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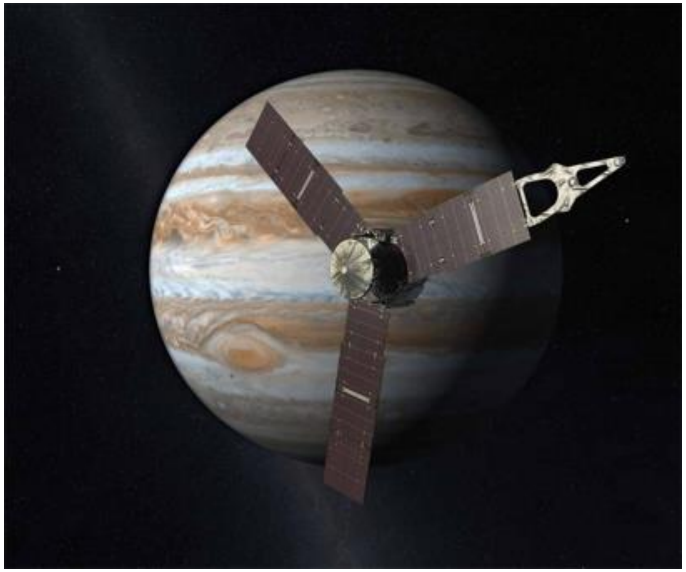


Technical Challenges In The Development Of Jupiter-Bound Interplanetary Spacecraft

Pablo S. Narvaez

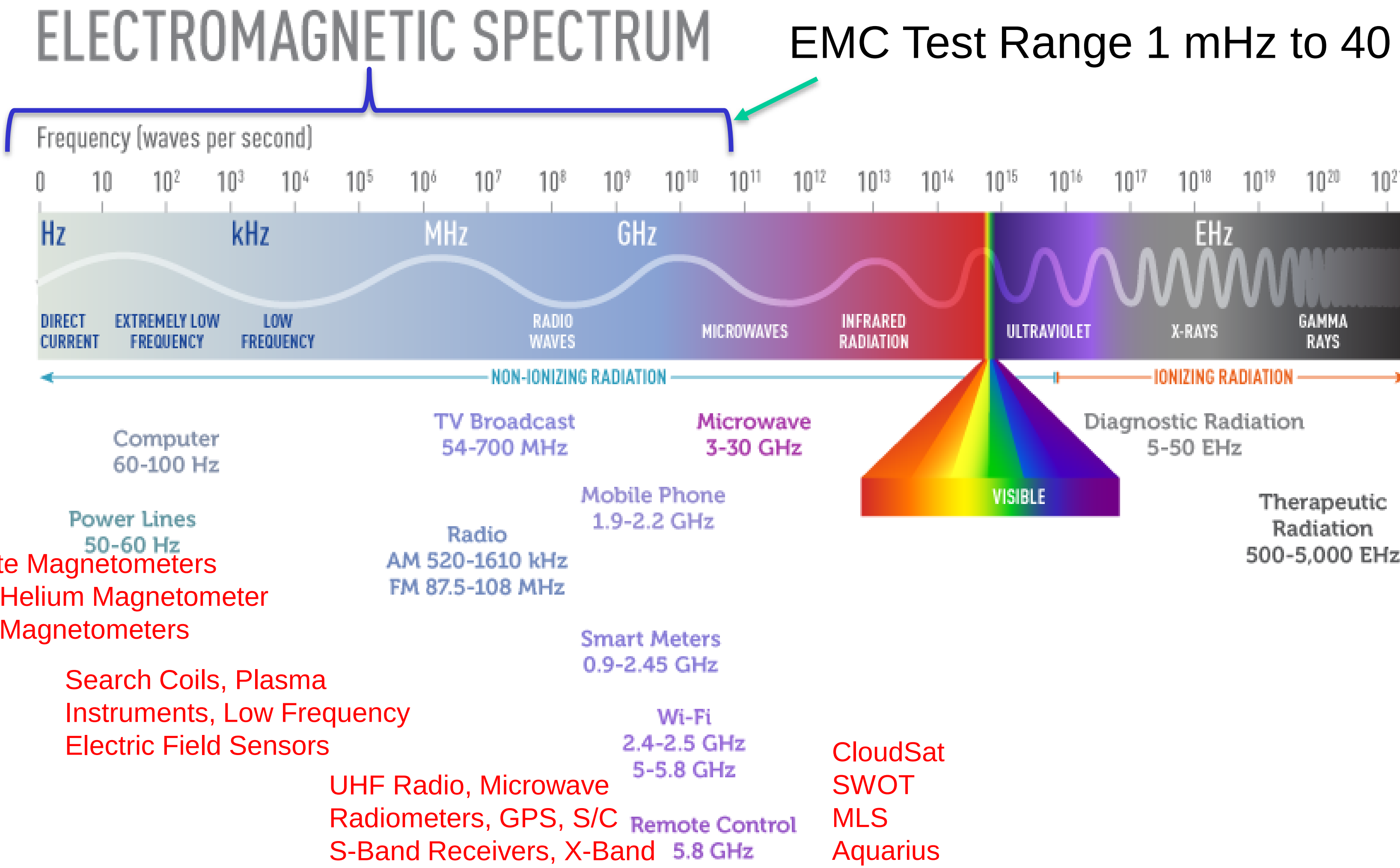
Jet Propulsion Laboratory, California Institute of Technology

June 6, 2018

IEEE ARGENCON 2018

Electromagnetic Spectrum

EMC Test Range 1 mHz to 40 GHz



Fluxgate Magnetometers
Vector Helium Magnetometer
Scalar Magnetometers

Search Coils, Plasma Instruments, Low Frequency Electric Field Sensors

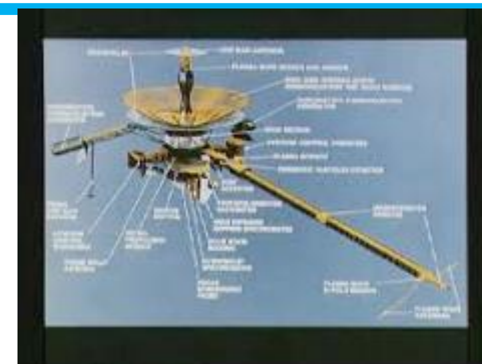
UHF Radio, Microwave Radiometers, GPS, S/C S-Band Receivers, X-Band Focal Plane Arrays/Detectors

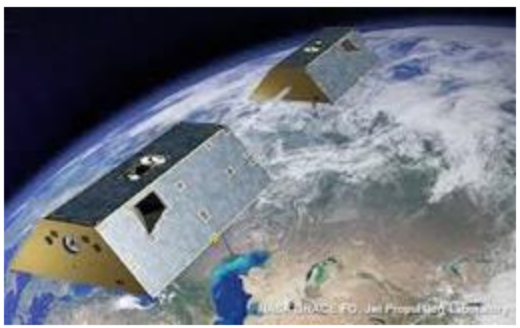
CloudSat
SWOT
MLS
Aquarius

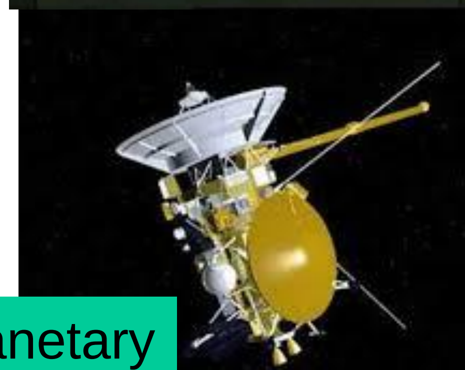
Electromagnetic Compatibility/Interference

- ElectroMagnetic Compatibility (EMC) is the branch of electrical sciences which studies the intentional and unintentional generation, propagation and reception of electromagnetic energy and its unwanted effects. EMC ensures that electronic components/subsystems function together in the resulting electromagnetic environment and ensures the ability of a system that contains multiple electronic boxes (ie typical science instruments with electronics and sensor elements) to function as intended without degradation or malfunction in their intended operational electromagnetic environment.
  - Emissions are related to the unwanted generation of electromagnetic energy by a source (a component/subsystem that is an emitter of electromagnetic energy).
  - Susceptibility or immunity, in contrast, refers to the correct operation of electrical equipment, referred to as the victim, in the presence of unplanned electromagnetic disturbances. A victim is a component/subsystem that is susceptible to interference).
- ElectroMagnetic Interference (EMI) is a phenomenon in which one component/subsystem interferes with the proper operation of another subsystem due to the propagation of electromagnetic energy.
- Interference, or noise, mitigation and hence electromagnetic compatibility is achieved primarily by addressing both emission and susceptibility issues, i.e., quieting the sources of interference and hardening the potential victims.

Which Typical Projects Requires EMC?







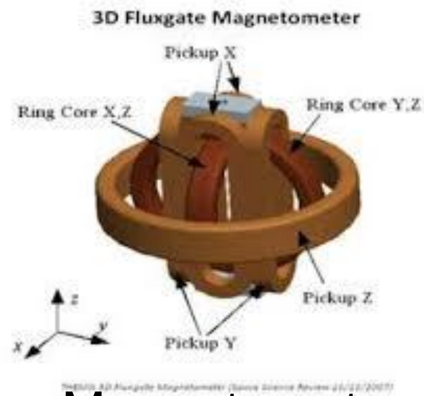
Interplanetary

Earth Orbiters

Landed Systems

Typical Sensitive Instruments To EMI

Detectors



Magnetometers

Plasma Waves Search Coils

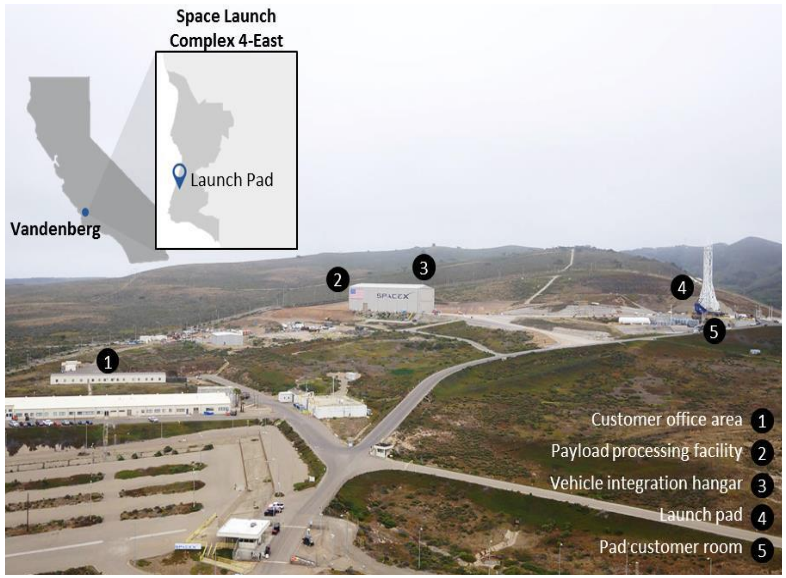
Focal Plane Arrays

Radiometers

UHF/GPS
S/X/Ka Band
Telecom/Receivers

KSC or VAFB Launch Site

On Site Base Transmitters For Weather, Airplane (FAA) Tracking, Launch Tracking, etc.



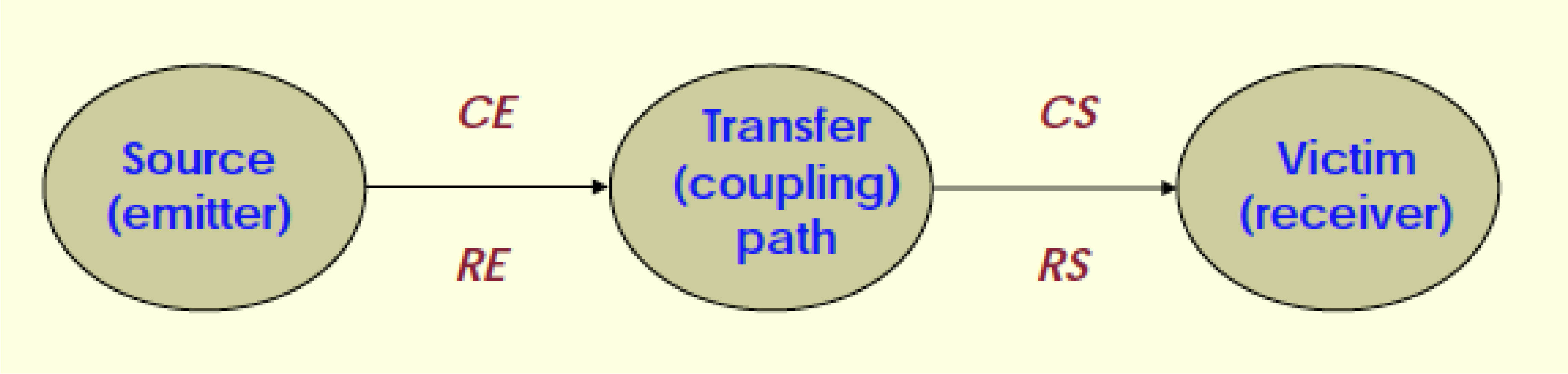
Low Earth Orbit

Research, Military, Commercial Radars and Tracking Stations Based Throughout The Globe

High Powered Tx
Russia
China
US
UK etc…

EMC Interactions

- **Basic EMI Interactions**
  - **EMI is controlled by four categories**
    - **Conducted Emissions (CE)**
    - **Conducted Susceptibility (CS)**
    - **Radiated Emissions (RE)**
    - **Radiated Susceptibility (RS)**

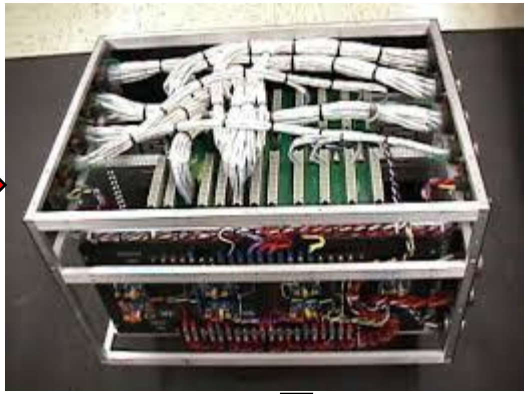


EMI At Every Level

Part Level

PC Board Level

Box Level

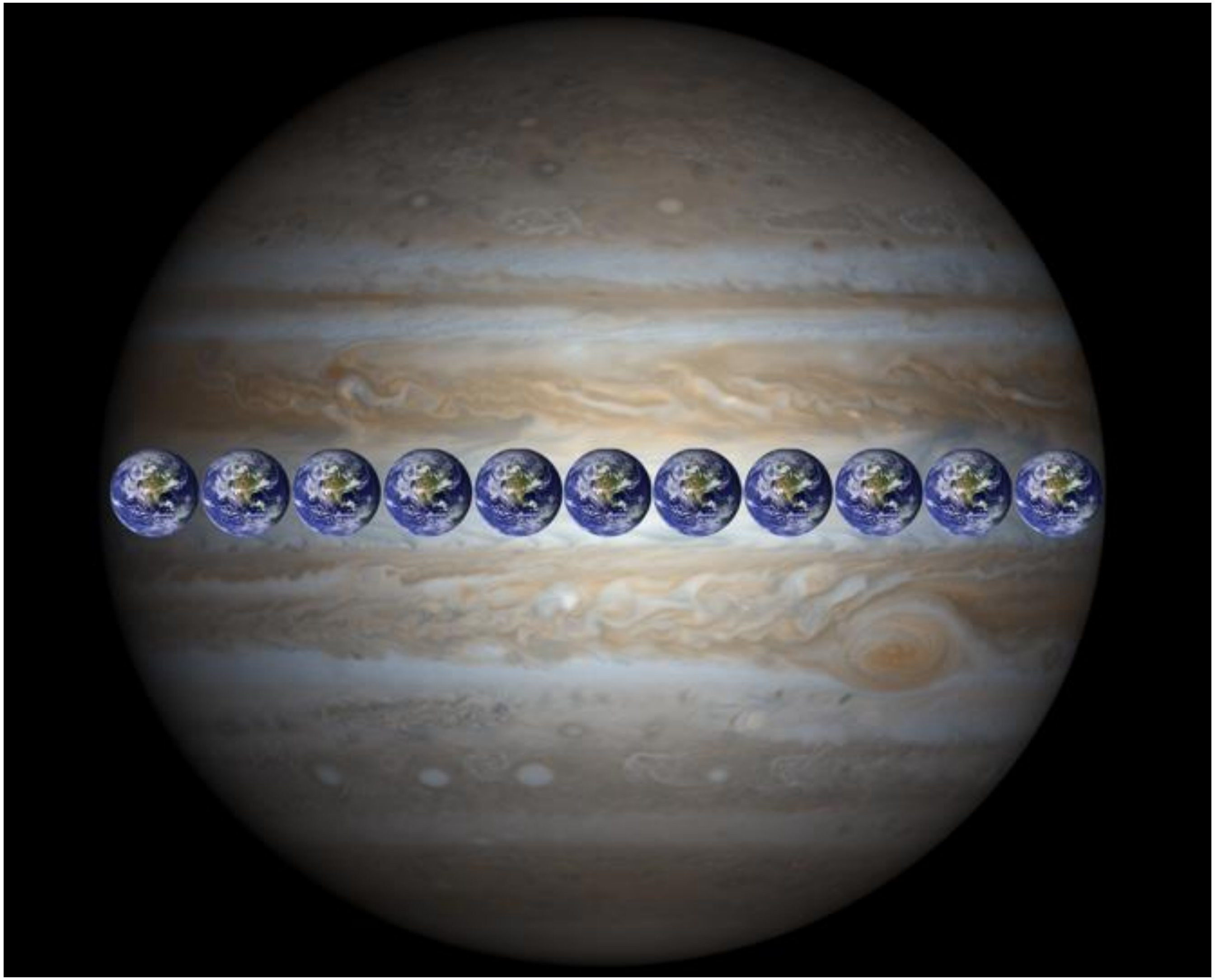


System Level

Instrument Level

Subsystem Level

Jupiter



The Pioneer Spacecraft

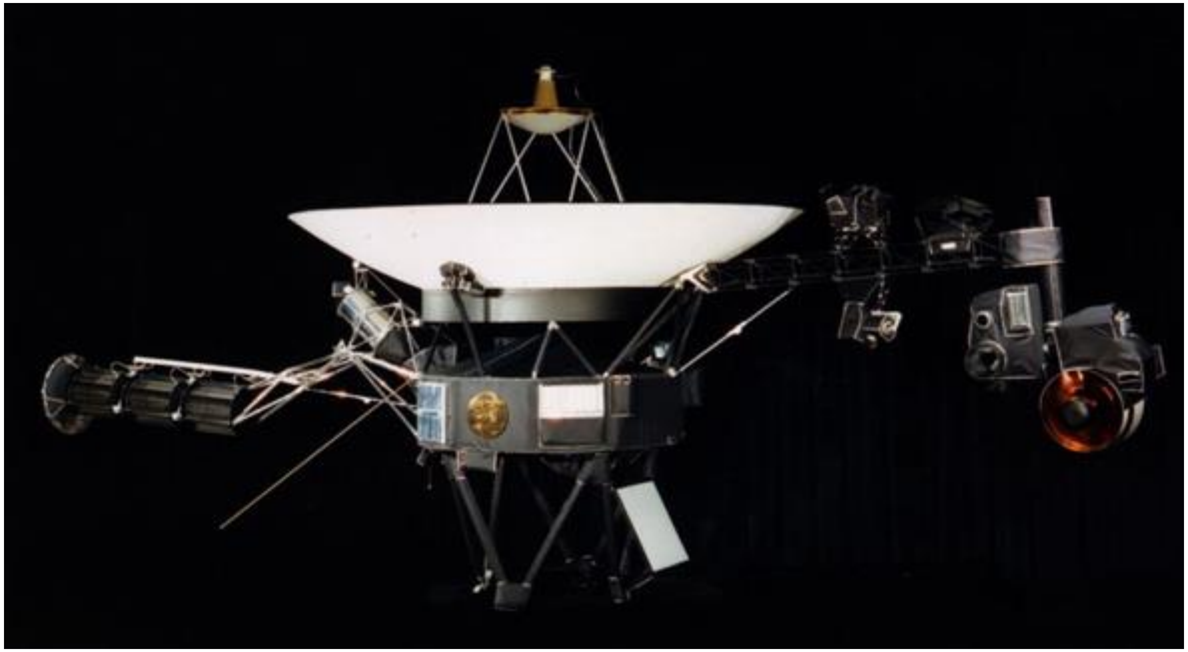
Pioneer 10 & 11

Pioneer 10 and Pioneer 11 were the first spacecraft to travel to a planet beyond Mars. They were launched one year apart, in 1972 and 1973. They both flew by Jupiter (Pioneer 10 arriving first), and Pioneer 11 went on to Saturn.

The Voyager Spacecraft

Voyagers 1 and 2

The Voyagers made many important discoveries at Jupiter. Launched in 1977, they sent back detailed pictures of Jupiter's incredible cloud system, including the Great Red Spot, a giant storm that rotates endlessly like an enormous hurricane. The Voyagers also took pictures of Jupiter's major moons.



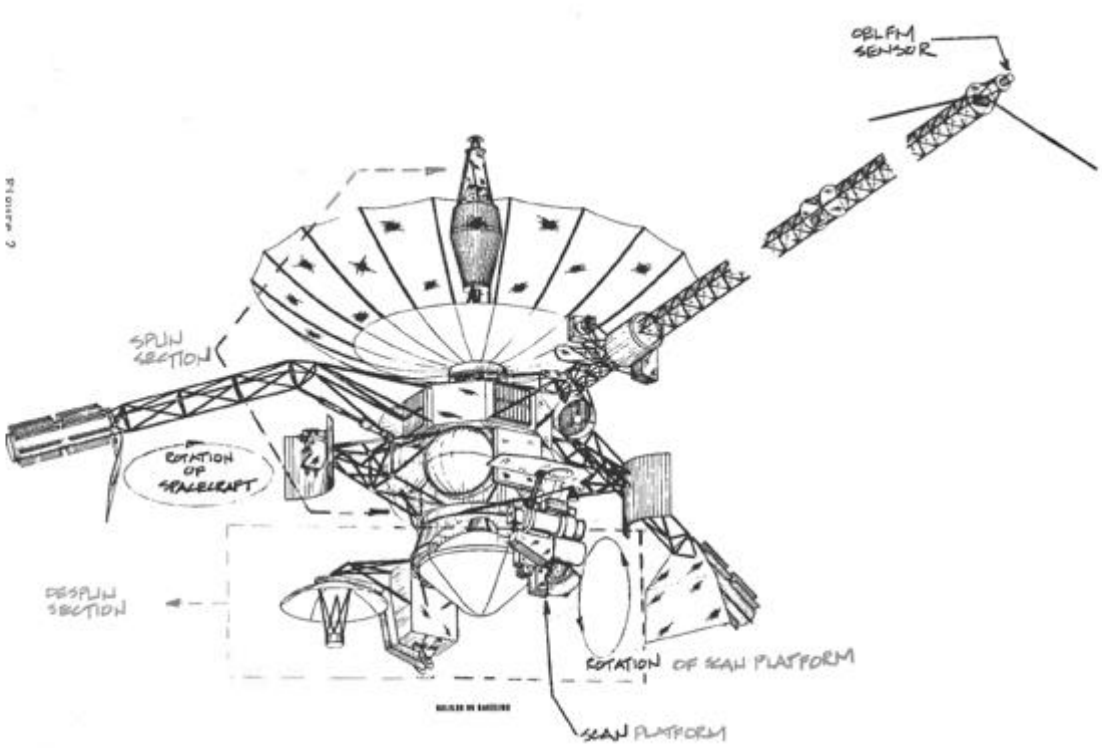
The Galileo Spacecraft

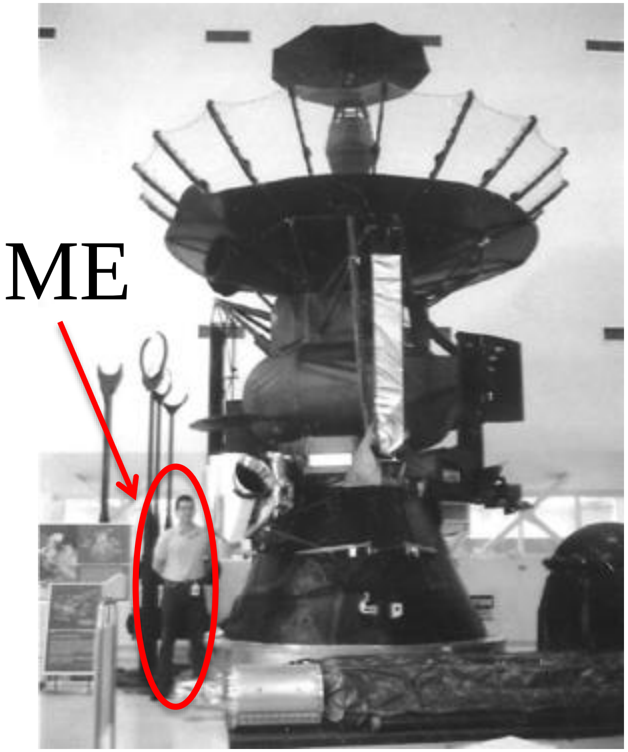
Galileo

No spacecraft revealed more about Jupiter and its moons than the Galileo orbiter. Galileo, launched in 1989, spotted the first of evidence of an ocean on Europa, and also found signs a few other large moons may have liquid water under an icy crust.

