devices ionizes the medium they pass through leaving trail of electron-hole pairs
- A single event upset (SEU) is a change of state caused by the radiation striking a sensitive node in an electronic device
- Generally a SEU will cause the device to become non-operational until it is power cycled
- Single Event Latchup (SEL) can also occur which causes a short circuit and permanently damages the device
- Unless units are specifically designed for and ionizing radiation environment there is generally no indication how they will behave when tested



Radiation ionizes the medium they pass through leaving trail of electron-hole pairs

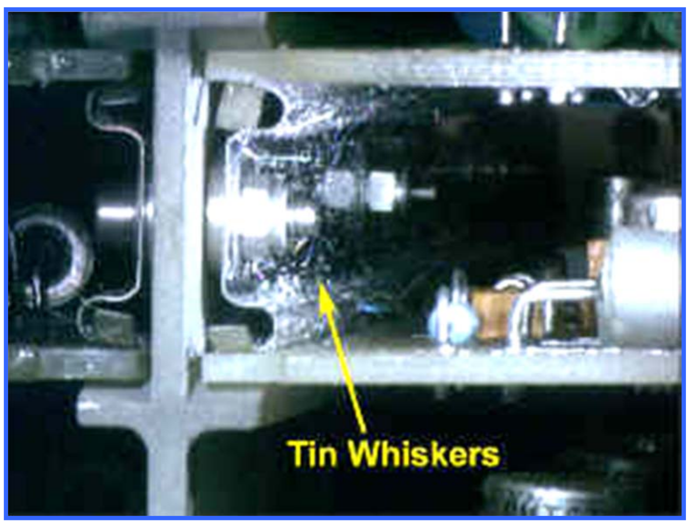


Radiation Testing

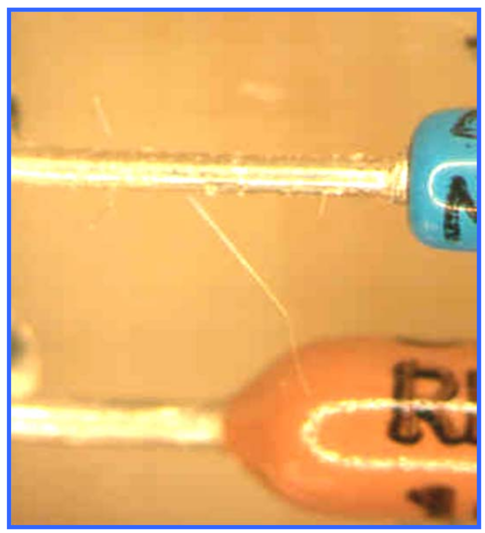
- **Devices planned for use on ISS are tested at a cyclotron facility which create a beam of high energy protons that are directed at the electronic equipment**
- **To find a suitable 802.11n wireless access point for ISS, about 15 were tested**
  - 3 were suitable from a radiation standpoint
  - 1 unit had a destructive latch-up
  - The other units had SEU rates that were too high to make on orbit operation worthwhile
- **As electronics get smaller, more densely packed and lower power they become more vulnerable to the effects of ionizing radiation**
- **Concern grows with each generation of high speed networking hardware that it will be more difficult to find suitable candidates**

Tin Whiskers

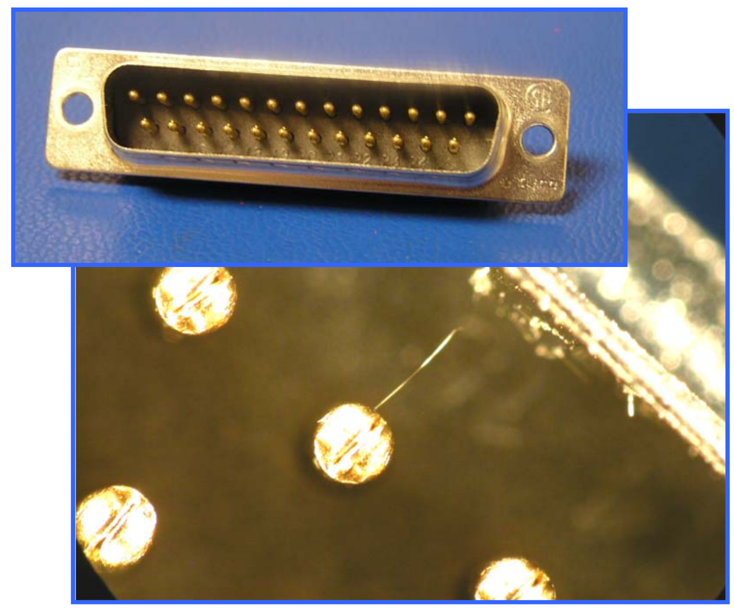
- **Tin whiskers are electrically conductive, crystalline structures of tin that sometimes grow from surfaces where tin is used as a final finish**
- **Numerous electronic system failures have been attributed to short circuits caused by tin whiskers**
- **Based on the type of conformal coating, it may or may not be an effective mitigation for tin whisker growth**



