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Pasadena, California

Electronic Failures in Spacecraft Environments

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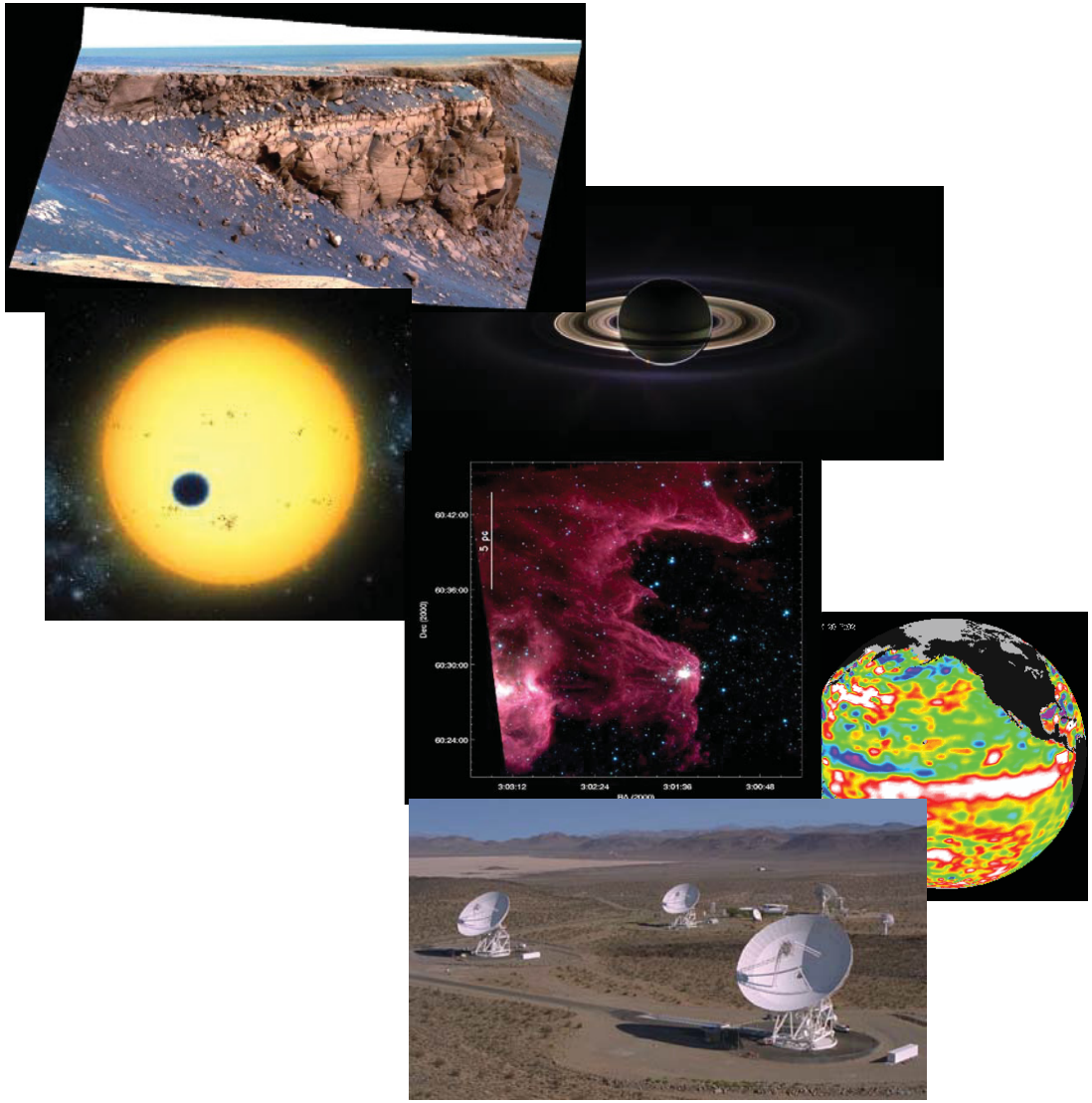
JPL's mission for NASA is *robotic* space exploration