The Galileo Spacecraft

Galileo

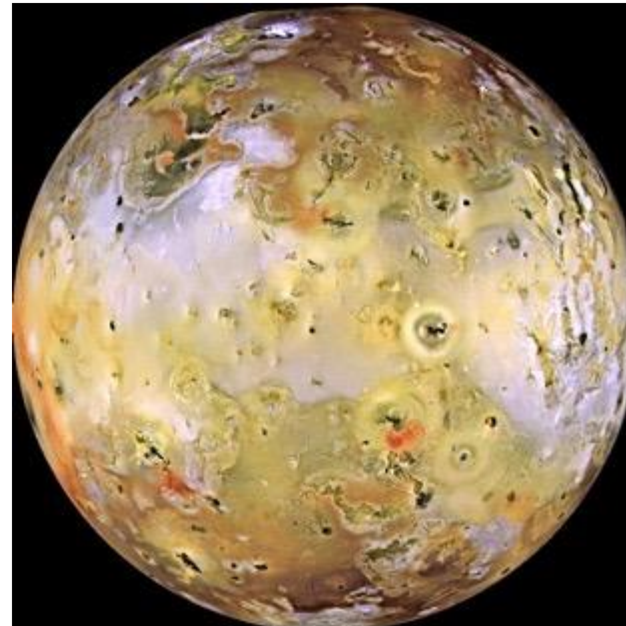


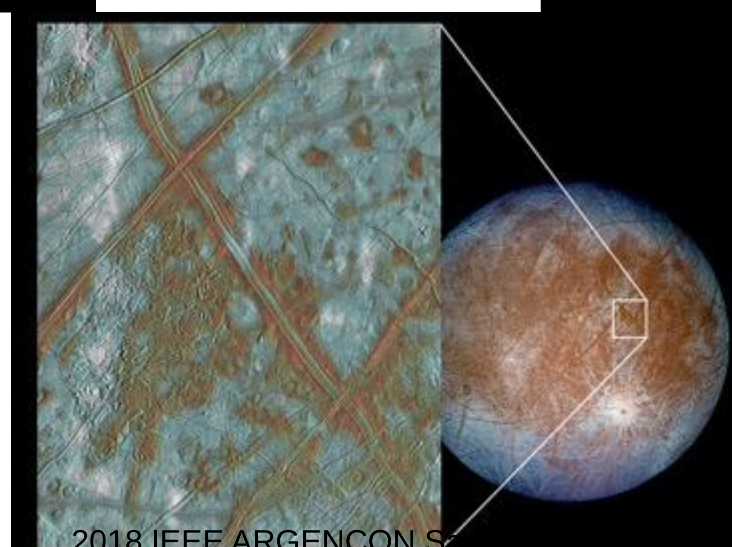


The Galileo Spacecraft

Galileo

The Galileo Spacecraft

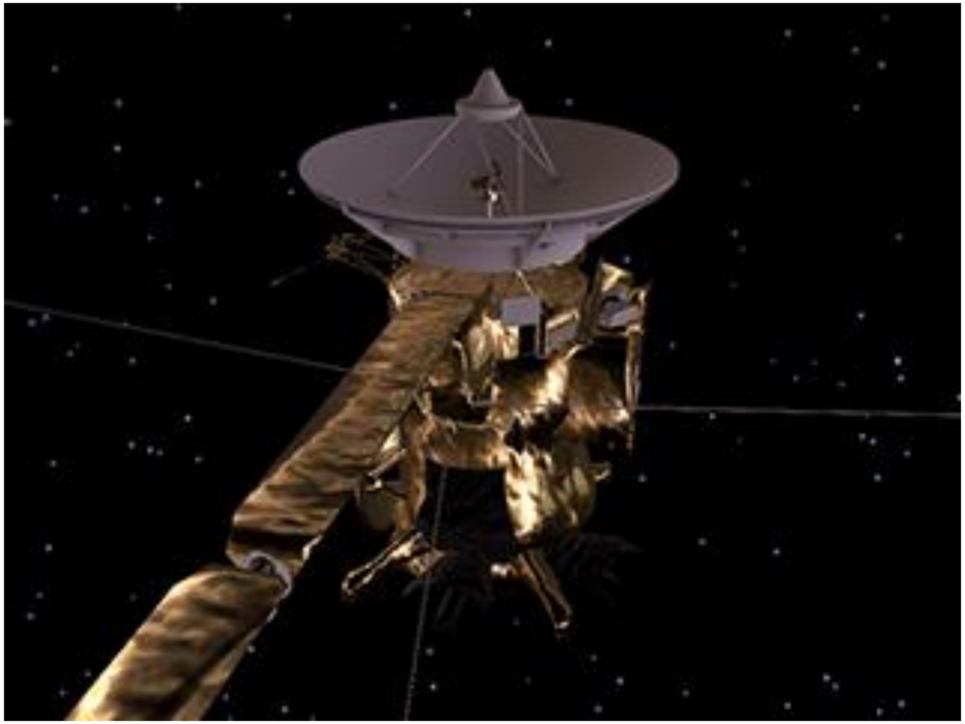




The Cassini Spacecraft

Cassini

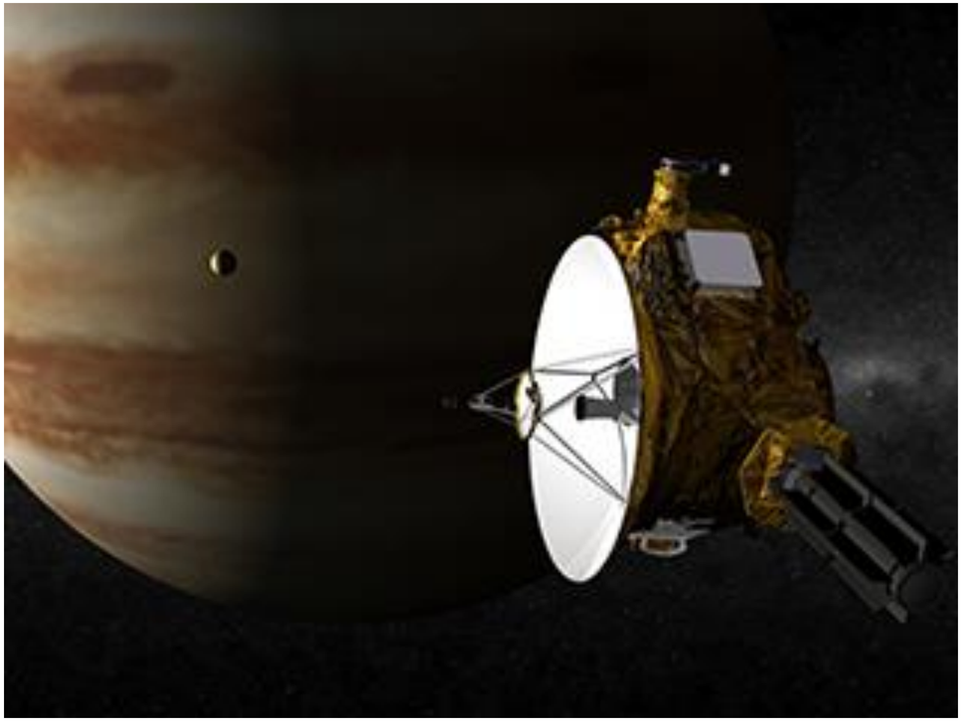
Cassini used Jupiter's gravity to boost it on to Saturn. Launched in 1997 on its way to Saturn, Cassini flew past Jupiter to get a gravity boost. The spacecraft also teamed up with the Galileo spacecraft, already in orbit at Jupiter at the time of Cassini's gravity boost, to study the Jovian system from two unique vantage points at the same time.



The New Horizons Spacecraft

<u>New Horizons</u>

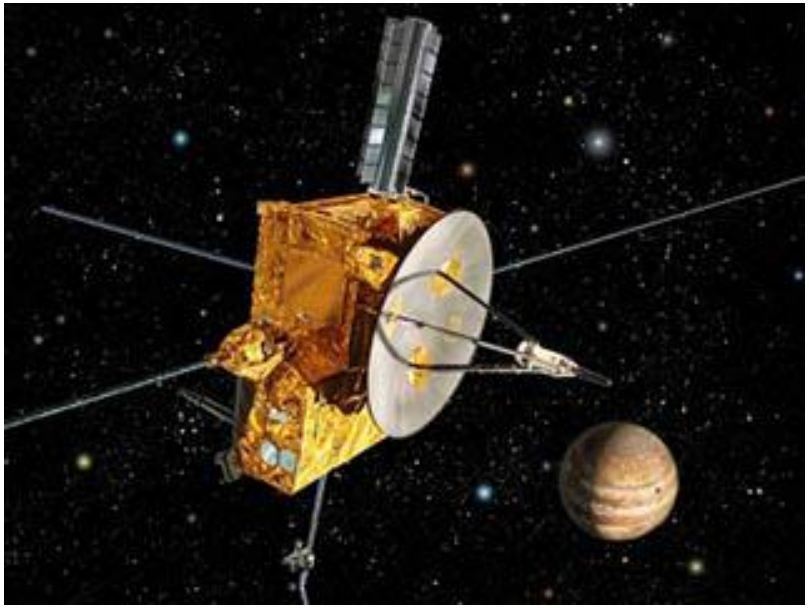
Pluto-bound New Horizons used a 2007 Jupiter gravity assist to study the giant world and test out its science instruments before its historic Pluto flyby in 2015. The spacecraft captured new images of Europa and other key moons.

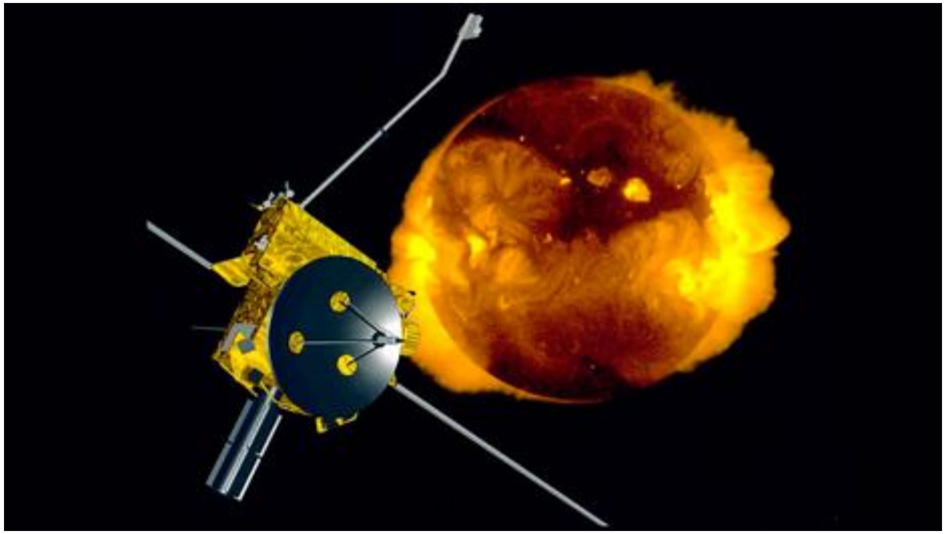


The Ulysses Spacecraft

<u>Ulysses</u>

On February 8, 1992 the Ulysses spacecraft used Jupiter's gravity to swing "up" so it could explore the poles of our sun. Ulysses found that Jupiter's gravity had changed, and there were fewer volcanoes erupting on Io.



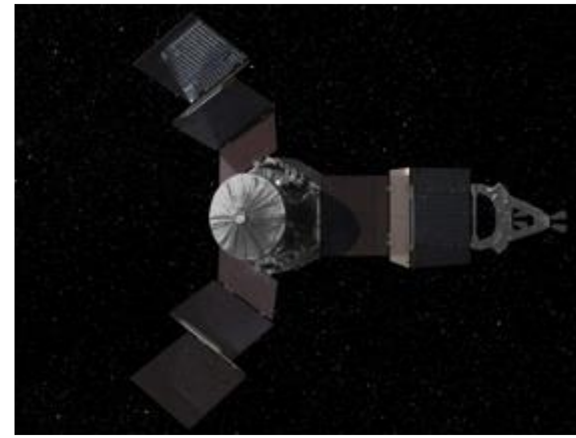


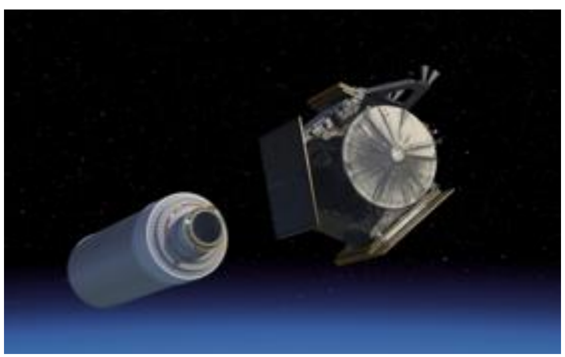
The JUNO Spacecraft

Juno

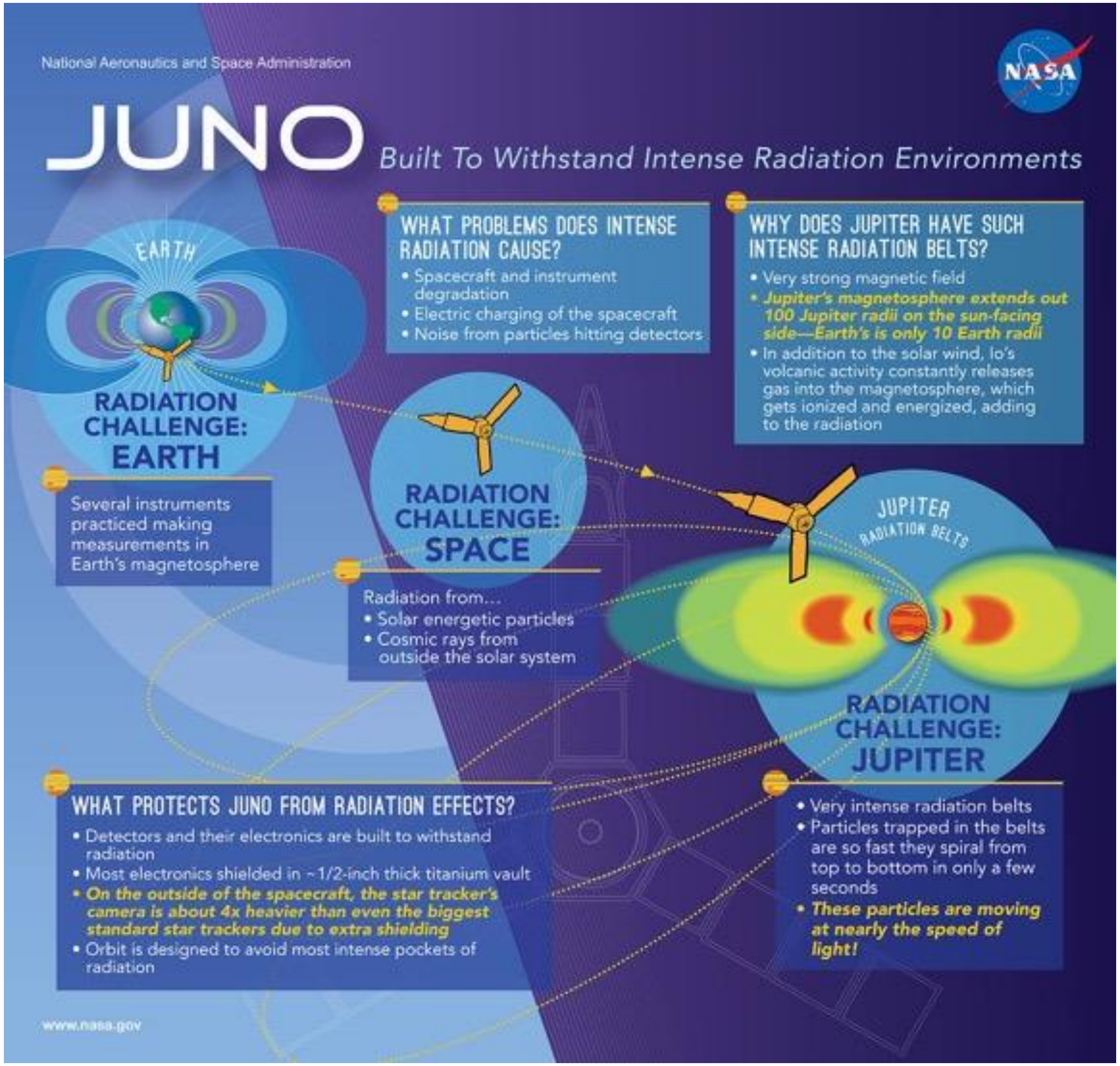
Juno is currently contributing to our knowledge of how Europa and Jupiter's other moons contribute to the planet's magnetosphere and auroras. Juno is also observing tides raised within Jupiter by the gravity of Europa and the other large moons.

JUNO



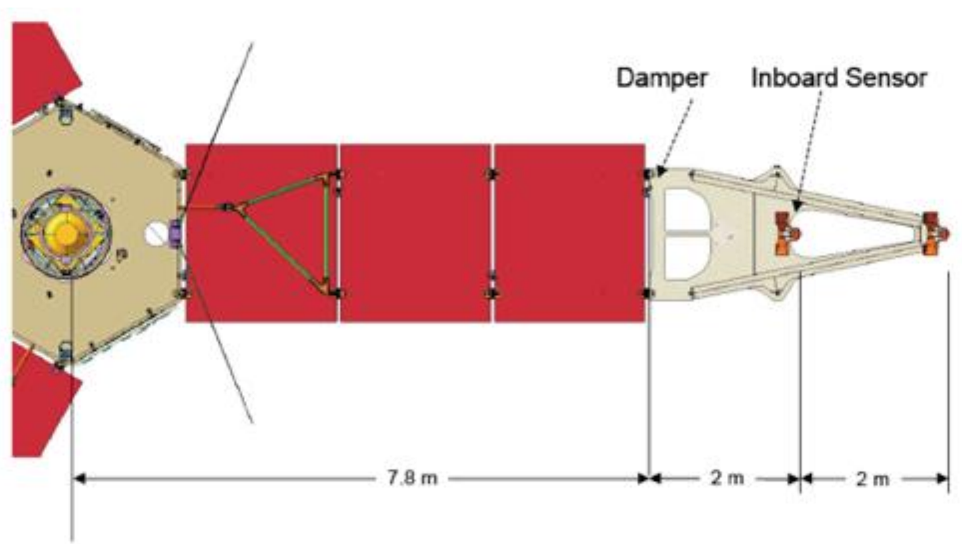


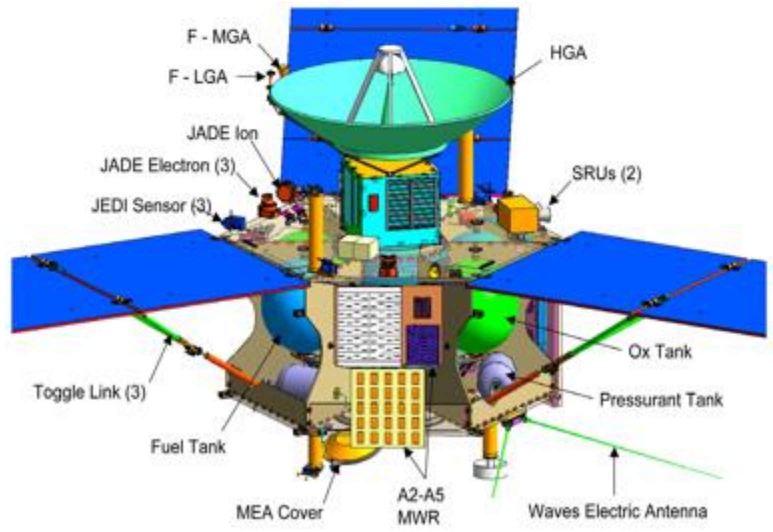
The JUNO Spacecraft



The JUNO Spacecraft

- **JUNO includes a magnetometer instrument that is presently performing measurements of Jupiter's magnetic field.**
  - **The instrument consists of two magnetic sensors; an Inboard Fluxgate Magnetometer sensor (IFGM) and an Outboard Fluxgate Magnetometer Sensor (OFGM).**
    - **Both sensors are mounted on a magnetometer boom platform whose closest edge is approximately 10 meters from the center of the spacecraft X-direction, with the IFGM located at about 10 meters, and the OFGM located at about 12 meters from the center of the spacecraft.**





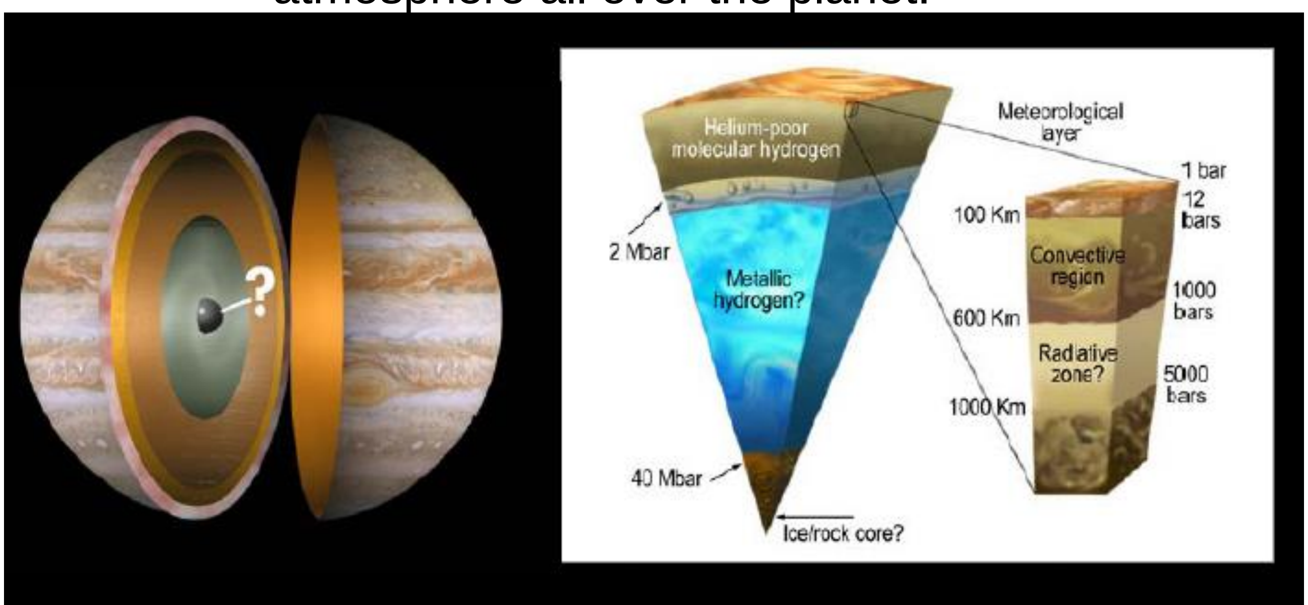
The JUNO Spacecraft- Instruments

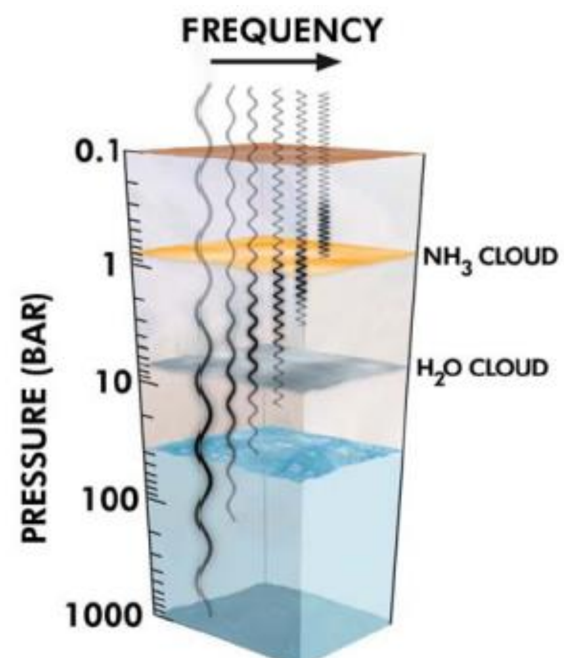
- JUNO Mission
  - NASA mission was launched in Aug 5, 2011, successfully entered Jupiter's orbit almost two years ago on July 4th, 2016.
  - Primary scientific goal is to improve our understanding of formation, evolution and interior structure of Jupiter
  - Juno mission carries nine instruments (some with multiple sensors)
    - Two Magnetometers, Gravity Science experiment, Jupiter Energetic Particle Detector Instrument (JEDI), Jovian Auroral Distributions Experiment (JADE), **Microwave Radiometer (MWR),** plasma instrument WAVES measures radio and plasma waves, The Ultra Violet Spectrogram (UVS), (JIRAM) Jovian Infrared Auroral Mapper, JUNOCAM is to photograph Jupiter's clouds.