Whiskers on Shuttle card guide



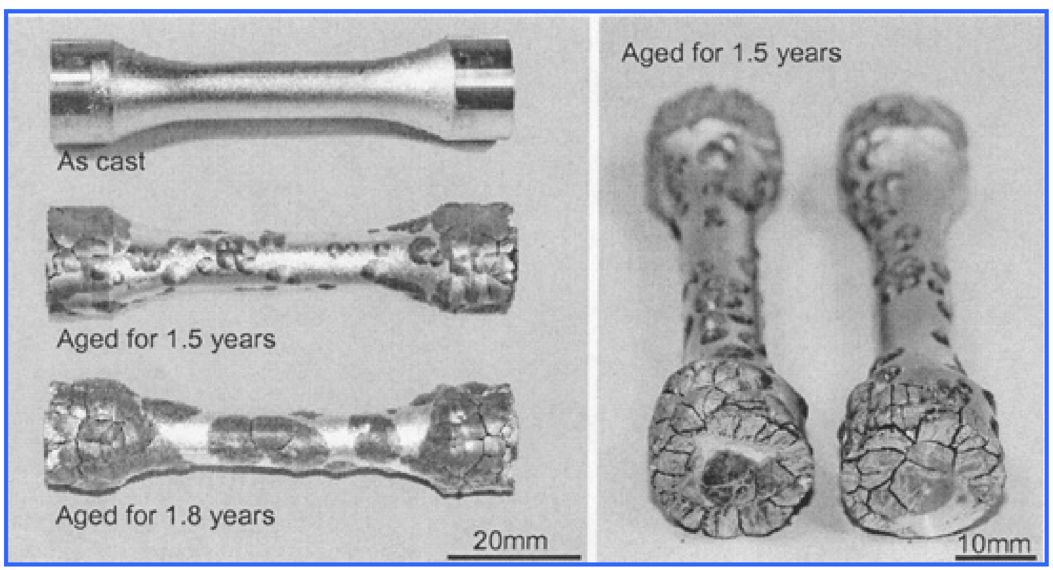
Whiskers on tin lead



Whiskers on common connector

Tin Pest

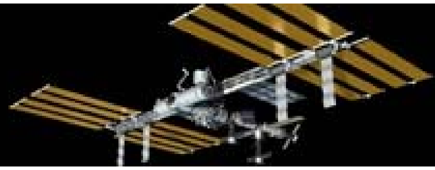
- **Tin pest is a change in the crystalline structure of tin from a ductile metallic beta tin to non-metallic alpha tin which then decomposes into a powder**
- **Tin pest can forms at temperatures less than 13.2 C (56 F), but most experts believe maximum rate of tin pest formation occurs at -30 C (-22 F) to -40 C (-40 F)**
- **Historical examples of tin pest included church pipe organs in medieval Europe that disintegrated in cold climates**



Tin pest seen on ISS

Restriction of Hazardous Substances (RoHS)

- **Traditionally, solders have been a mixture of lead and tin which reliably prevent tin whiskers and tin pest**
- **The Restriction of Hazardous Substances (RoHS) Directive in Europe restricts the use of lead in products has been the driver for use of lead free solders in most electronic devices worldwide**
- **This change has revived concerns over reliability of electronic components based on the known issues with tin**
- **The aerospace industry still requires use of solder with lead for core avionics and have been slow to adopt industrial COTS even in non-critical applications due to these reliability concerns**
- **Rationale for using COTS on ISS is based in part on the reliability achieved in the harsh operating conditions in industrial automation applications**