- Mars
- Solar system
- Exoplanets
- Astrophysics
- Earth Science
- Interplanetary network



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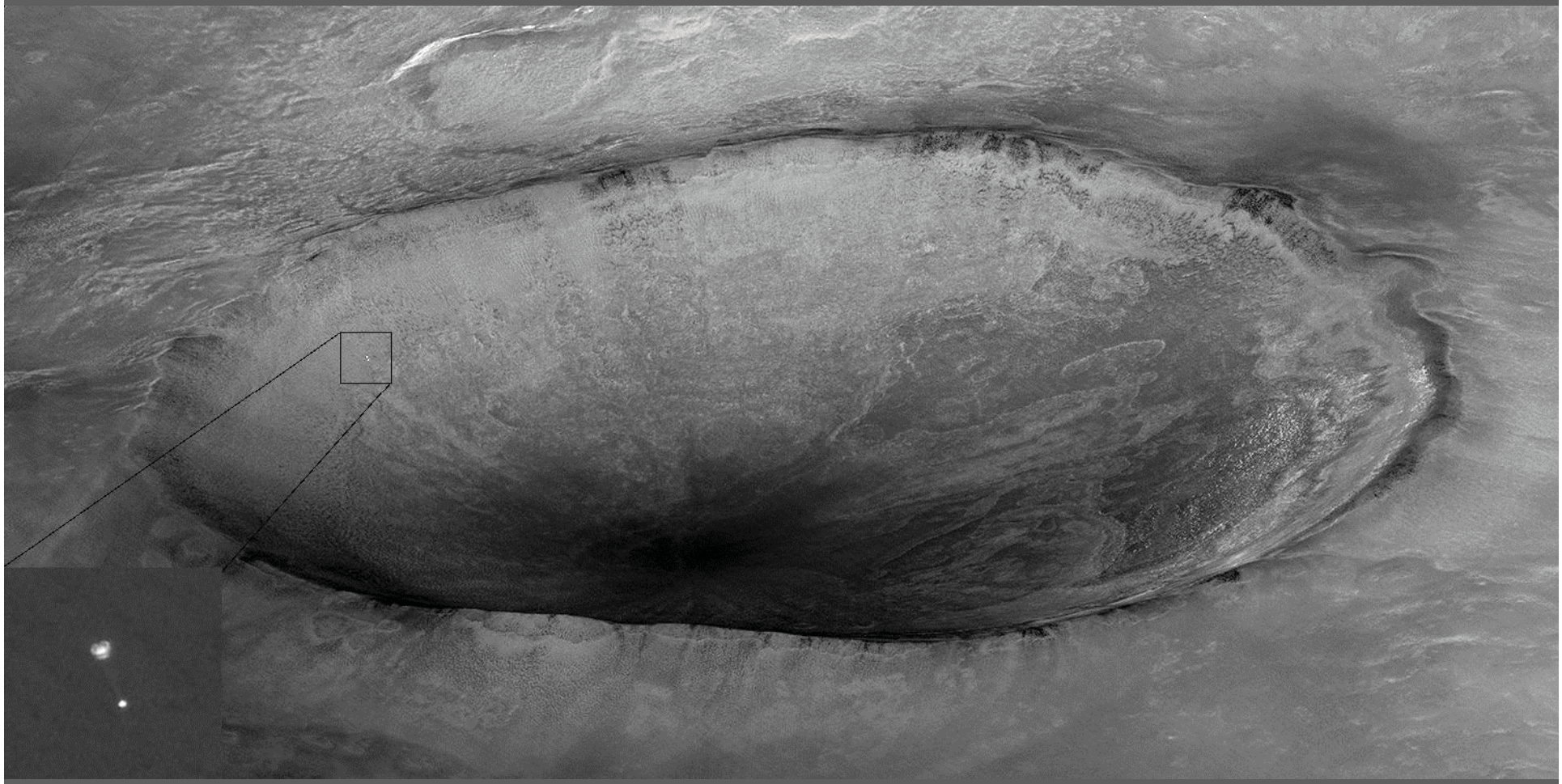
Mars Reconnaissance Orbiter captures descent of Phoenix Lander