JUNO Spacecraft (Courtesy of NASA)

The JUNO Spacecraft - MWR

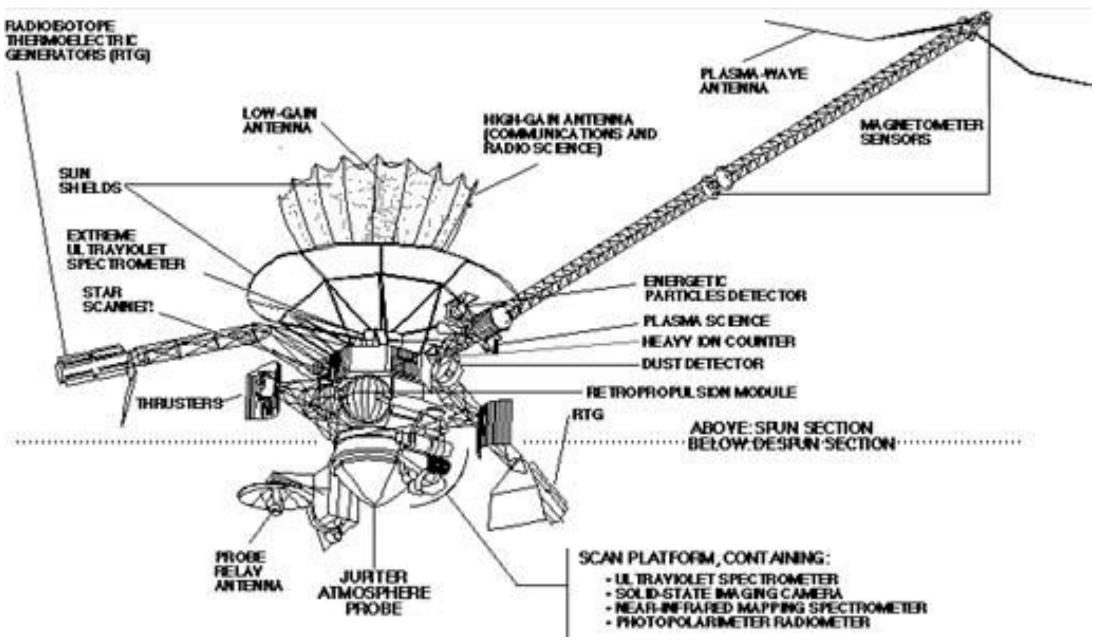
- JUNO Microwave Radiometer (MWR):
  - JUNO's MWR has been looking below the dense cover of clouds to answer questions about the gas giant and the origins of our solar system.
  - MWR measures thermal radiation from the atmosphere to as deep as 1000 atmospheres pressure (~500–600 km below Jupiter's visible cloud tops).
  - Determines water (H_2O) and ammonia (NH_3) abundances in the atmosphere all over the planet.



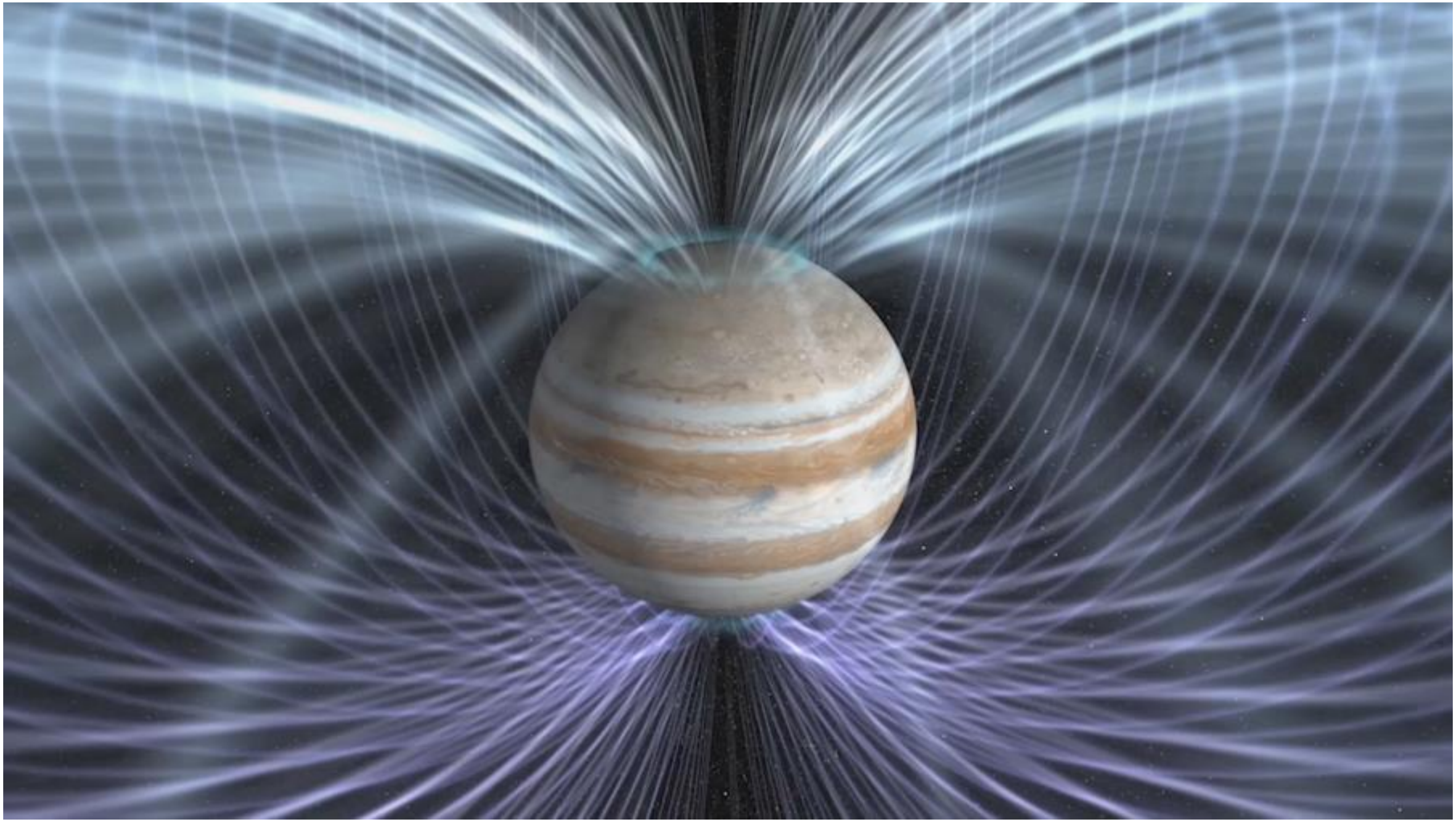


Galileo's Measurements of Magnetic Fields at Jupiter

- **Instruments measure mag fields to a high degree of accuracy and precision**
  - **Vector helium magnetometers (DC)**
  - **Fluxgate magnetometers (DC)**
  - **Plasma wave search coils (AC)**



Jupiter’s High Magnetic Fields

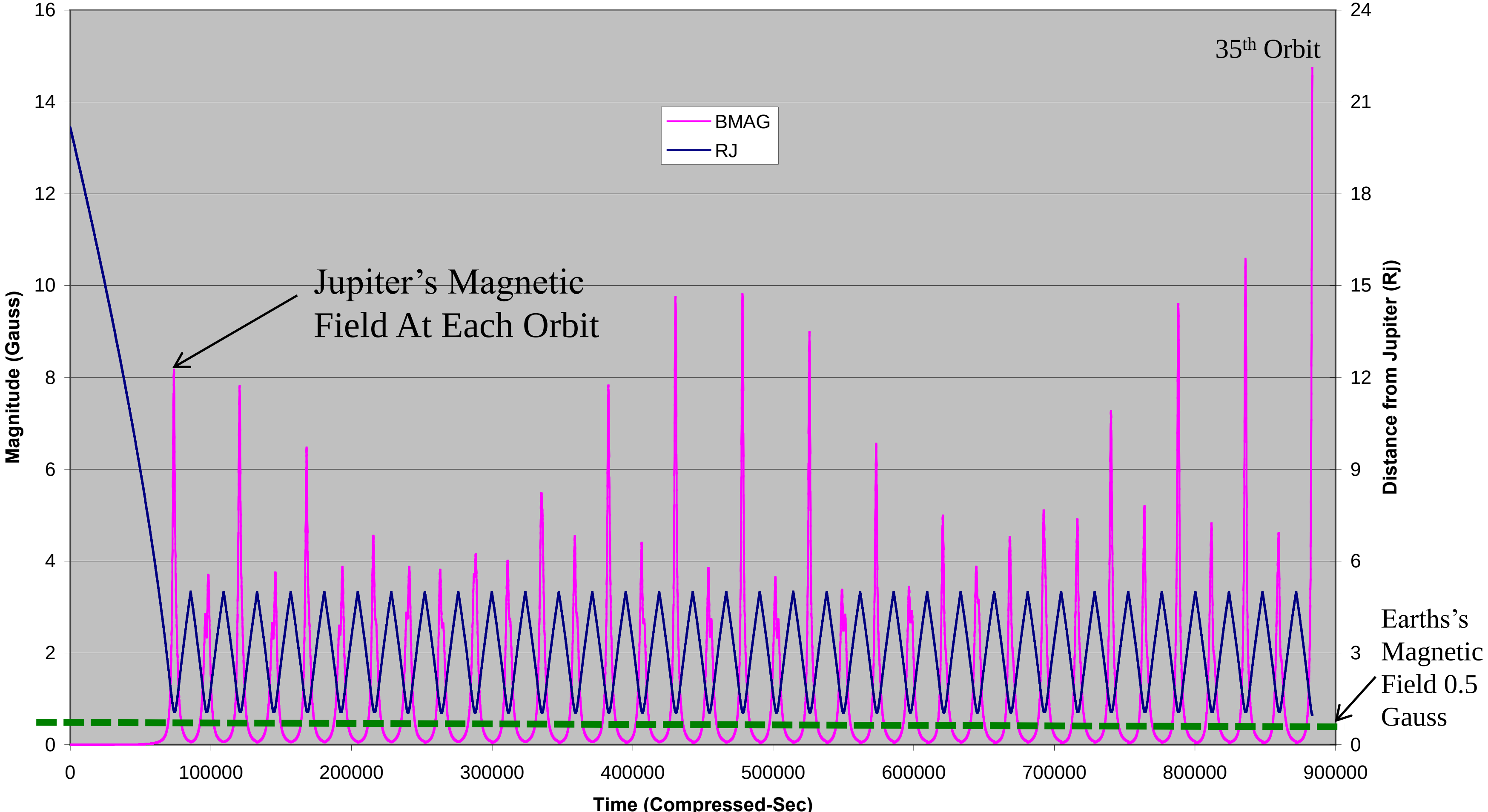


(Courtesy of NASA)

Jupiter’s Strong Magnetic Fields

JUNO magnetic field magnitudes in Jupiter’s Orbit

Jupiter’s magnetic field is on average 14 times larger than of earth!



Predicted Model, Actual Fields Are Higher

Magnetic Susceptibility
The Problem Statement

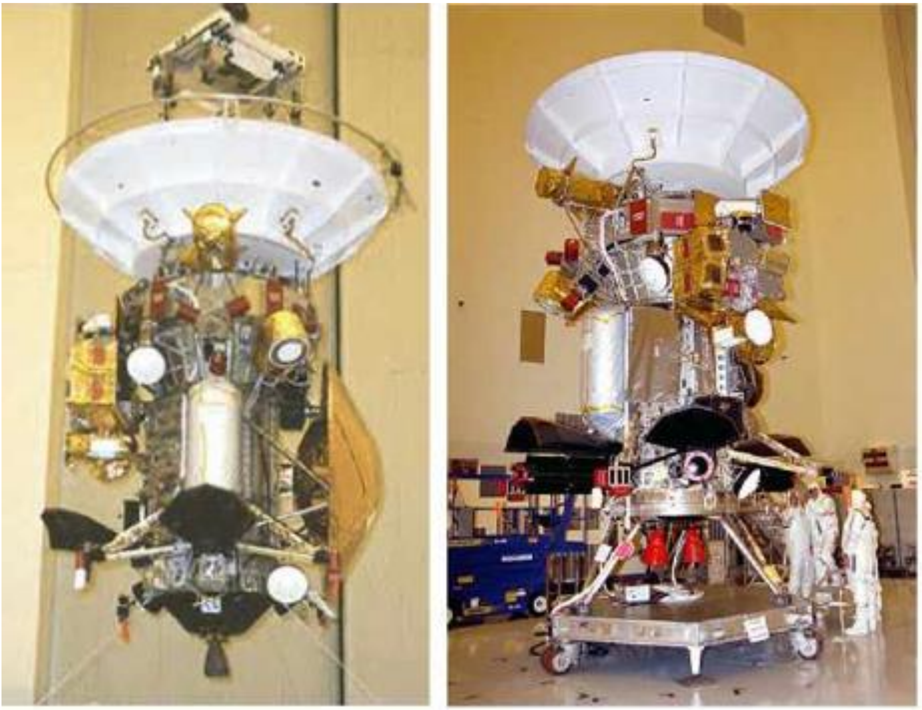
The isolators are in the front end of the microwave radiometer (MWR) science instrument. It is influenced by external magnetic fields. Jupiter's field, when seen from the rotation frame of the spacecraft, will cause cyclic variations in the gain and offset of the system. If uncorrected there would be a direct impact on the antenna temperature retrieval and limb darkening error.

MWR Has Six Radiometers Each With An Isolator, Thus Producing Six Magnetic Interference Concerns

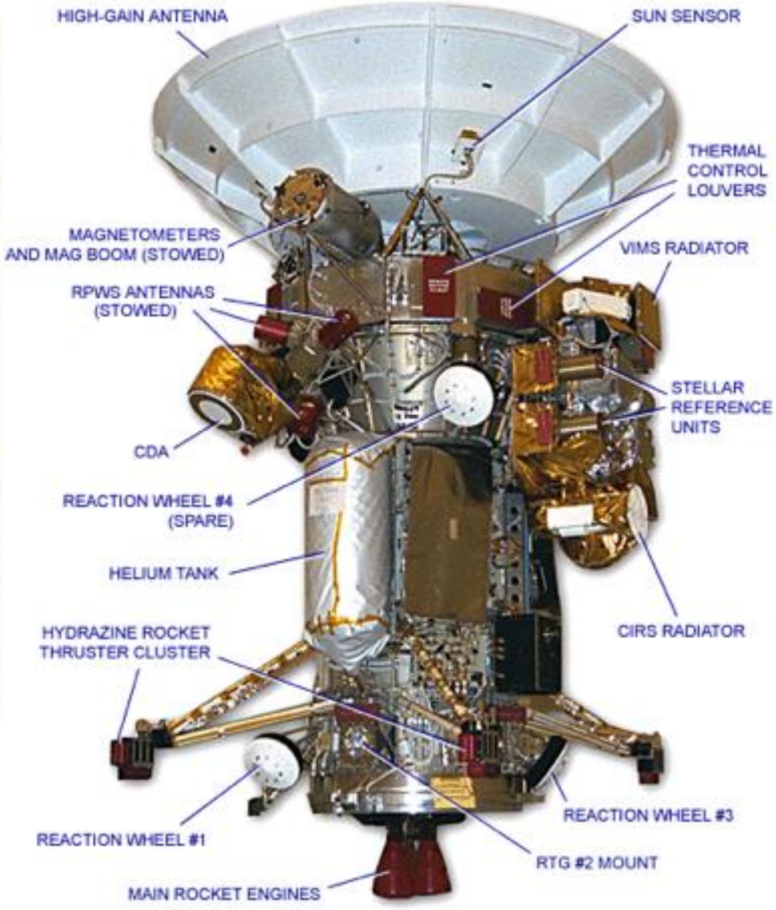
(Isolators Identified As R1 R2, R3, R4, R5, R6)

Magnetic Susceptibility
The Problem Statement

Cassini's Biggest Magnetic Interference From: Reaction Wheel Assemblies

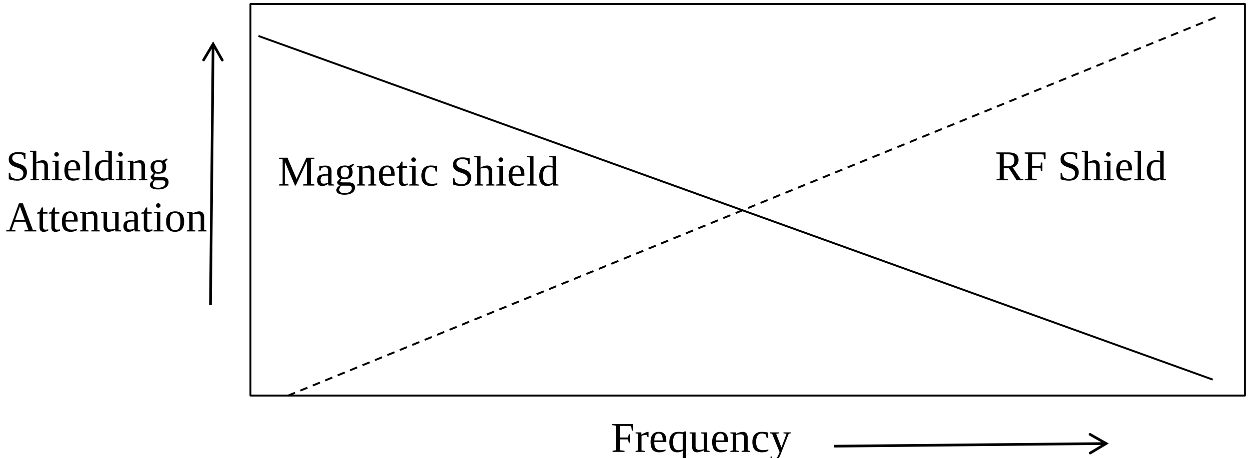


Cassini Spacecraft (Courtesy of NASA)



RF vs Magnetic Shielding

- RF shielding is required when it is necessary to shield against high frequency interfering sources, typically in the 100 kHz range and above.
- The RF shields are typically copper, aluminum, conductive cloth material, titanium etc.
- These materials work at high frequency by means of their high conductivity and require little or no magnetic permeability.
- Magnetic shields use their high permeability to attract magnetic fields and divert the magnetic energy within the walls of the magnetic shield.
- To protect the MWR, magnetic shielding was necessary and a requirement for mission success

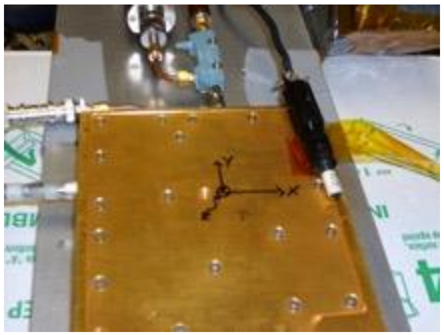


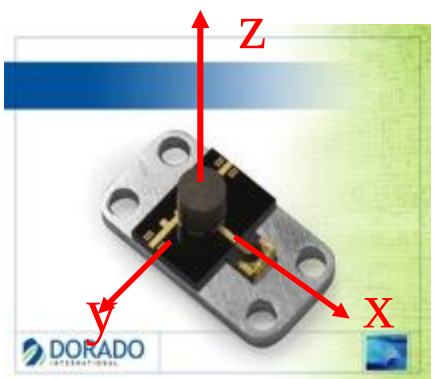
Magnetic Issues and Mitigations

- Exposure of MWR R2 radiometer to 16 Gauss magnetic field showed the radiometer system is
  - Sensitive to magnetic field vector when oriented in a plane perpendicular to the radiometer chain
  - The system gain and receiver noise temperature, and the other key radiometer parameters were changed with applied external magnetic field
  - The nearby isolators were impacted
    - Several tests were performed using magnetic shielding applied to the isolators. No significant improvement
    - Applied magnetic shielding over the whole radiometer chassis whereby two 20 mil thick shields were wrapped around the area of concern. This approach was successful in attenuating the external fields to the point of minimizing its impact on the isolators.
  - Conclusion- a total of **~2 kg of shielding material** is needed to reduces the field at the MWR with the radiometer isolator locations to an acceptable level.
    - Mass was a significant issue in this mission