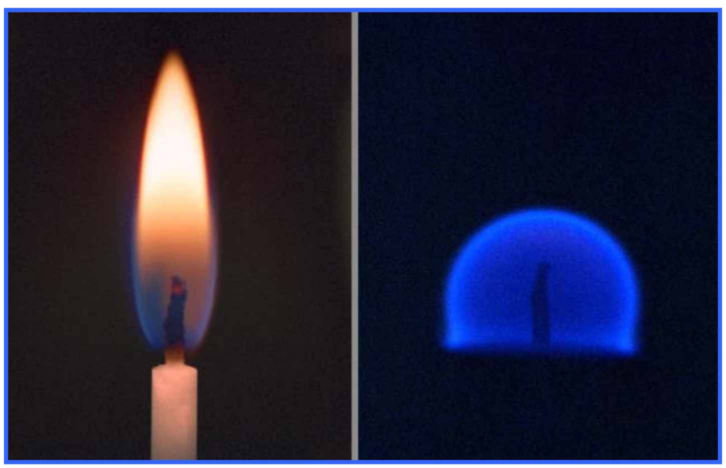
Flammability & Toxicity

- **Flammability and Toxicity are serious concerns on the ISS**
- **On February 24, 1997 a fire occurred on the Russian space station Mir after a cosmonaut routinely ignited a canister that produced oxygen**
- **The fire was eventually extinguished but is was a close call**
- **Materials are selected to prevent flame propagation and release of toxic byproducts produced by burning or melting**
- **Unfortunately most industrial cables do not meet these requirements and they either need to be wrapped in Teflon or cables must be custom manufactured with better materials**
- **Plastic enclosures on some COTS can also be an requiring repackaging for use on ISS**
- **General toxicity is also a concern since ISS is a totally self contained environment so anything that gets in the atmosphere stays there**
- **All items are screened for off gassing (ie new car smell) to make sure they do not pose a hazard to the crew**

COTS Thermal Challenges – Inside ISS

- **Convection cooling is much less efficient on ISS then on the ground since hot air does not rise in space**
- **In the absence of force air cooling convection only occurs by molecular motion**
- **Most COTS is placed in the crew volume where the life support system fans circulate air and can aid cooling**
- **Even with the cabin air circulation the COTS items still tend to get warmer in space than they do in the lab environment**
- **The issue then with these items in the cabin is if they pose a burn hazard to the crew**

On earth hot combustion products rise away from the wick



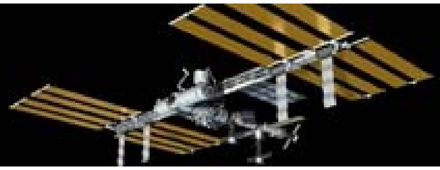
In space combustion products stay concentrated around the wick

COTS Thermal Challenges – Outside ISS

- Most external payloads are built vacuum tolerant so the integrated COTS equipment will also need to operate in a vacuum
- Since conduction is non-existent in space vacuum care must be taken to design an enclosure that can draw heat from the COTS board using only conduction and radiation
- Also some locations of ISS can see temperature differences from -100 C to +100 C between orbital winter and orbital summer
- The day night cycle occurs every 90 minutes on orbit so the temperature can swing 60 C
- Power is a limited resource on ISS so most systems have heaters that activate around -20 to -40 C, this means that the COTS item is going through massive thermal cycles every 90 minutes usually over a significant portion of their design range

Environmental Protection

- **Environmental protection like IP67 can also be important inside ISS**



Summary

- **In an effort to reduce integration cost and speed deployment of the latest technology to ISS, tools and techniques for the industrial automation industry have been leveraged**
- **Many factors must be considered when using COTS in space to provide a safe and reliable devices**
- **Improvements in ruggedness and reliability driven largely by the automation and automotive industries have gradually changed attitudes in the aerospace community to allow COTS use**
- **Industrial COTS is now being deployed for non-critical but very important research and crew support functions on ISS**

Questions??