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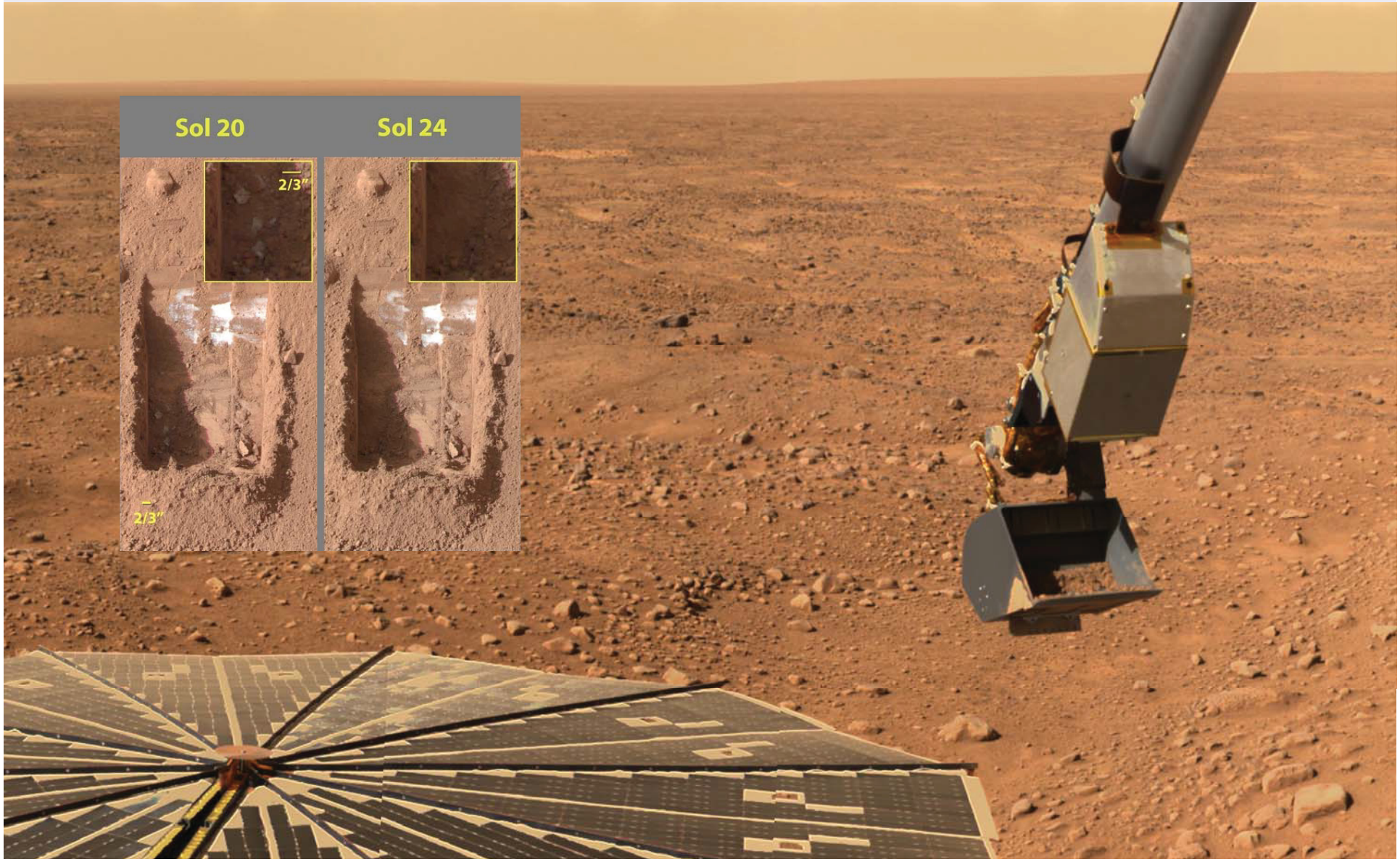
Phoenix makes it official: There is water on Mars