Efforts to Map the Constraint Space

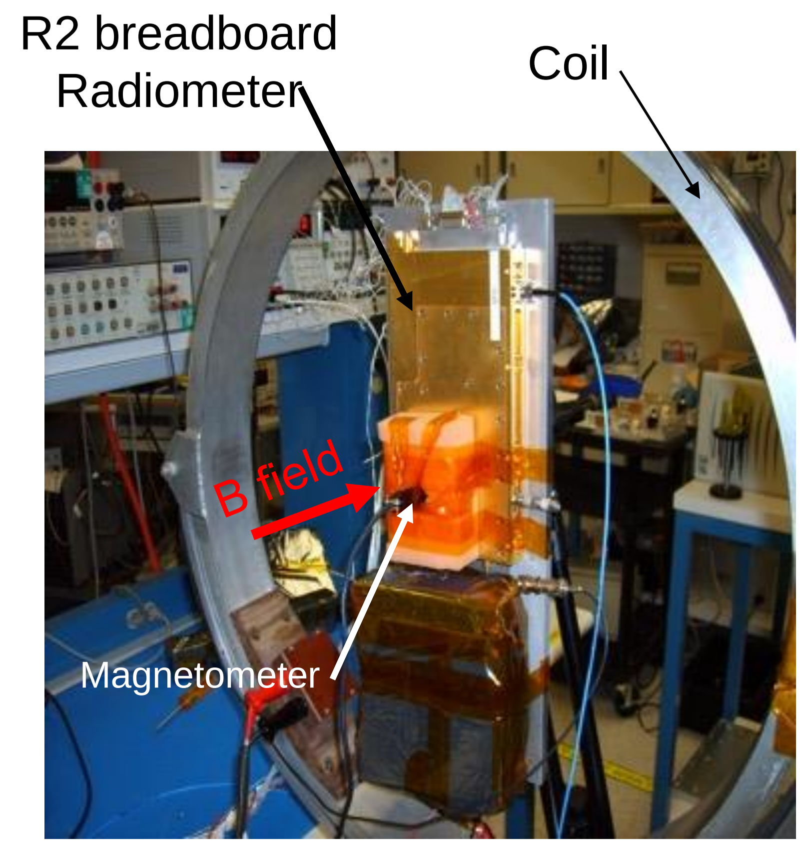
MWR Tested In Three Axes





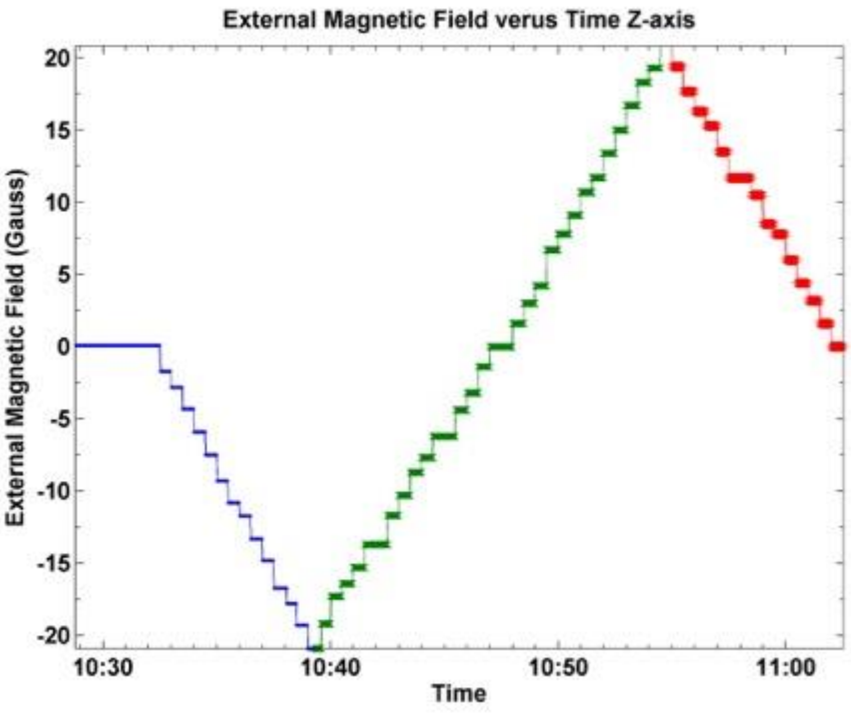
- Defined coordinate system with isolator at the origin
- X& Y axis – B field is in the plane of the radiometer
- Z-axis – B field is perpendicular to the radiometer
- Tested S-parameters on an R4 isolator in the presence of a magnetic material to determine guidelines for minimum spacing between shielding and isolator
- Tested R4 isolator S-parameters in Helmholtz coil in all three axis
  - Test with no magnetic shielding to baseline performance
  - Tested with a magnetic shield around the entire R4 isolator test housing as a proof of concept
- Simulated a magnetic shield package around an individual isolator to determine material saturation and external field attenuation

MWR Magnetic Susceptibility Tests



Magnetic field in z-axis
Test setup

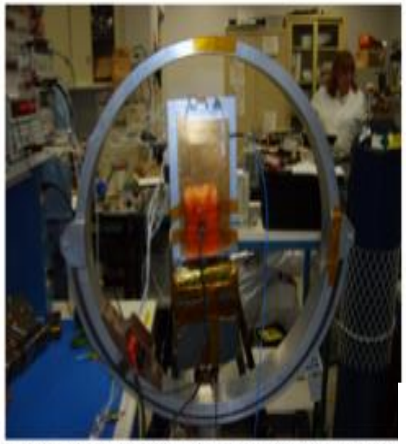
- Radiometer and directional Gauss meter mounted inside a coil.
- Current in coil stepped to vary magnetic field at center of coil (isolator location) from 0 Gauss to -20 Gauss to +20 Gauss then back to 0 Gauss



MWR Magnetic Susceptibility Tests

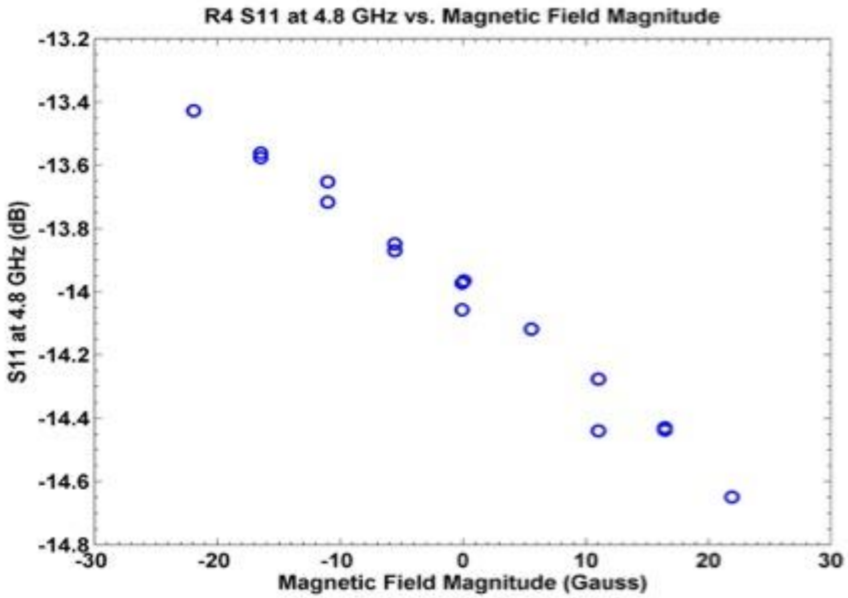
R2 breadboard Radiometer

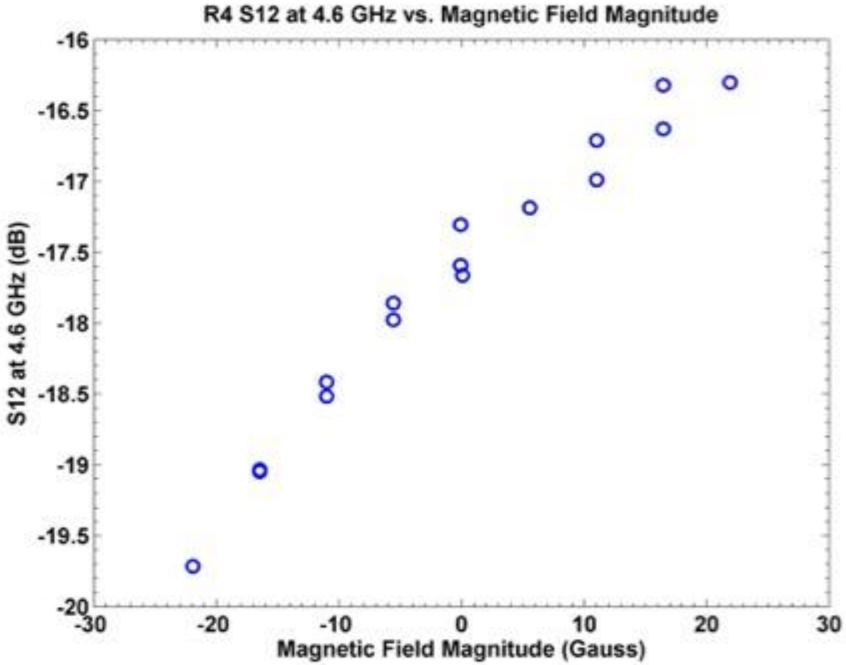
Coil



MWR Tested In Three Axes

- S11 changes by as much as 1.4 dB
- S12 changes by as much as 4 dB
- Change in system gain mainly due to change in S11 (85%) and less from S21 (15%)
- R4 isolator would see a 0.03%/gauss gain modulation, similar to R2 result





Mitigation Approaches

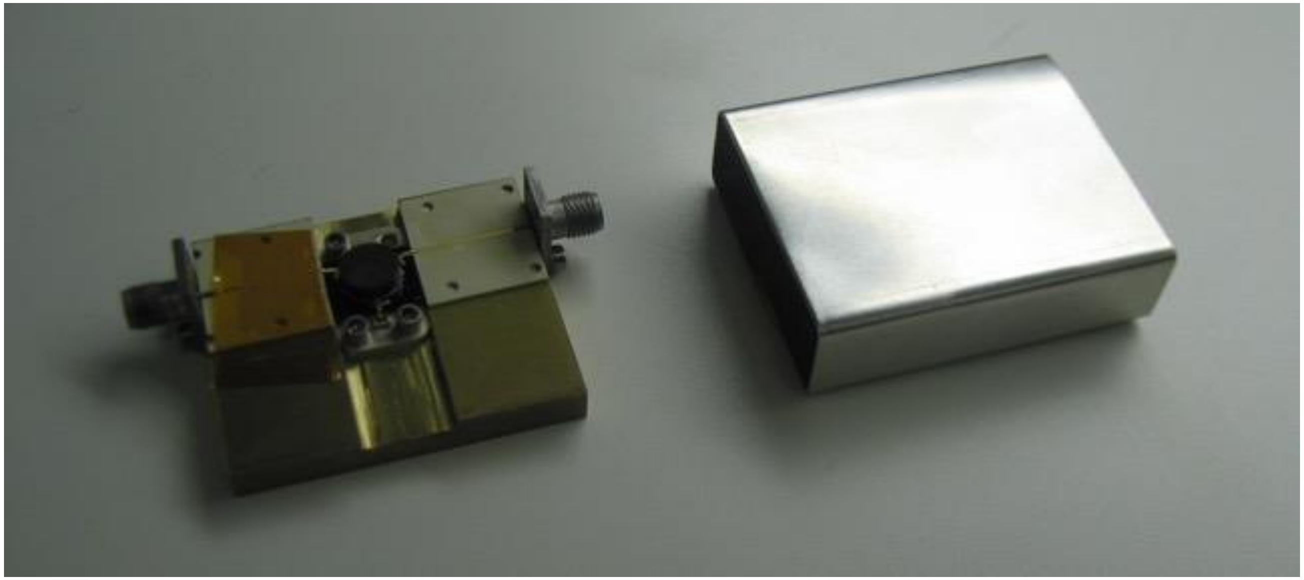
- **Shield entire box**
  - Looks effective from modeling and shielding vendor recommendation
  - No receiver package impact
  - Too much work for the packaging folks, expensive and too heavy
- **Package individual isolators**
  - Needs isolator level pass criterion
  - Impact packaging in very compact board layout
- **Break receivers into two boxes and shield smaller front-end part**
  - Package impact (long time to layout and causes more test effort)
- **Use no isolator**
  - No package impact
  - Carries much more complicated characterization scheme
  - Custom Low Noise Amplifier design
- **Characterize magnetic field impact and calibrate out using data from the magnetometer**
  - No package impact
  - More characterization
  - Could have interference from spacecraft

Mitigation Approaches– cont.

- **Individual Isolator Package Constraints**
  - Magnetic shield will influence RF performance of the isolator if it is too close
  - Isolator magnets may saturate the the magnetic material, reducing its ability to shield against the external field
  - A magnetic shield that provides (X) amount of attenuation will lower the impact of the errors to an acceptable amount
- **Shielding Approach/ Solutions**
  - Shield entire MWR stack
  - Break MWR into two packages and shield smaller front end package
  - Shield individual isolators within one MWR package
- **Looked At The Brute Force Approach (Overall Big Shield)**
  - Least impact on Radiometer packaging and design
  - R2 magnetic shielding tests and vendor initial remarks indicate a need for ~40 mils of magnetic shielding (~2kg)
  - Initial FEM simulations indicate that 40 mils of mu-metal is needed
- **Will meet the 0.01 % gain goal (based on R2 data)**

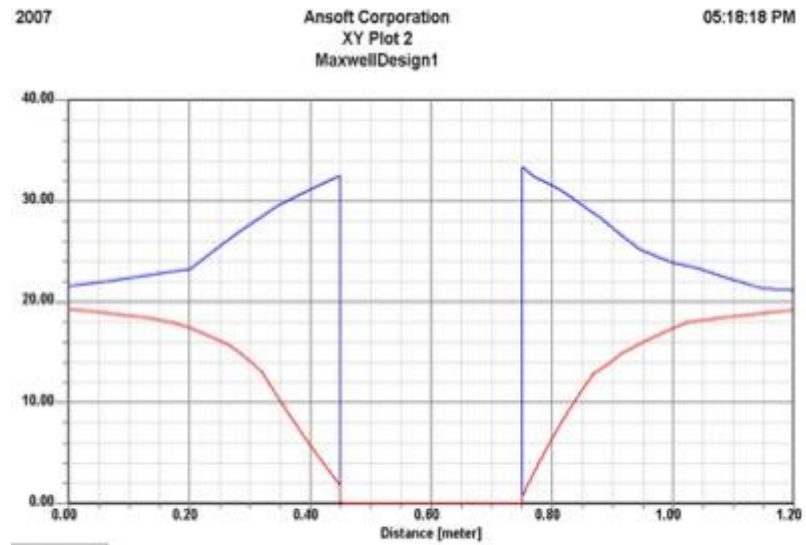
How Magnetic Shields Perform

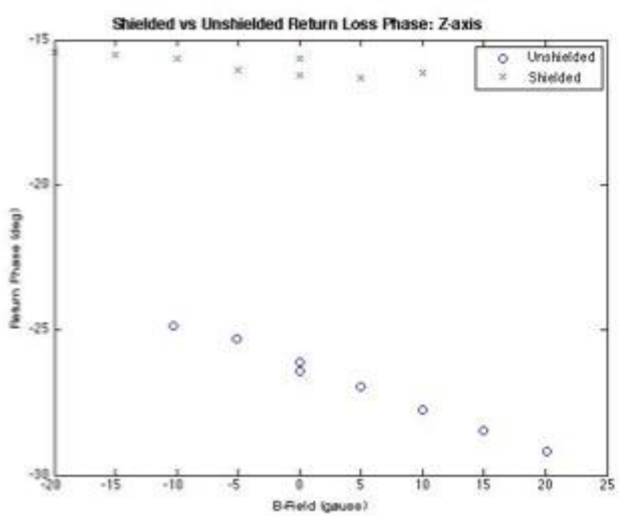
- There are many factors to consider in a shield design
  - Appropriate shielding material/alloy must be selected
  - Right shielding thickness for the needed attenuation
  - Most effective shape (round, square etc)
  - Size, penetrations for inputs/outputs
  - Location of the shield relative to the source

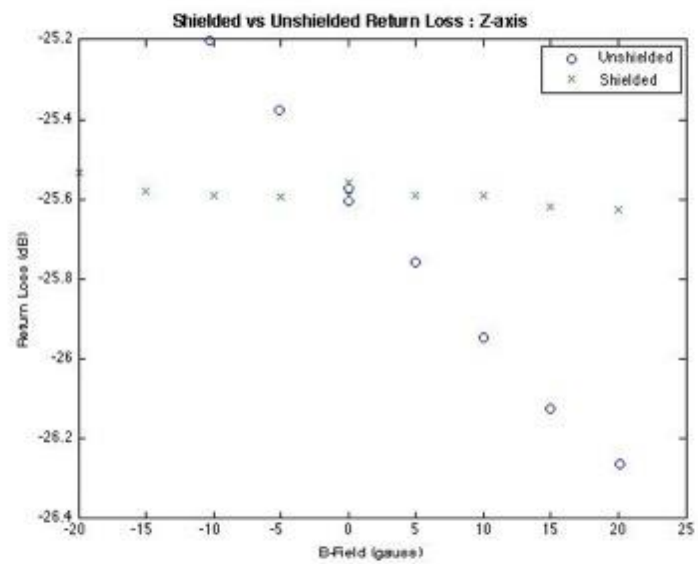


Modeling Approach and Solutions

- Model consists of a 30 cm 1 cm thick cube surrounded by 40 mils of mu-metal in a 20 gauss uniform field
  - Used vendor “stock” mu-metal B/H curve
  - Shielding may actually be more effective than indicated due to the fidelity of the simulation
- Experience with using Mu-metal shield from past NASA missions in general: Voyager, Galileo, Cassini
- R4 shielding results are presented



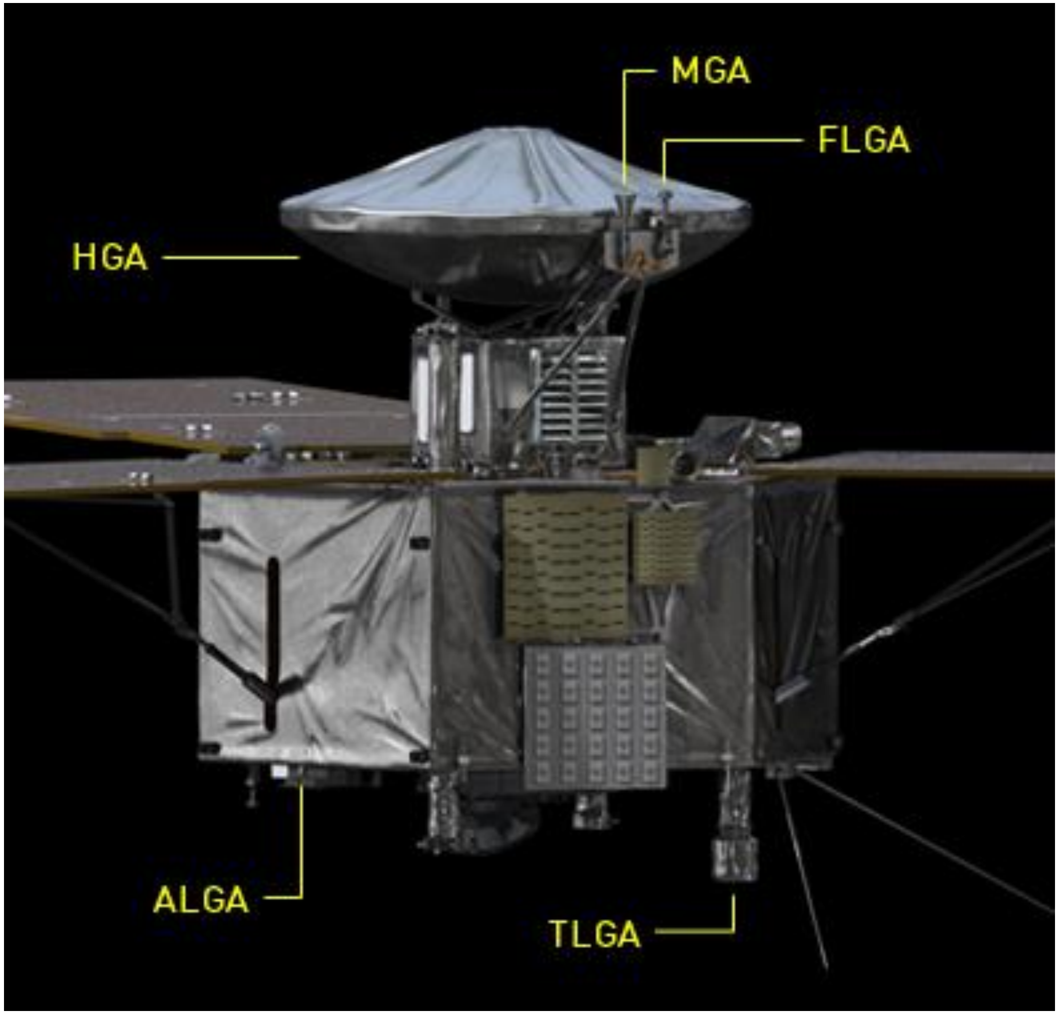




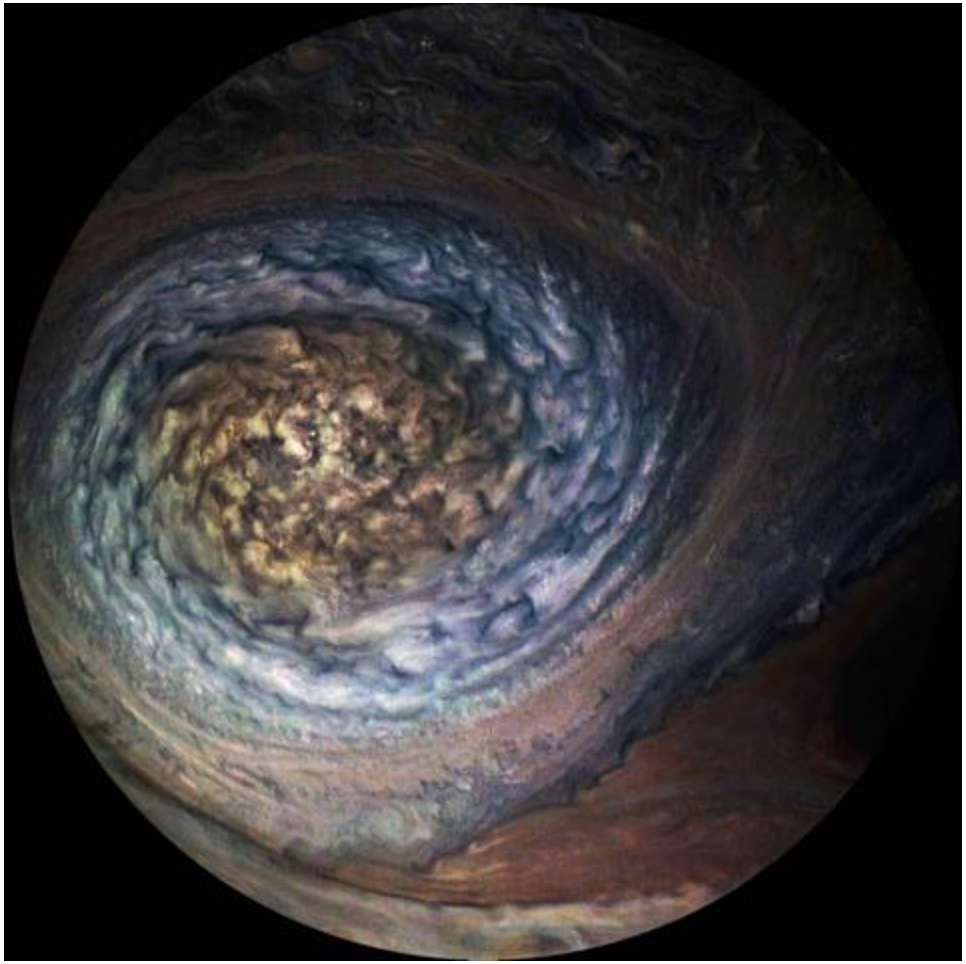
Final Verification Of MWR

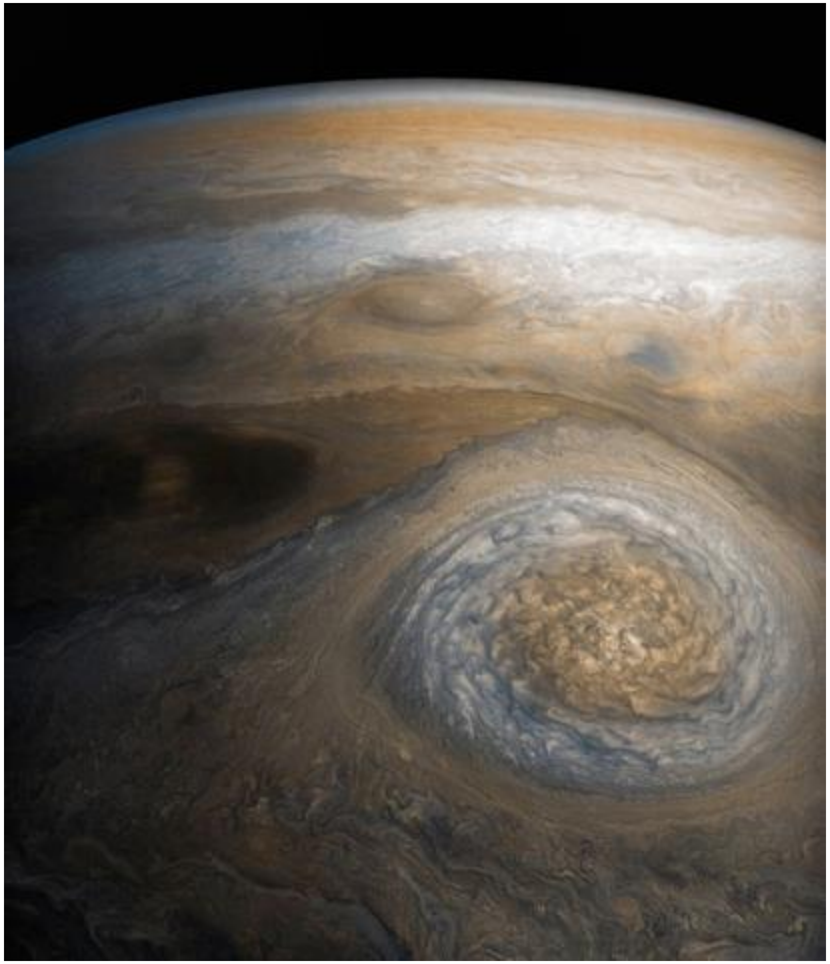
- MWR Flight Unit Placed Inside Helmholtz Coil
- External coils generated uniform fields with a magnitude of 16 Gauss with the field parallel to the coil axis and encompassing all of MWR
- The magnetic field was modulated at 2 rpm (simulates a rotating spacecraft)
- **MWR MET ALL ITS PERFORMANCE CRITERIA**

JUNO Telecom System



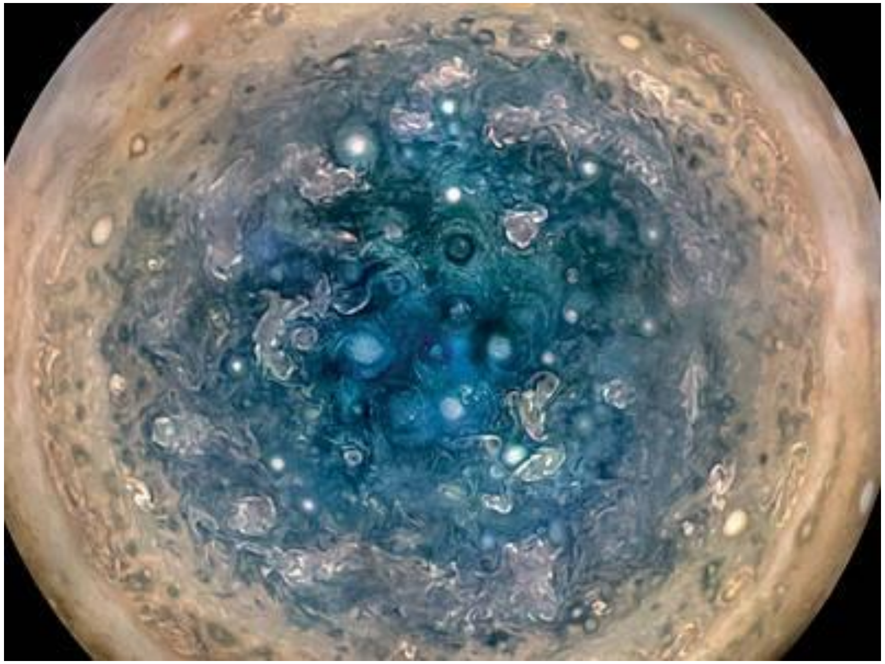
Close Up Images Of Jupiter





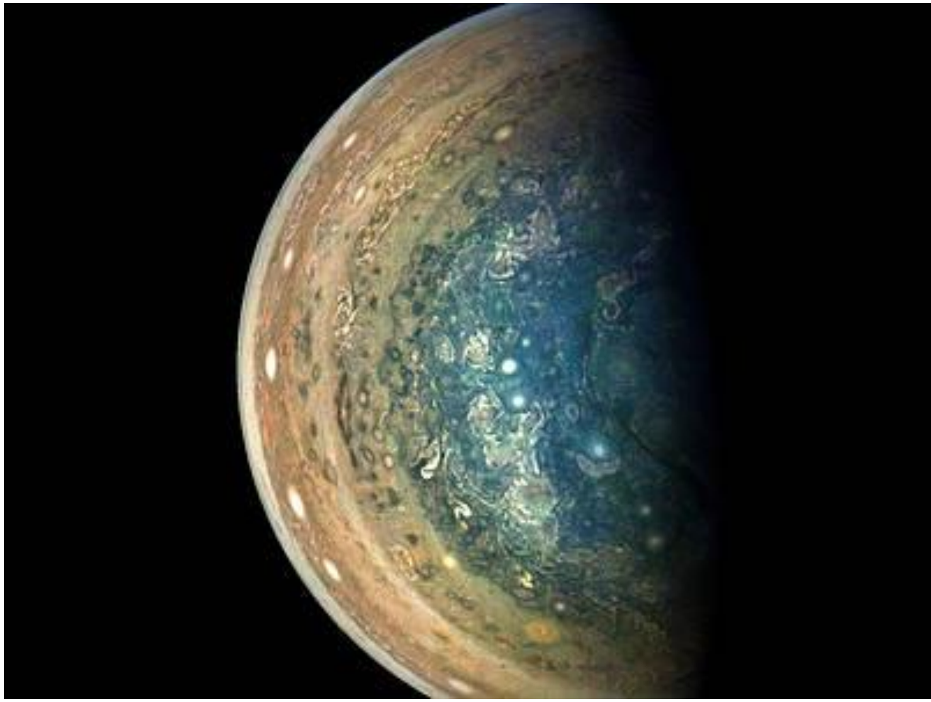
Close Up Images Of Jupiter

Close Up Images Of Jupiter

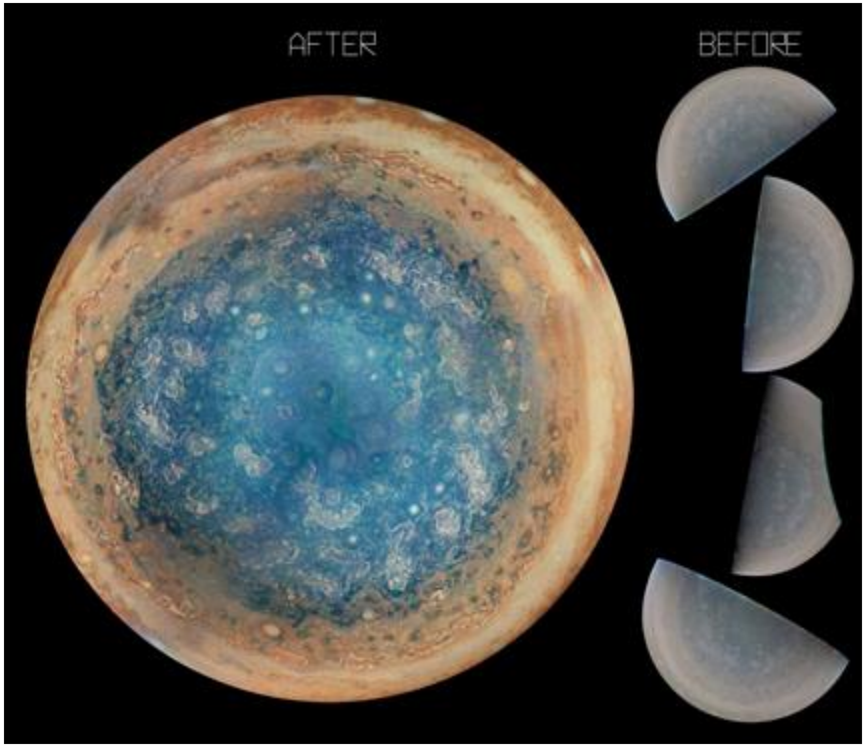


Close Up Images Of Jupiter

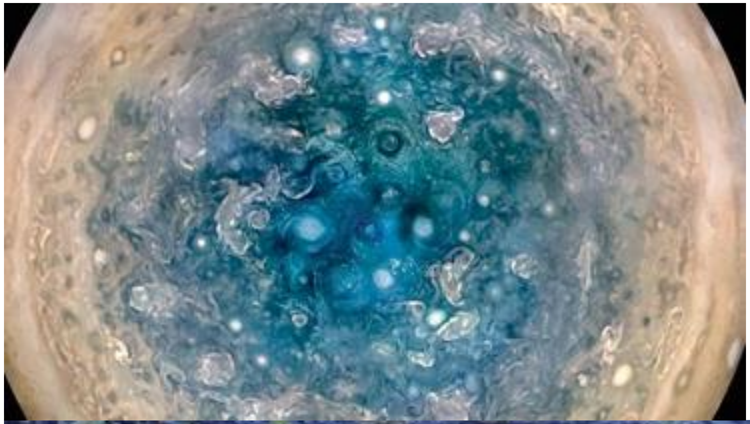
Close Up Images Of Jupiter



Images From JUNOCAM

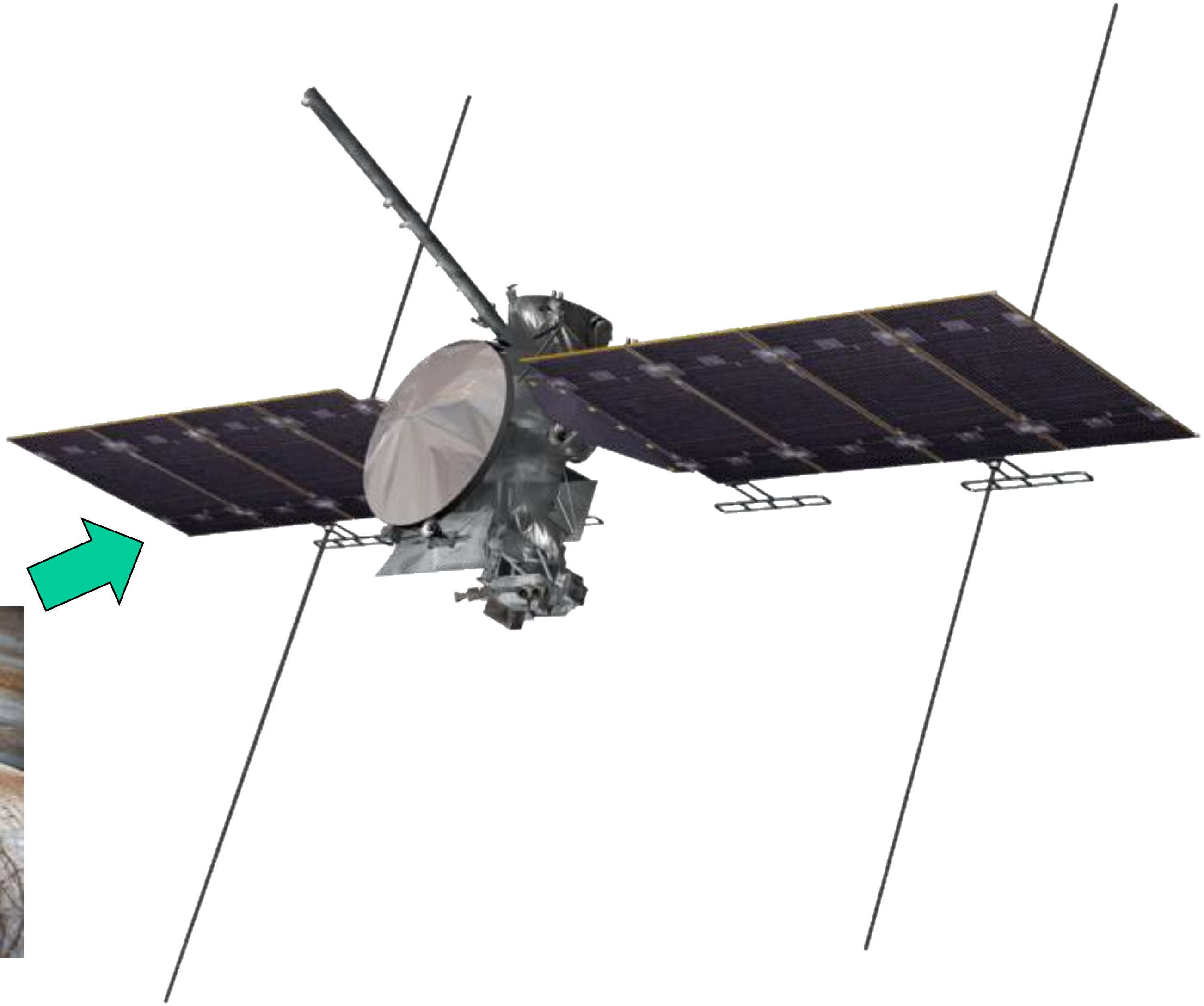


Huge Cyclones at Jupiter's Poles

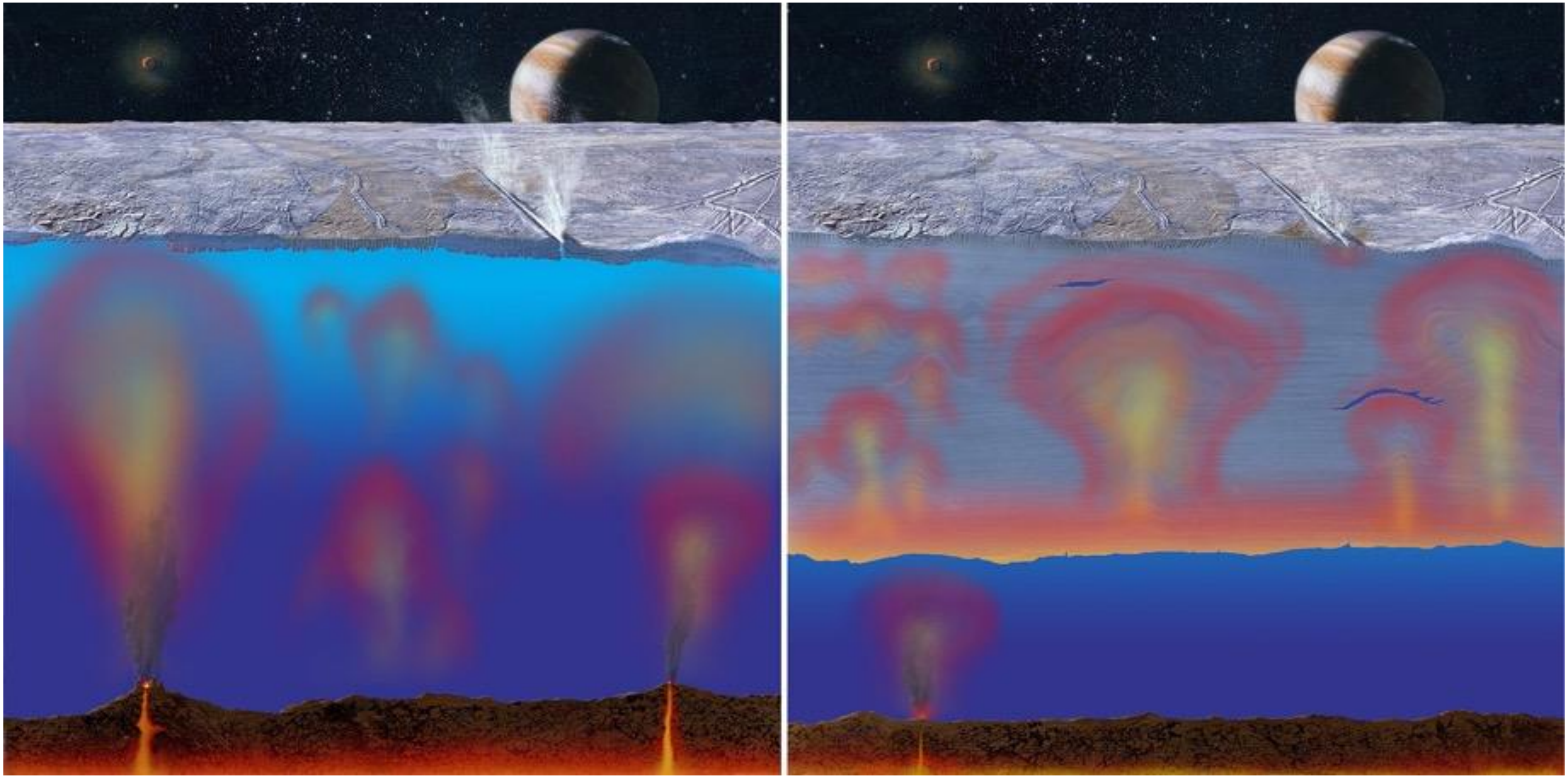


Vincent Van Gogh

The Europa Clipper Spacecraft



The Europa Clipper Spacecraft



Europa Clipper Science Instruments

- **Plasma Instrument for Magnetic Sounding (PIMS)** -- This instrument works in conjunction with a magnetometer and is key to determining Europa's ice shell thickness, ocean depth, and salinity by correcting the magnetic induction signal for plasma currents around Europa.
- **Interior Characterization of Europa using Magnetometry (ICEMAG)** -- This magnetometer will measure the magnetic field near Europa and - in conjunction with the PIMS instrument - infer the location, thickness and salinity of Europa's subsurface ocean using multi-frequency electromagnetic sounding.
- **Mapping Imaging Spectrometer for Europa (MISE)** -- This instrument will probe the composition of Europa, identifying and mapping the distributions of organics, salts, acid hydrates, water ice phases, and other materials to determine the habitability of Europa's ocean.

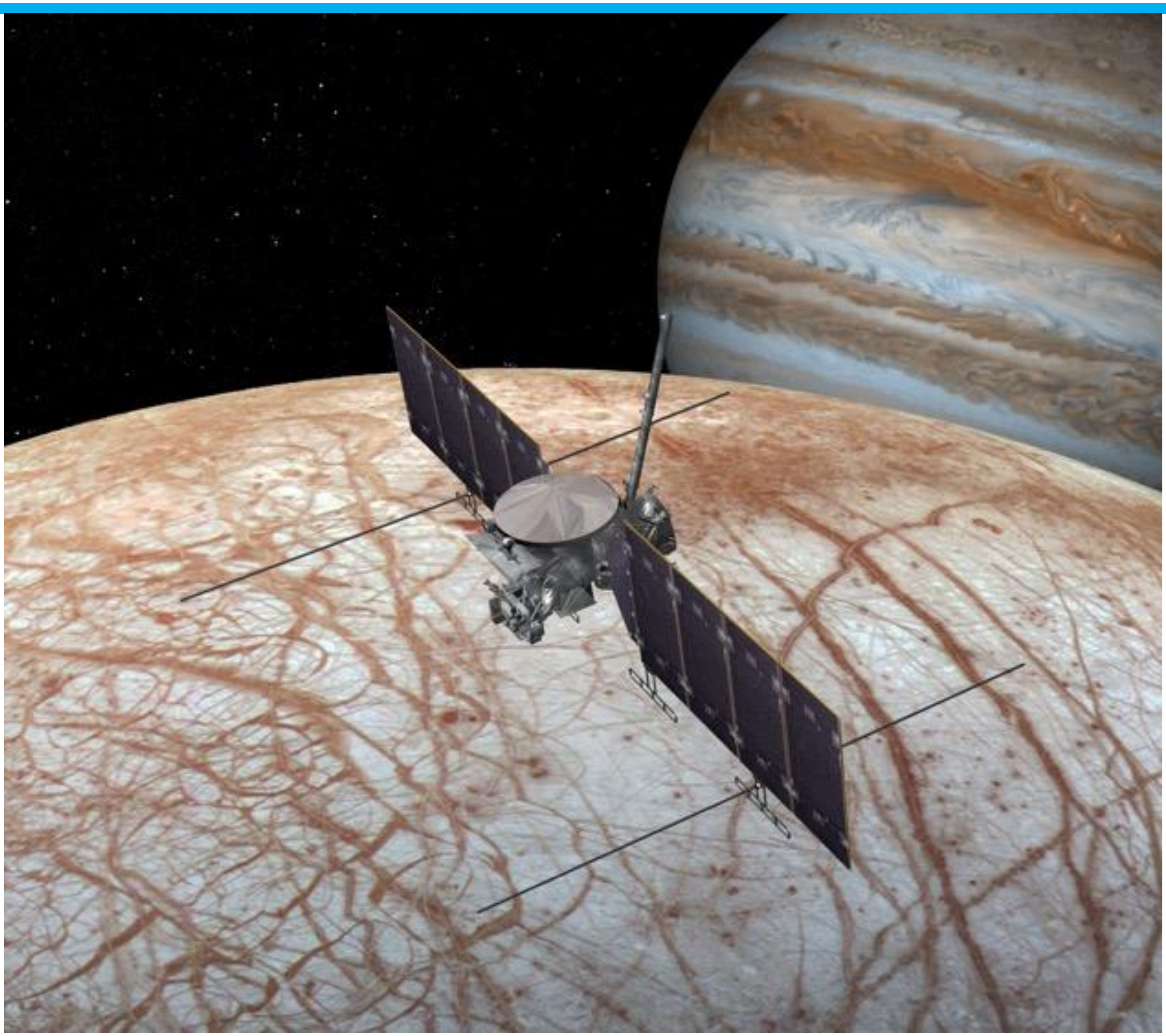
Europa Clipper
Science Instruments

- **Europa Imaging System (EIS)** -- The wide and narrow angle cameras on this instrument will map most of Europa at 50 meter (164 foot) resolution, and willprovide images of areas of Europa's surface at up to 100 times higher resolution.
- **Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON)** -- This dual-frequency ice penetrating radar instrument is designed to characterize and sound Europa's icy crust from the near-surface to the ocean, revealing the hidden structure of Europa's ice shell and potential water within.
- **SUrface Dust Mass Analyzer (SUDA)** -- This instrument will measure the composition of small, solid particles ejected from Europa, providing the opportunity to directly sample the surface and potential plumes on low-altitude flybys.

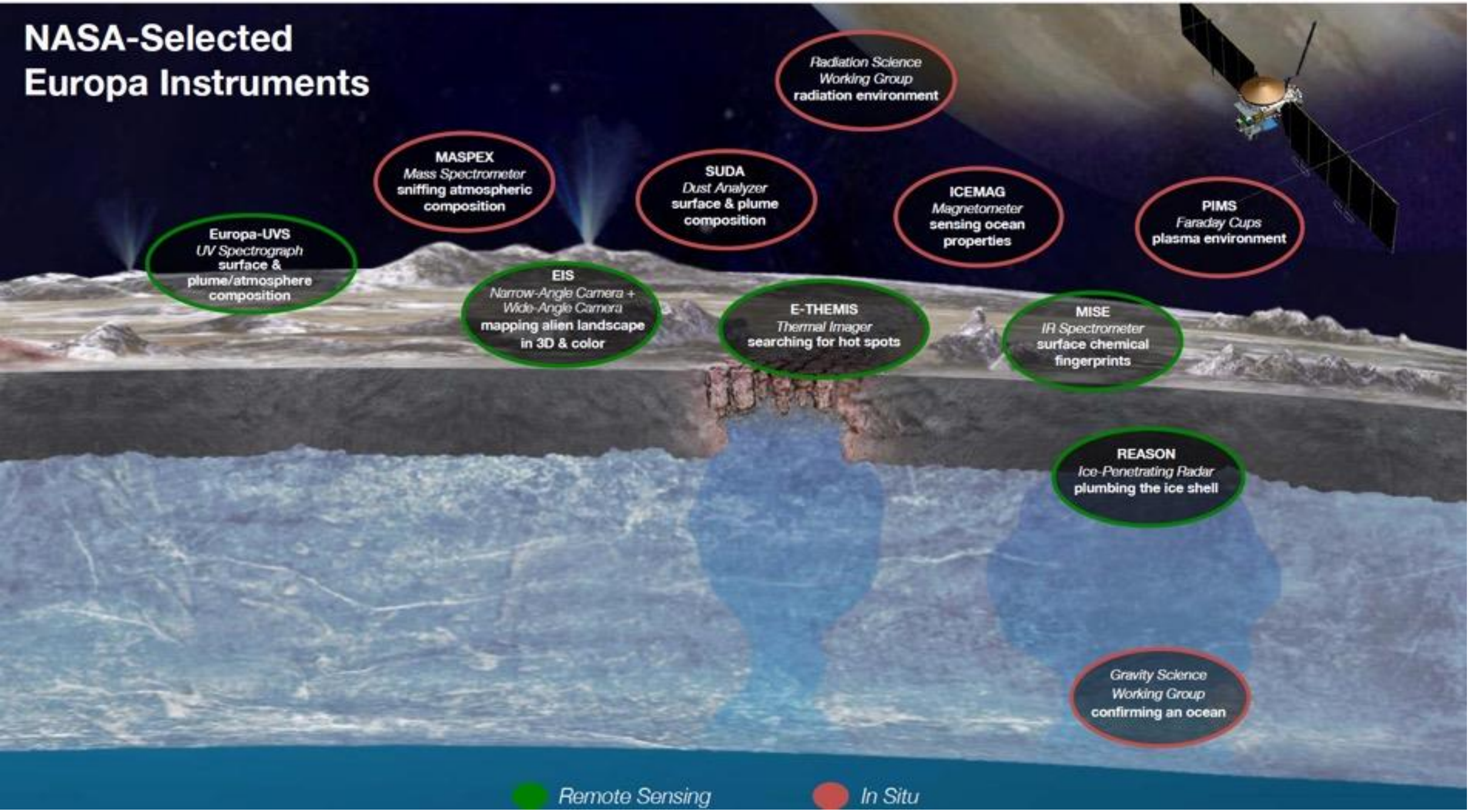
Europa Clipper Science Instruments

- **Europa Thermal Emission Imaging System (E-THEMIS)** -- This "heat detector" will provide high spatial resolution, multi-spectral thermal imaging of Europa to help detect active sites, such as potential vents erupting plumes of water into space.
- **MAss SPectrometer for Planetary EXploration/Europa (MASPEX)** -- This instrument will determine the composition of the surface and subsurface ocean by measuring Europa's extremely tenuous atmosphere and any surface material ejected into space.
- **Ultraviolet Spectrograph/Europa (UVS)** -- This instrument will adopt the same technique used by the Hubble Space Telescope to detect the likely presence of water plumes erupting from Europa's surface. UVS will be able to detect small plumes and will provide valuable data about the composition and dynamics of the moon's rarefied atmosphere.

The Europa Clipper Spacecraft



The Europa Clipper Spacecraft



CONAE/INVAP

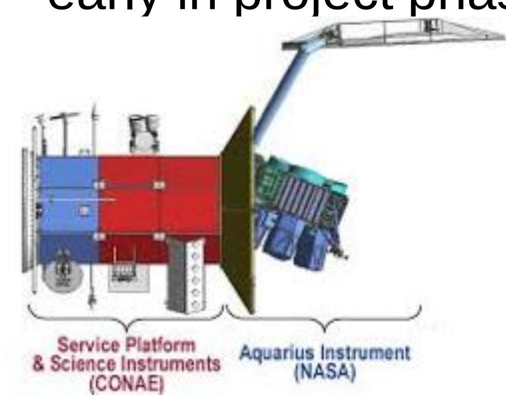
San Carlos de Bariloche

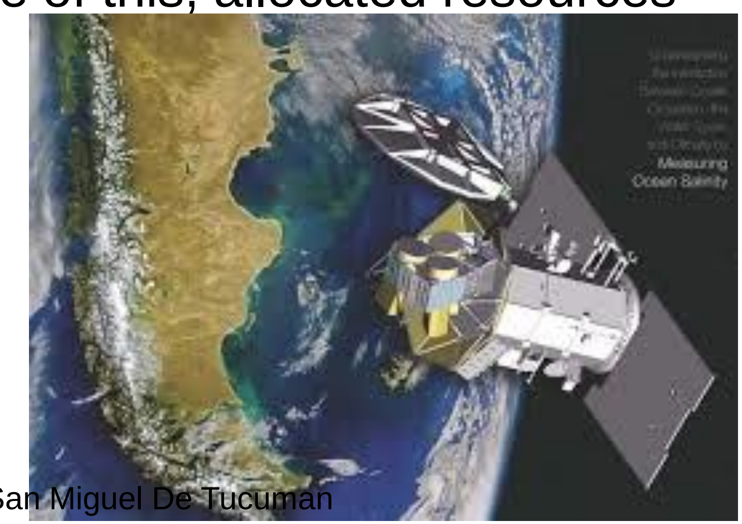
SAC-A
SAC-B
SAC-C
SAC-D/Aquarius

INVAP Spacecraft Integrator Located in Bariloche In The Patagonia Region Alongside the Andes Mountains

SAC-D/Aquarius

- Cooperative international mission between CONAE and NASA.
  - Primary science goal was to study the processes that couple changes in the water cycle and ocean circulation.
  - Measure Sea Surface Salinity (SSS)
- Sensitive GSFC Radiometer and JPL Scatterometer
  - Most Sensitive L-Band Instrument Flown to Date
    - Requirement set at -6 dB uV/m and 1 dB uV/m, respectively
  - Challenge Noticed Early In Program
    - Aquarius/SAC-D project aware of this, allocated resources early in project phase





SAC-D/Aquarius RE Requirements

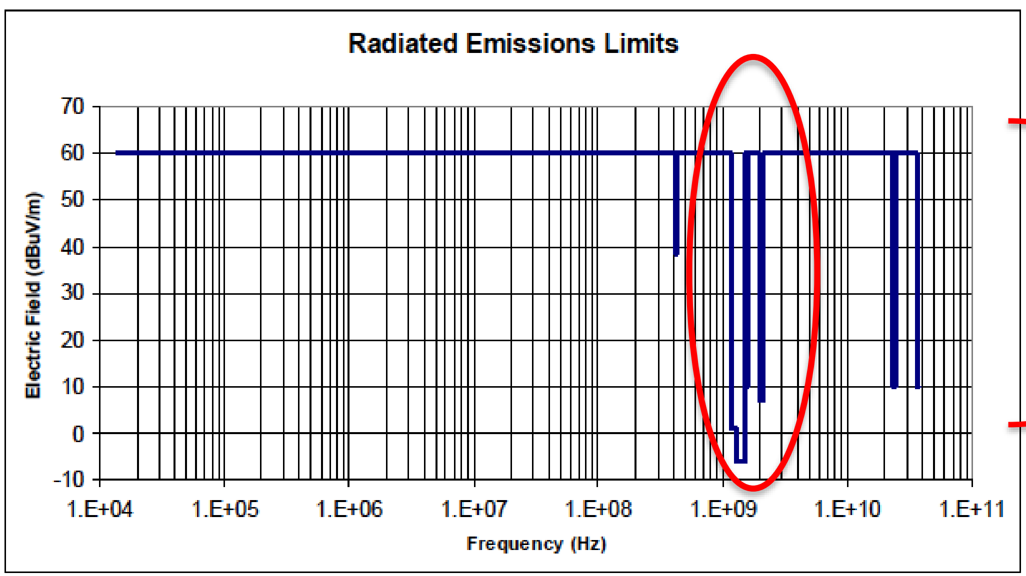
Table 3- 1: Aquarius Radiated Emissions E-Field Specification Levels @ 1 meter

L2B-AS-c-889

Frequency Range	Electric Field Limit	Potential Victim
14 kHz to 18 GHz	60 dBµV/m	Baseline Maximum Allowable Radiated Emissions Limits
408 to 430 MHz	36 dBµV/m	Launch Vehicle Command/Destruct UHF Rx Protection Band
461.62 MHz +/- 15 kHz	20 dBµV/m	DCS +Z UHF Omni
1300 to 1500 MHz	-6 dBµV/m	Aquarius L-Band Radiometer
1160 to 1360 MHz	1 dBµV/m	Aquarius L-Band Scatterometer
1217 to 1238 MHz	10 dBµV/m	GPS L2 Receiver (TDP & ROSA)
1565 to 1586 MHz	10 dBµV/m	GPS L1 Receiver (Navigation)
2035 MHz +/-60 KHz	7 dBµV/m	SAC-D S Band Uplink TC
23.3 to 24.3 GHz	10 dBµV/m	CONAE MWR K-Band
36.4 to 37.6 GHz	10 dBµV/m	CONAE MWR Ka-Band

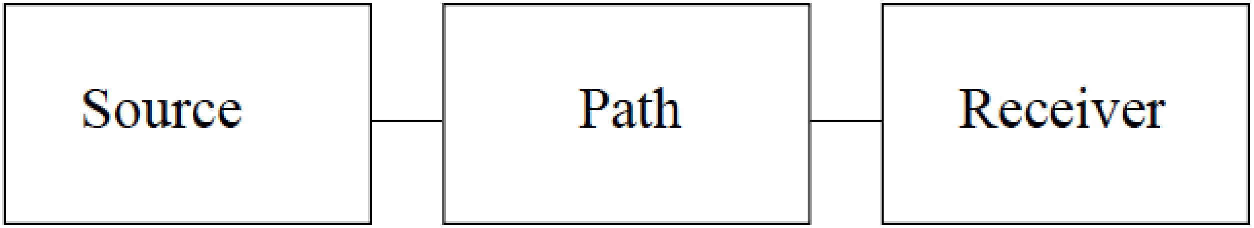
Huge Challenge
Most Stringent
Specs To Date
Never Attempted
At JPL

L2B-AS-c-890



Notch
66 dB
Drop
From
General
Spec Limit

The EMC "Model"

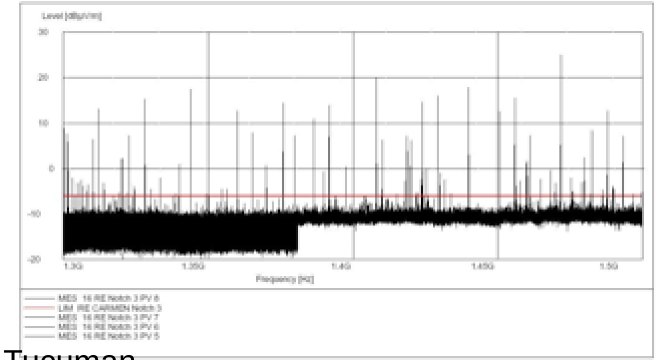


- The EMC model consists of three key elements
  - In theory, elimination of any element will eliminate EMC issues.
  - In practice, we can only minimize their impact.

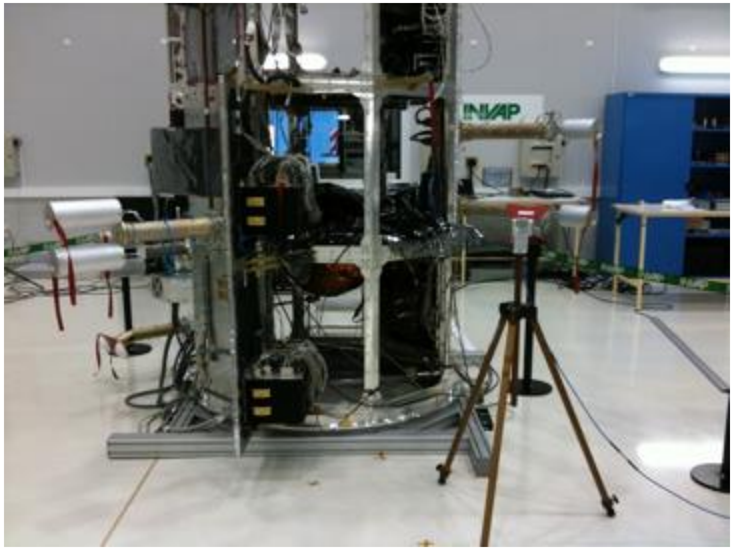
Aquarius/SAC-D EMC/EMI JPL/CONAE/INVAP Tiger Team

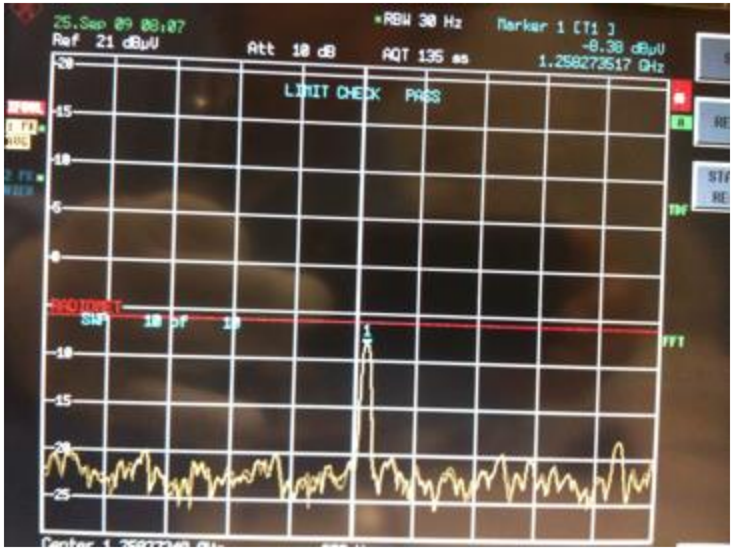
- Spent Summer (southern hemisphere winter) of 2009 in Argentina Leading EMI Tiger Team
- Most SAC-D Boxes Produced Higher Than Expected Emissions In L-Band
- Crack team of CONAE/INVAP EMI/RF Experts Assembled
- Tackled Each And Every Issue Successfully (instruments and engineering subsystems such as Mass Memory, ST, IMU, RWA, Mag, Telecom etc)
- Needed to Have A High Degree Of Confidence Going Into System Level EMC/Self-Compatibility Tests Scheduled for Summer 2010 At INPE/LIT In Sao Jose dos Campos, Brazil
- One instrument was of concern: CARMEN SODAD from CNES (France)
  - EMI engineer's heroic efforts in mitigating noise still produced exeedances in L-Band spec limit
  - Decided to move forward with delivery and determine impact to Aquarius at system level EMC tests at INPE

"….my initial reaction is bad. These exceedances are large and surely detectable by the radiometer" 2/3/2009 Fernando Pellerano Radiometer team GSFC on SODAD radiated emissions



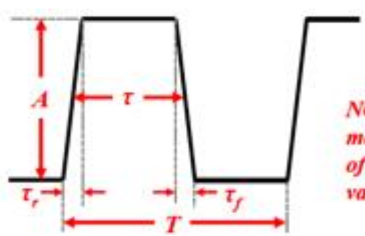
Aquarius/SAC-D EMI Tiger Team





Fourier Series

- **Circuitry with fast rise times present an EMI challenge, particularly for sensitive instruments**



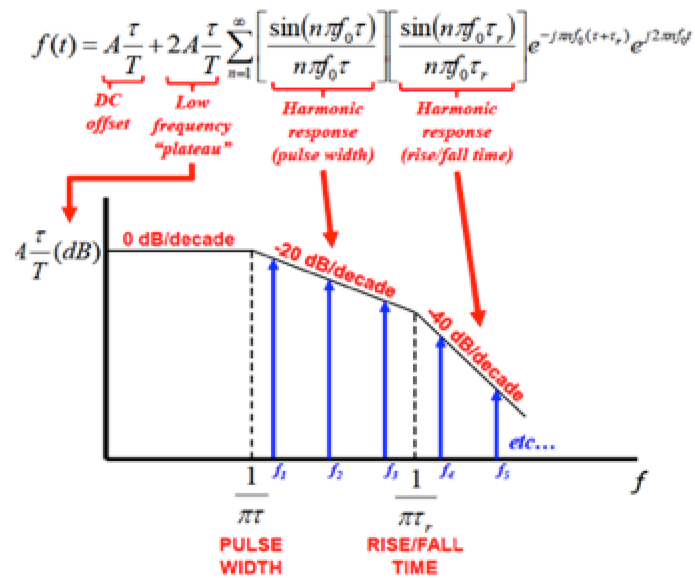
$f_0 = \frac{1}{T}$

NOTE: τ_r and τ_f are generally measured between 10% and 90% of the minimum and maximum values of the waveform.

Assume $\tau_r = \tau_f$:

$$f(t) = A\frac{\tau}{T} + 2A\frac{\tau}{T}\sum_{n=1}^{\infty}\left[\frac{\sin(n\pi f_0\tau)}{n\pi f_0\tau}\right]\left[\frac{\sin(n\pi f_0\tau_r)}{n\pi f_0\tau_r}\right]e^{-jn\pi f_0(\tau+\tau_r)}e^{j2\pi n f_0 t}$$

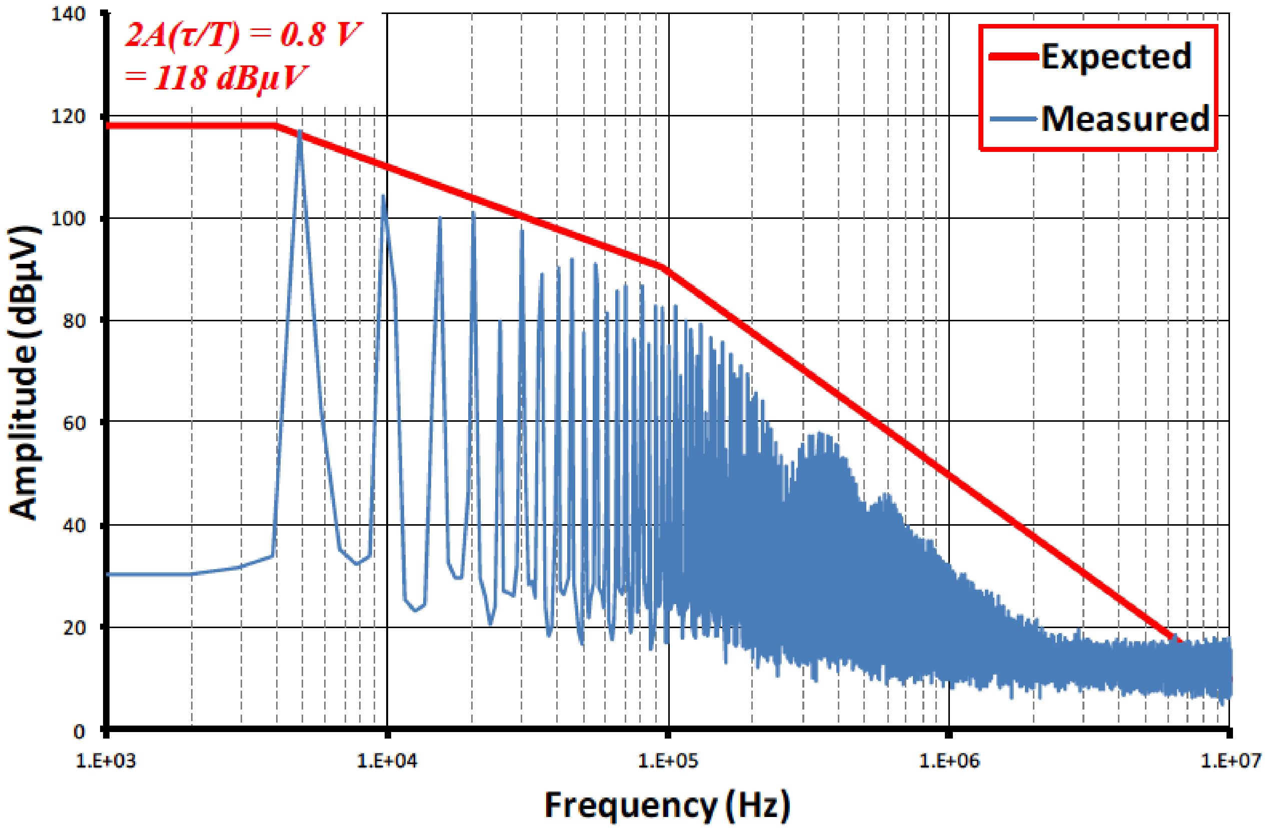
$$= A\frac{\tau}{T} + 2A\frac{\tau}{T}\sum_{n=1}^{\infty}\left[\frac{\sin(n\pi f_0\tau)}{n\pi f_0\tau}\right]\left[\frac{\sin(n\pi f_0\tau_r)}{n\pi f_0\tau_r}\right]\cos\left[2\pi n f_0 t - \pi n f_0(\tau - \tau_r)\right]$$

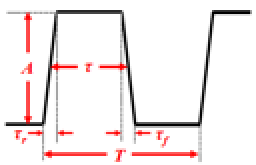


TIME DOMAIN PULSE

PULSE IN FREQUENCY DOMAIN

TYPICAL "SLOW" RISE TIME PULSE SPECTRUM





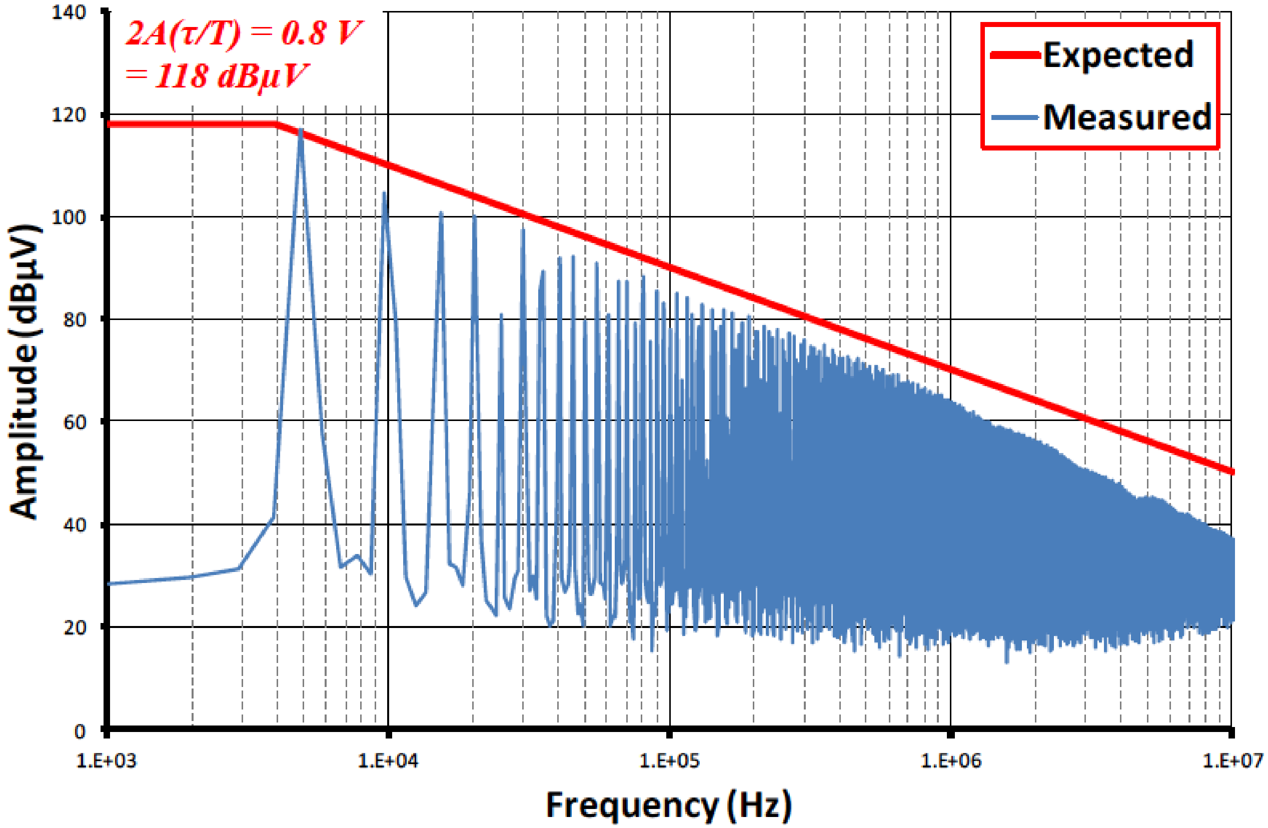
$A = 1\ V$

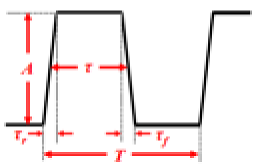
$T = 200\ \mu s \quad (f_0 = 5\ kHz)$

τ, τ_r, & τ_f varied as indicated on following slides

$\tau = 80\ \mu s\ (\tau/T = 40\%);\ \tau_r = \tau_f = 3.3\ \mu s$

TYPICAL "FAST" RISE TIME PULSE SPECTRUM





$A = 1\ V$

$T = 200\ \mu s\quad (f_0 = 5\ kHz)$

τ, τ_r, & τ_f varied as indicated on following slides

$\tau = 80\ \mu s\ (\tau/T = 40\%);\ \tau_r = \tau_f = 40\ ns$

SAC-D/Aquarius
DSC RF Emissions Profile

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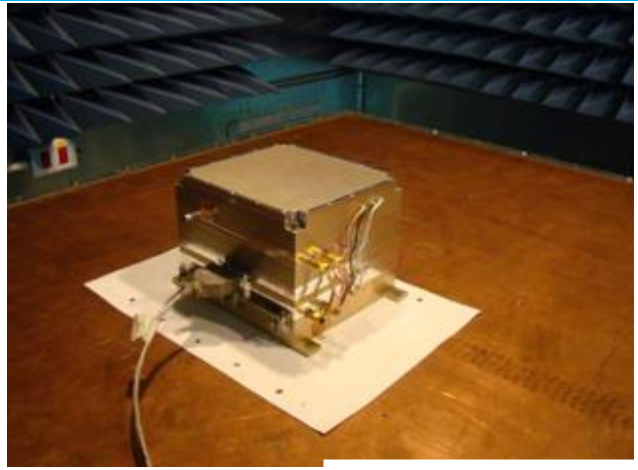
SAN MIGUEL DE TUCUMÁN

A narrowband EMI source has an effective noise temperature

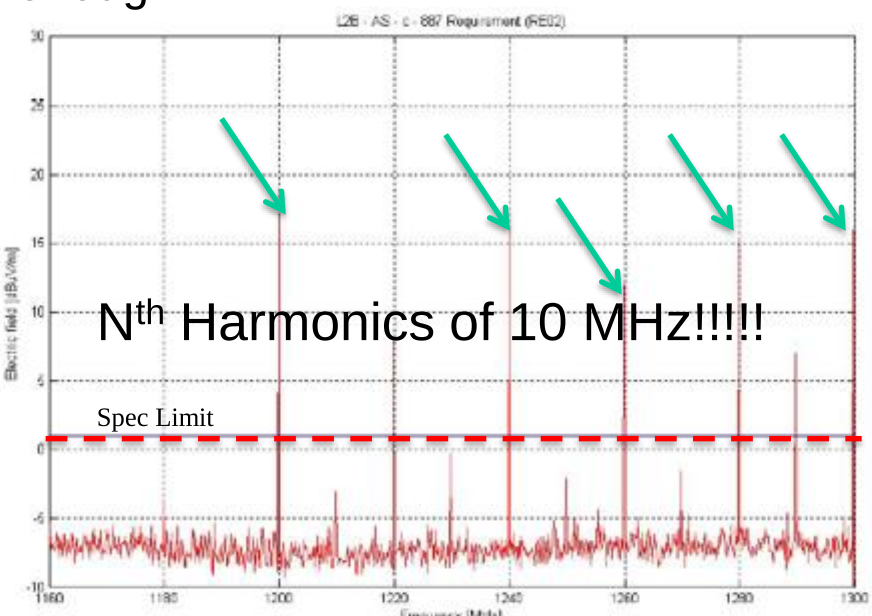
$$dT_N = \frac{dP_{EMI}}{kB}$$

Radiometer can detect this "Signal" if it is large enough

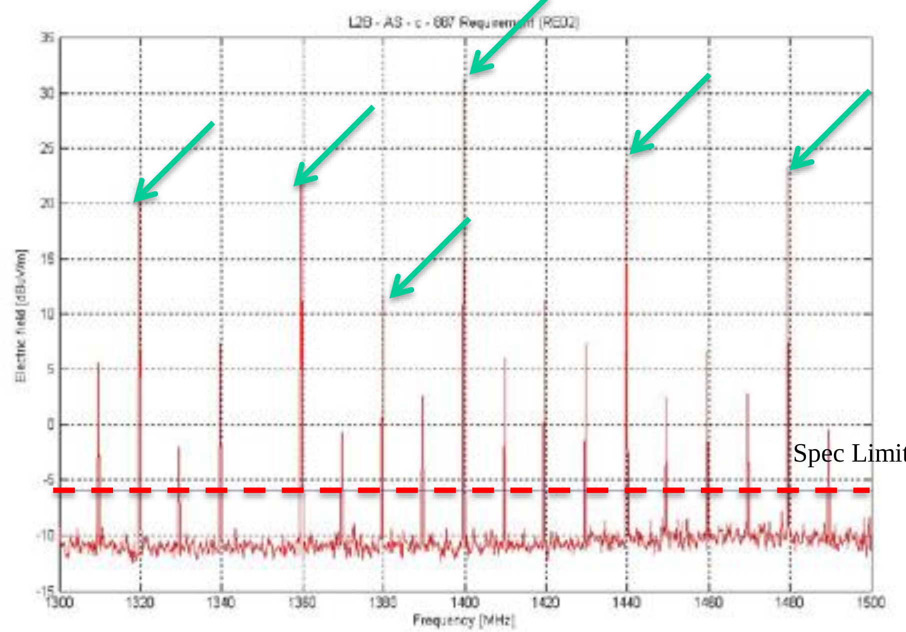


Cordoba EMC Test Chamber

Typical SAC-D Box Digital Collection System (DSC)



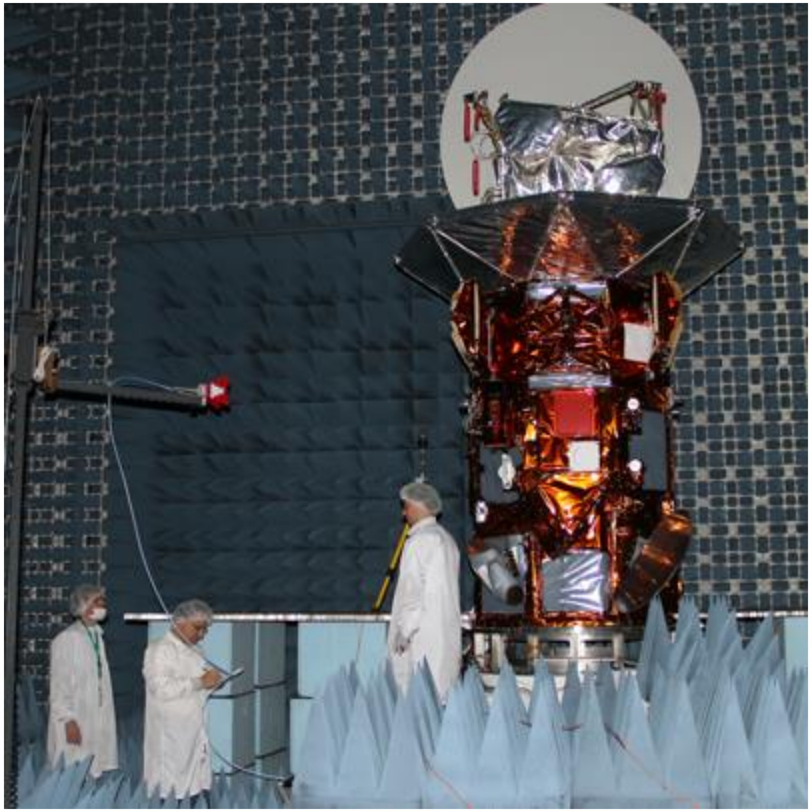
Scatterometer Band



Radiometer Band

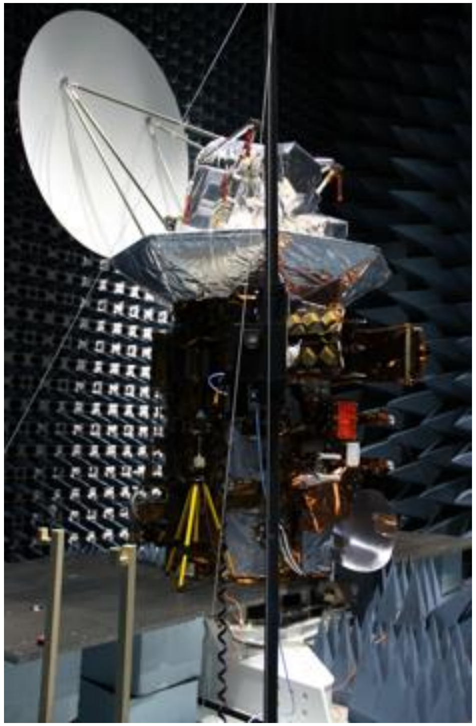
How Were SAC-D/Aquarius EMI/EMC Risks Eliminated?

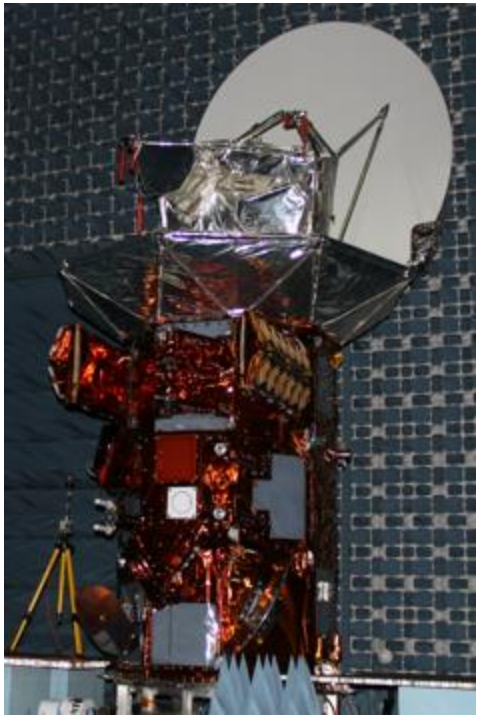
- **Seriousness of issue identified and immediately a plan was developed to address it thoroughly and comprehensively: Instrument then system level**



Aquarius/SAC-D EMC System Test At INPE, Brazil

- Comprehensive Tests Showed Only One Interferer (CARMEN-SODAD)
  - Operational work-around restricts SODAD to specific operational modes that do not interfere with Aquarius
- Most Sensitive L-Band Instruments Flown to Date Performance Validated
  - Significant and important lesson learned is that comprehensive system tests validated the original -6dBu/m & 1dBuV/m requirements at L-Band to protect radiometer and scatterometer



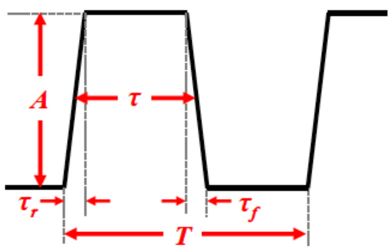


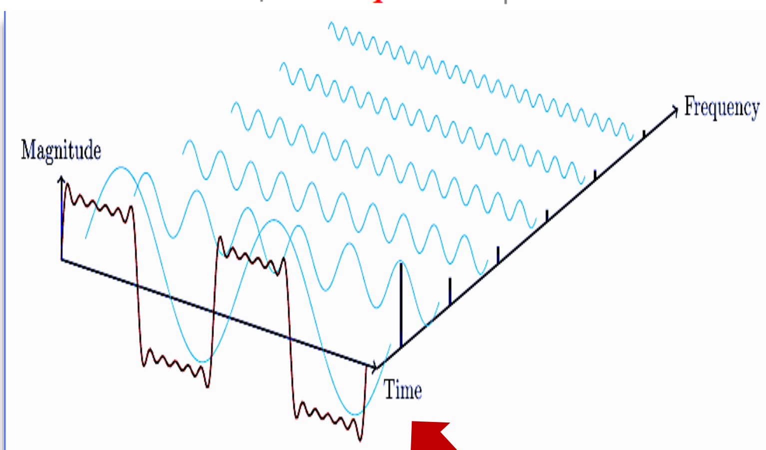
INPE/LIT, Sao Jose Dos Campos Brazil

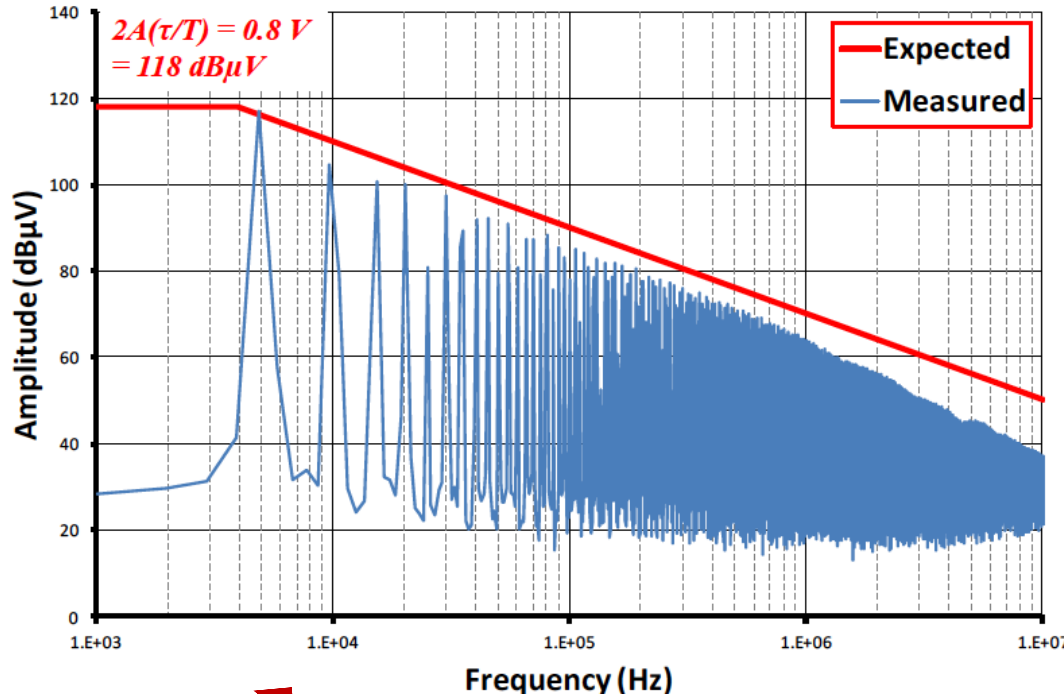
Radiated Emissions Example

LVDS – Low Voltage Differential Signaling

TYPICAL SPECTRUM OF PULSE







Time Domain Mapping Into Frequency Domain

Radiated Emissions In LVDS

Radiated Emissions Example

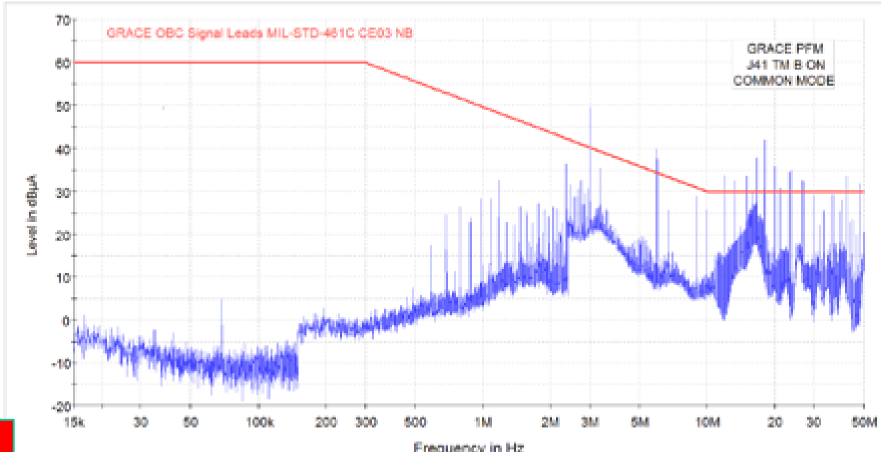
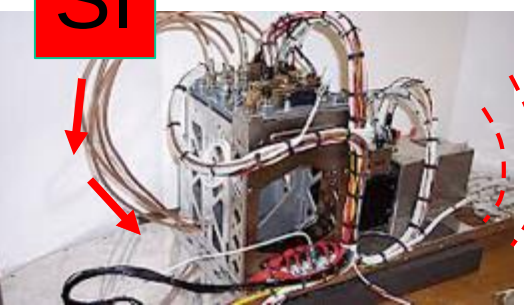


Figure 3.2-3. J41 CECM Data, PFM OBC

Common Mode Noise Works Its Way To Efficient Antenna Elements Such As Cables, Slots, Connectors Etc…

SI



EMI

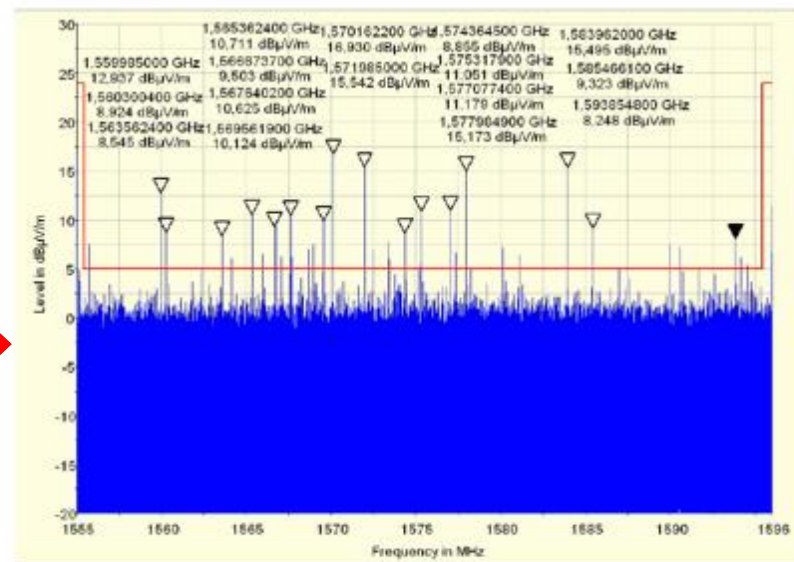
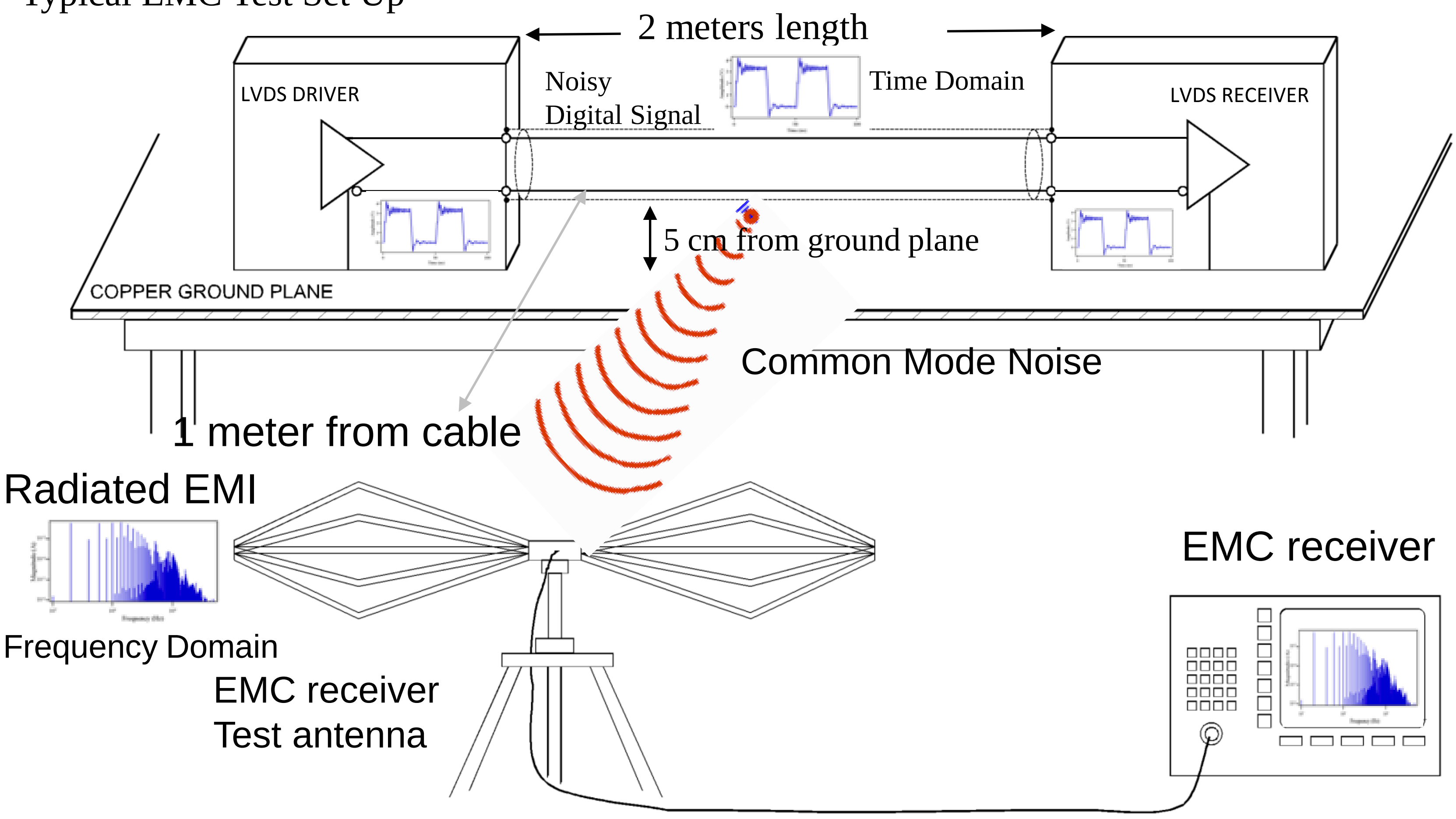


Figure 3.3-1. OBC PFM RE02 Data, GPS L1 Band, Vertical Polarity

…Resuting In Radiated Emissions In Sensitive Receiver Bands Such As GPS L1, Or UHF Or S-Band....

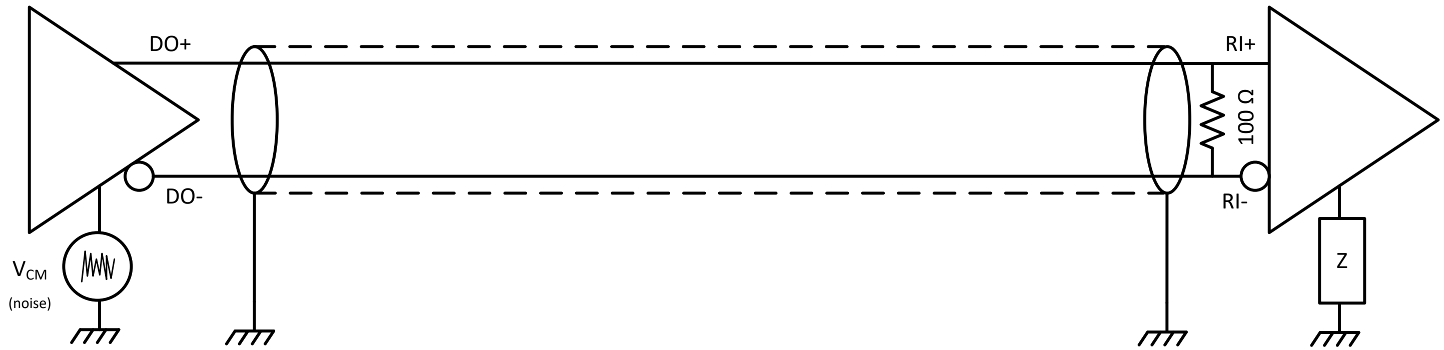
Radiated Emissions Example

Typical EMC Test Set Up

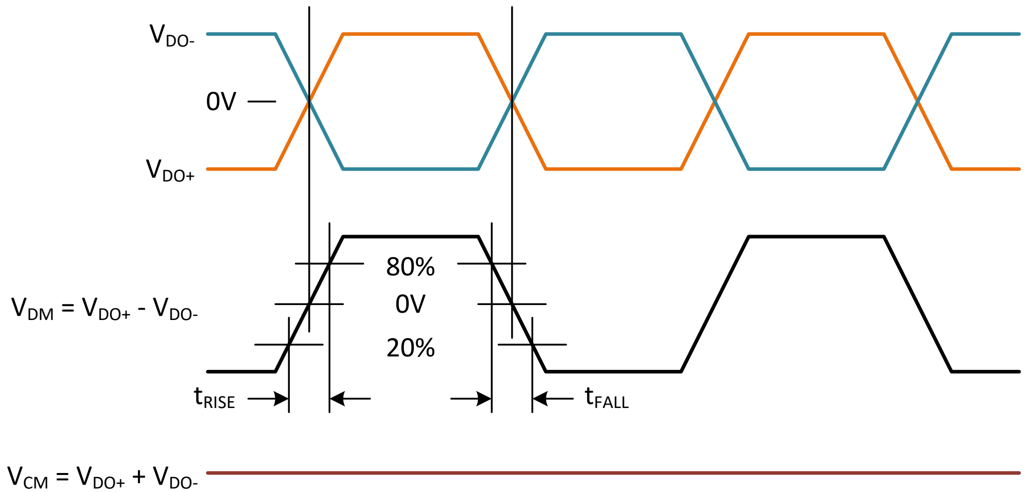


LVDS Condition 1 – Good SI Design

Braided Shielded Cable, No Skew and No CM Noise

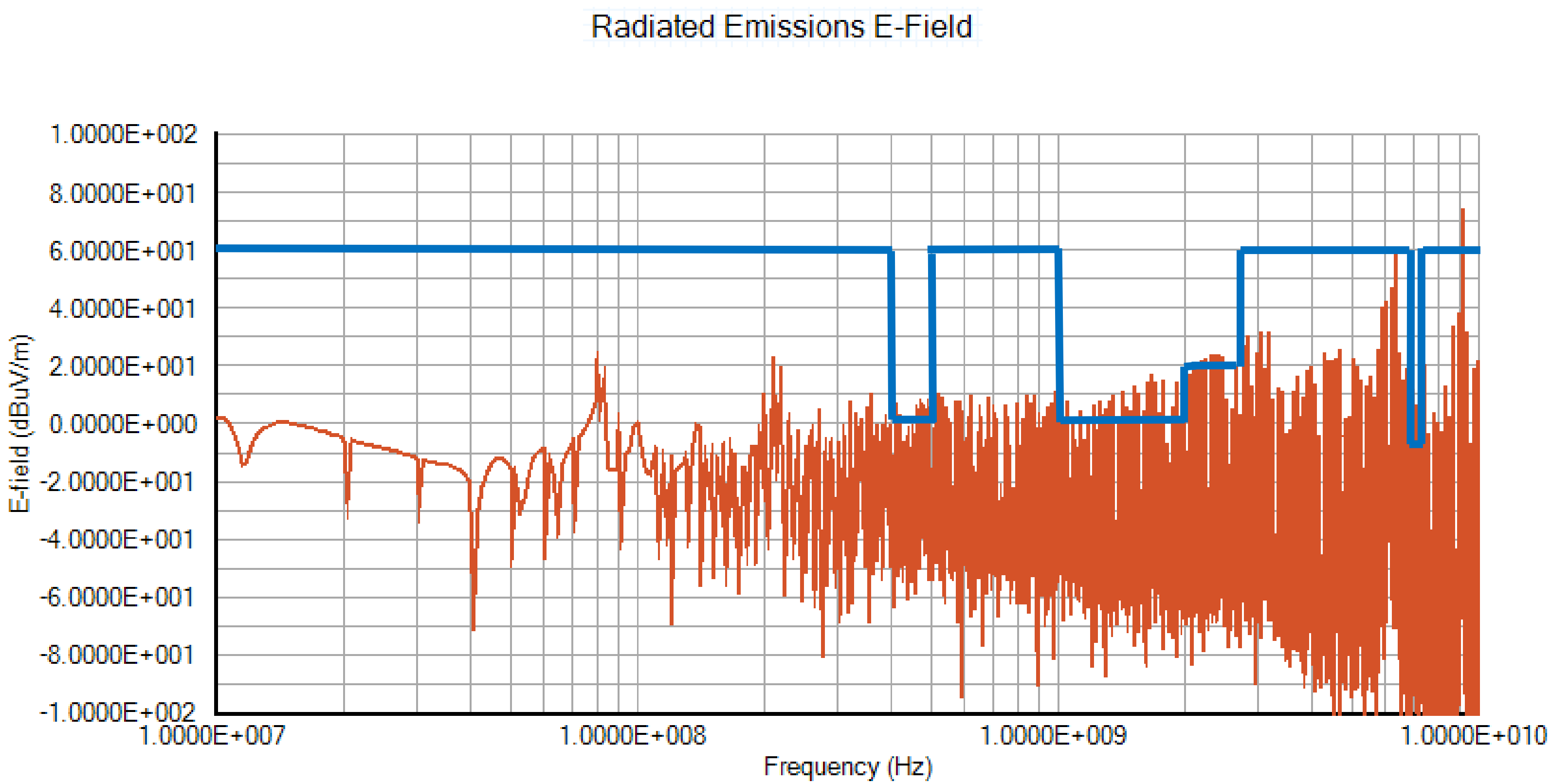


- **Conditions**
  - **10 MHz data rate**
  - **No Skew**
  - **No system CM noise**



RE Results for Condition 2 – Bad SI Design

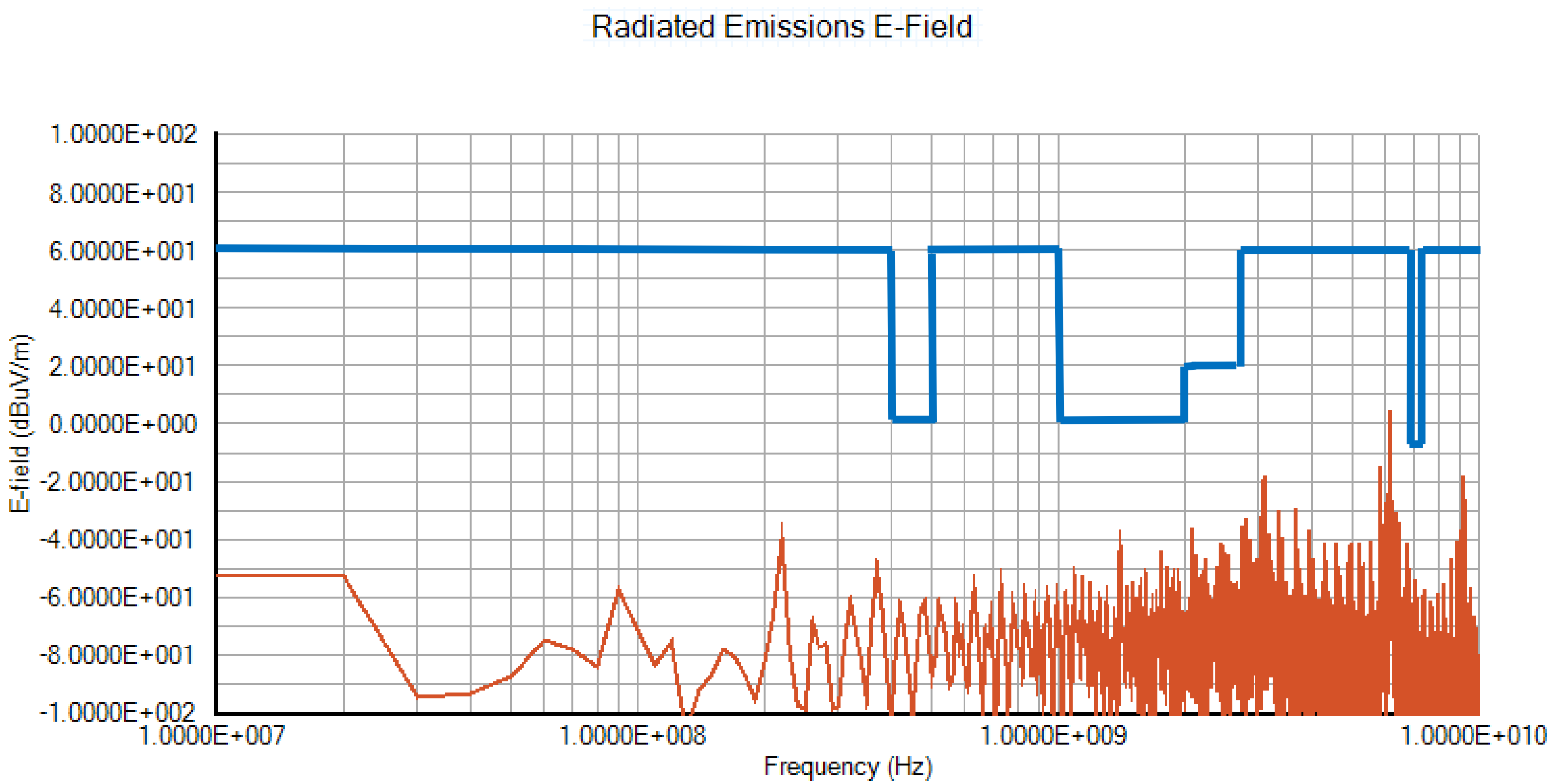
Braid Shielded Cable, with 200 picoSec Skew and CM Noise



<u>Bad SI Design Produces Common Mode Noise Which Produces Significant Radiated Emissions</u>

RE Results for Condition 1 – Good SI Design

Braid Shielded Cable, No Skew, No CM Noise

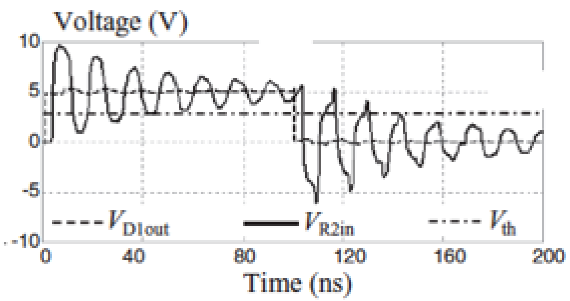


Good SI Design Eliminates Common Mode Noise Which Reduces Radiated Emissions

Radiated Emissions Due To High Speed Digital Systems

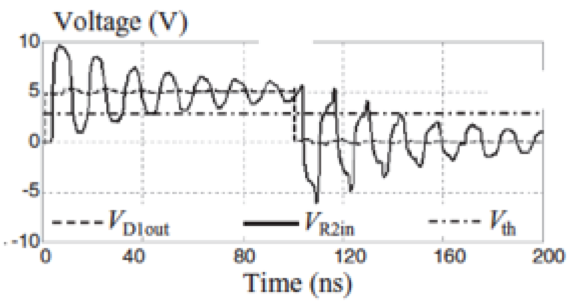
SI to EMI Takeaway

Poor Signal Integrity PCB Design….



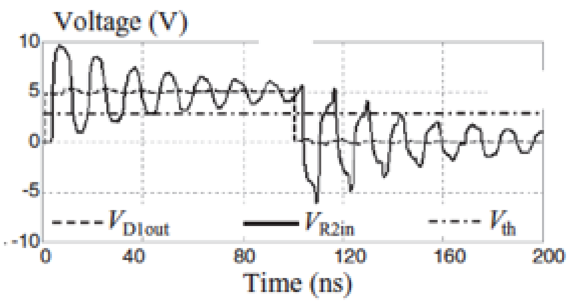
SI to EMI Takeaway

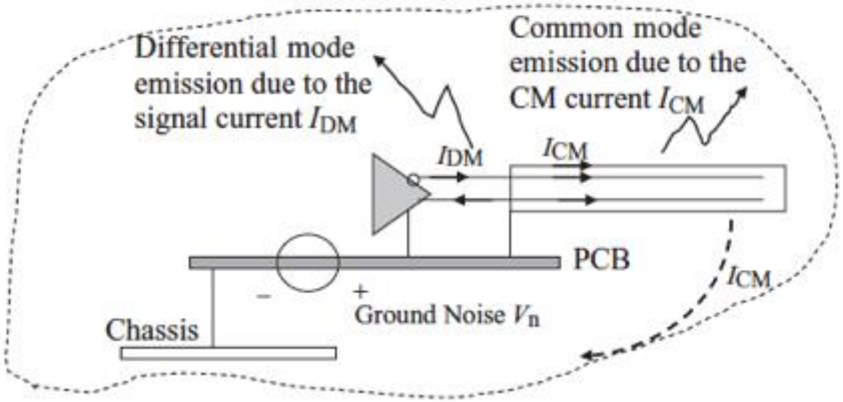
Poor Signal Integrity PCB Design….



SI to EMI Takeaway

Poor Signal Integrity PCB Design…. Leads To Common Mode Noise…

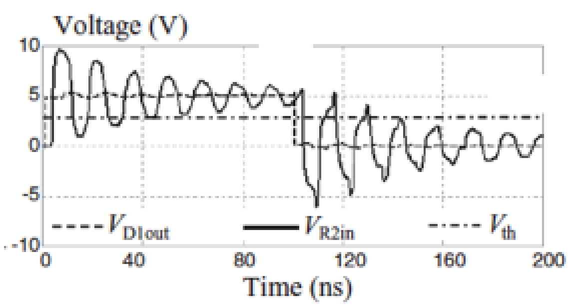


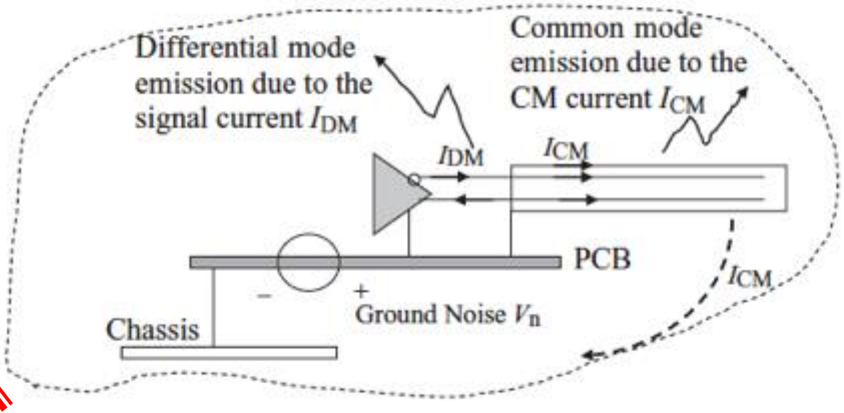


SI to EMI Takeaway

Poor Signal Integrity PCB Design….

Leads To Common Mode Noise…





Radiated Emissions Due To High Speed Digital Systems

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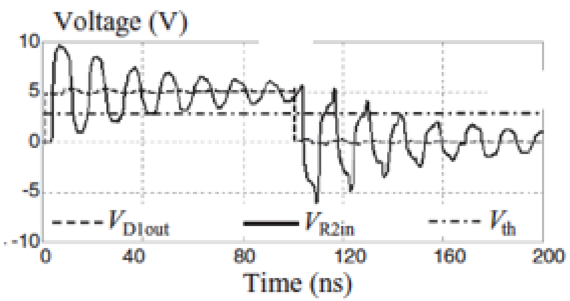
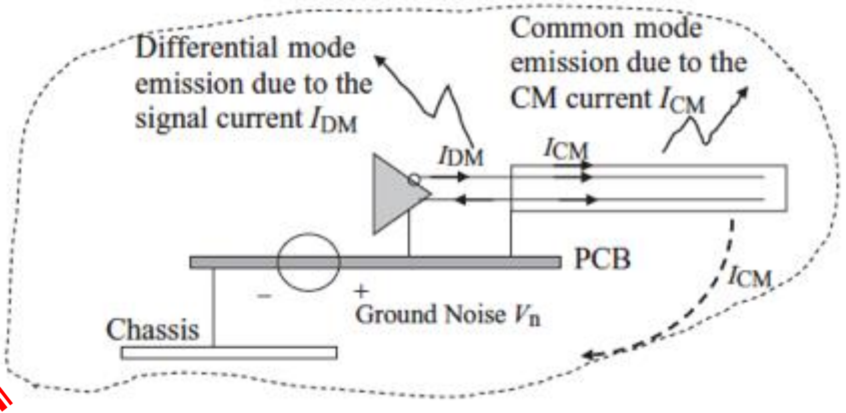
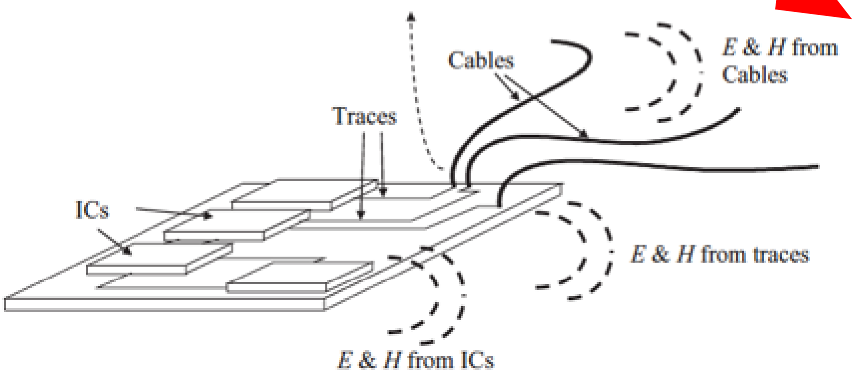
SI to EMI Takeaway

Poor Signal Integrity PCB Design….



Leads To Common Mode Noise…

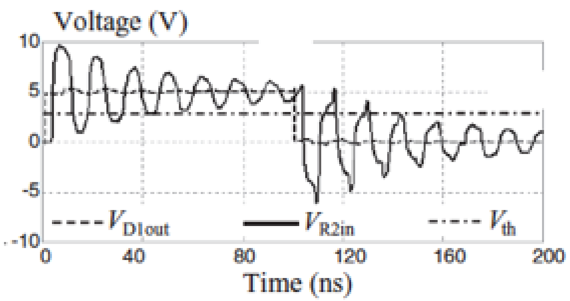




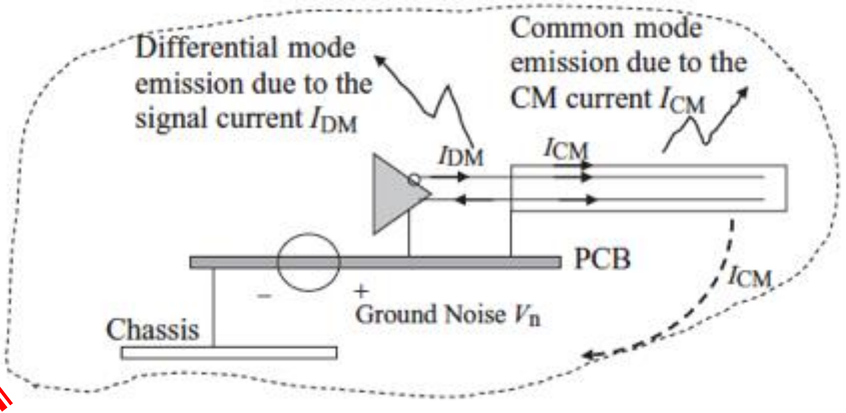
Which Leads To PCB Radiated EMI Noise

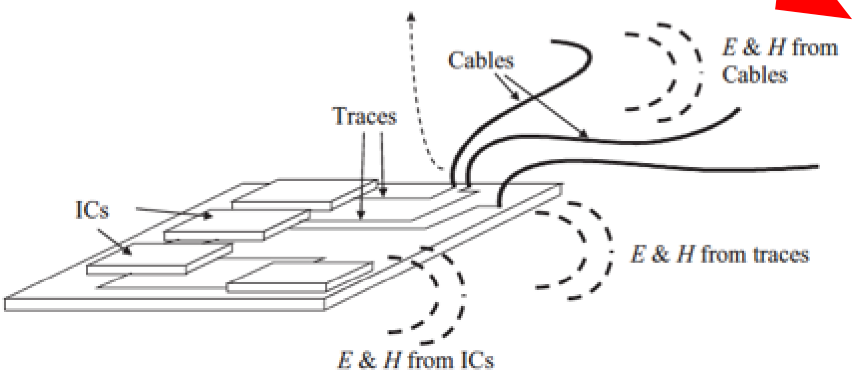
SI to EMI Takeaway

Poor Signal Integrity PCB Design….



Leads To Common Mode Noise…





Which Leads To PCB Radiated EMI Noise

Radiated Emissions Due To High Speed Digital Systems

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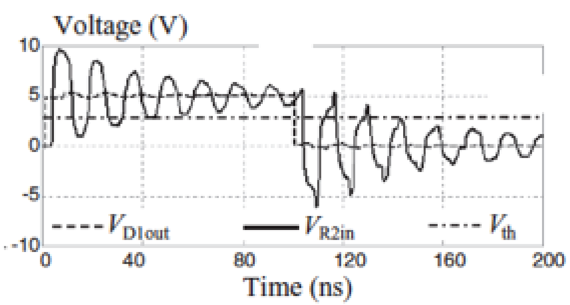
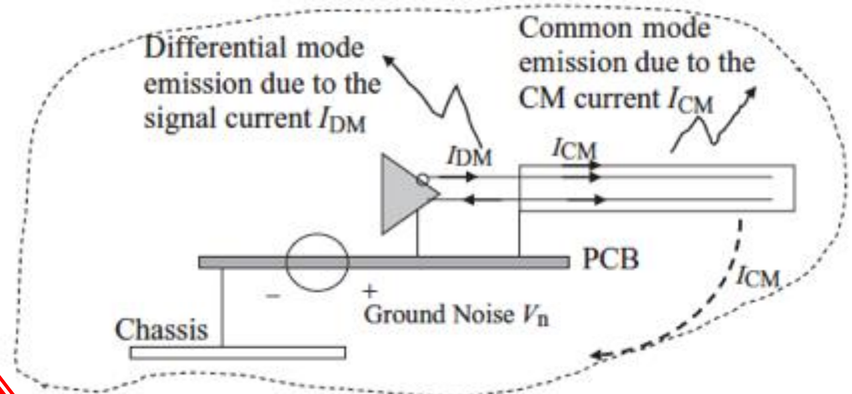
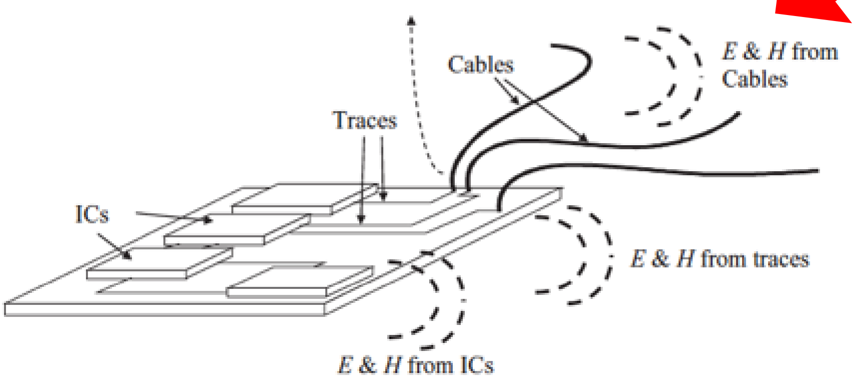
SI to EMI Takeaway

Poor Signal Integrity PCB Design….



Leads To Common Mode Noise…





Which Leads To PCB Radiated EMI Noise

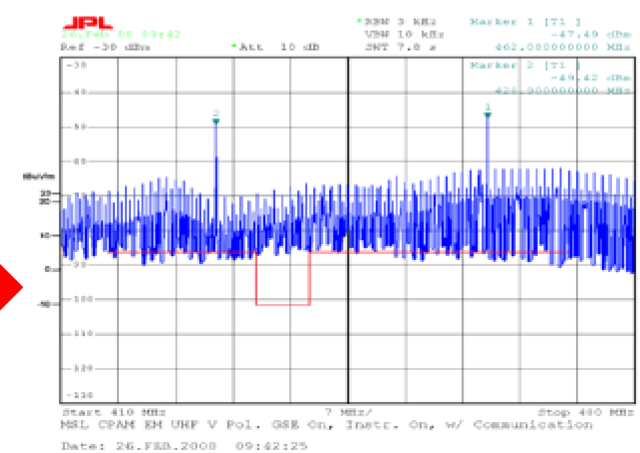
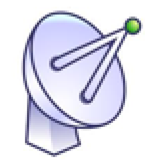


Figure 65, Follow-on diagnostics, UHF notch, 410 – 480 MHz, vertical polarization



Impacting Sensitive RF Receivers

Radiated Emissions Due To High Speed Digital Systems

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SI to EMI Takeaway

PCB Physical Geometry Creates The Amount Coupling Between Noisy Circuits and Structures (Ground Planes, Chassis, Cables) …

→ ...Due To Parasitic Capacitance And Inductance That Exists Within These Structures…

→ Capacitance and Inductance Is The Main Mechanism…

→ …That Produces Noise Due To dV/dt and dI/dt Switching Conditions…

→ …Generating Unwanted Common Mode Noise Flowing On Cables/Structures and Thus …

→ Producing Unwanted Radiated Emissions

<u>REDUCE RADIATED EMISSIONS</u> By Managing PCB Physical Geometry.
<u>MINIMIZE COMMON MODE NOISE</u> By Controlling Trace Layout, Ground Planes, Edge Rates, Ringing, Overshoot/Undershoot,

THANK YOU!