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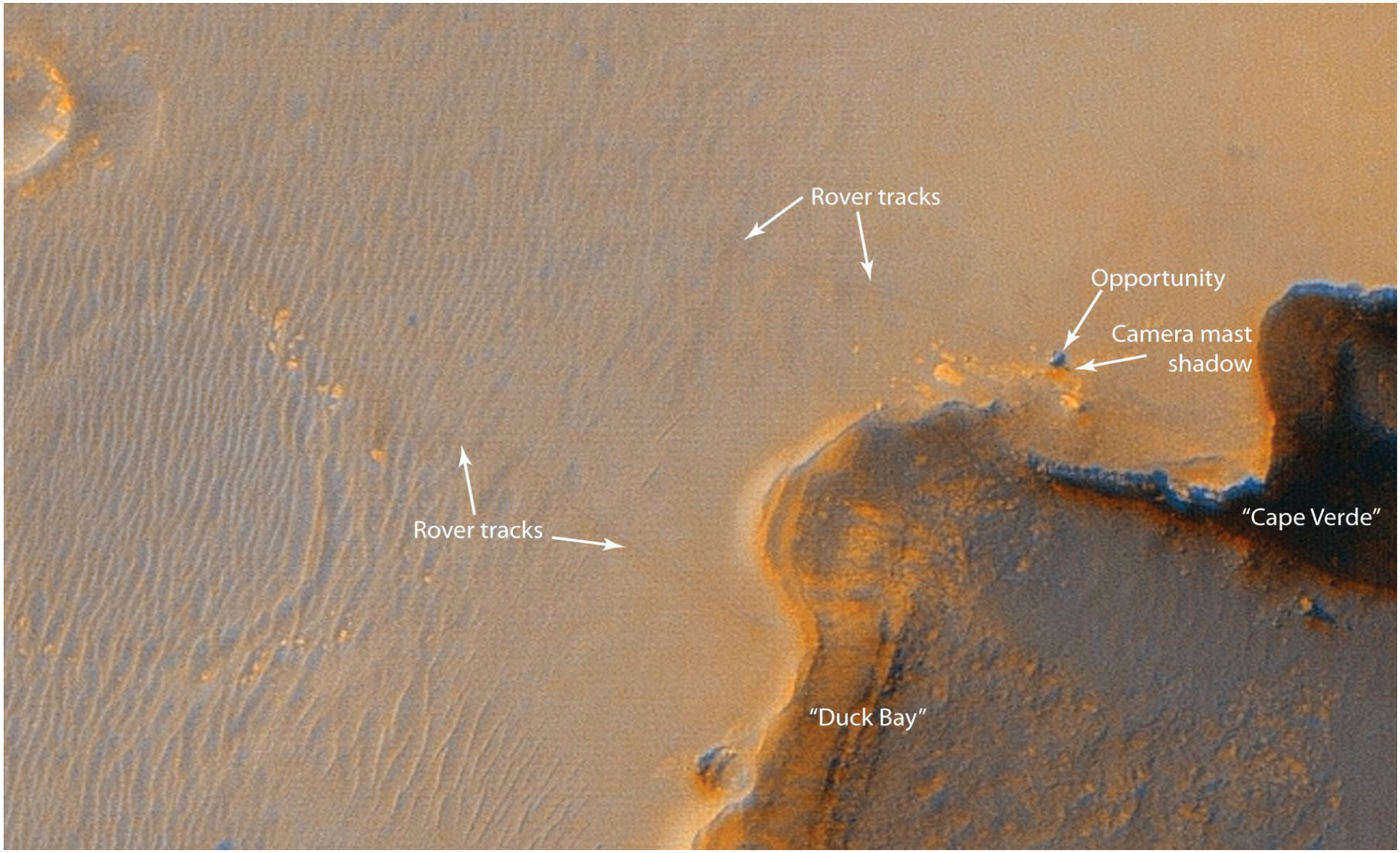
MRO takes a picture of MER (Opportunity)



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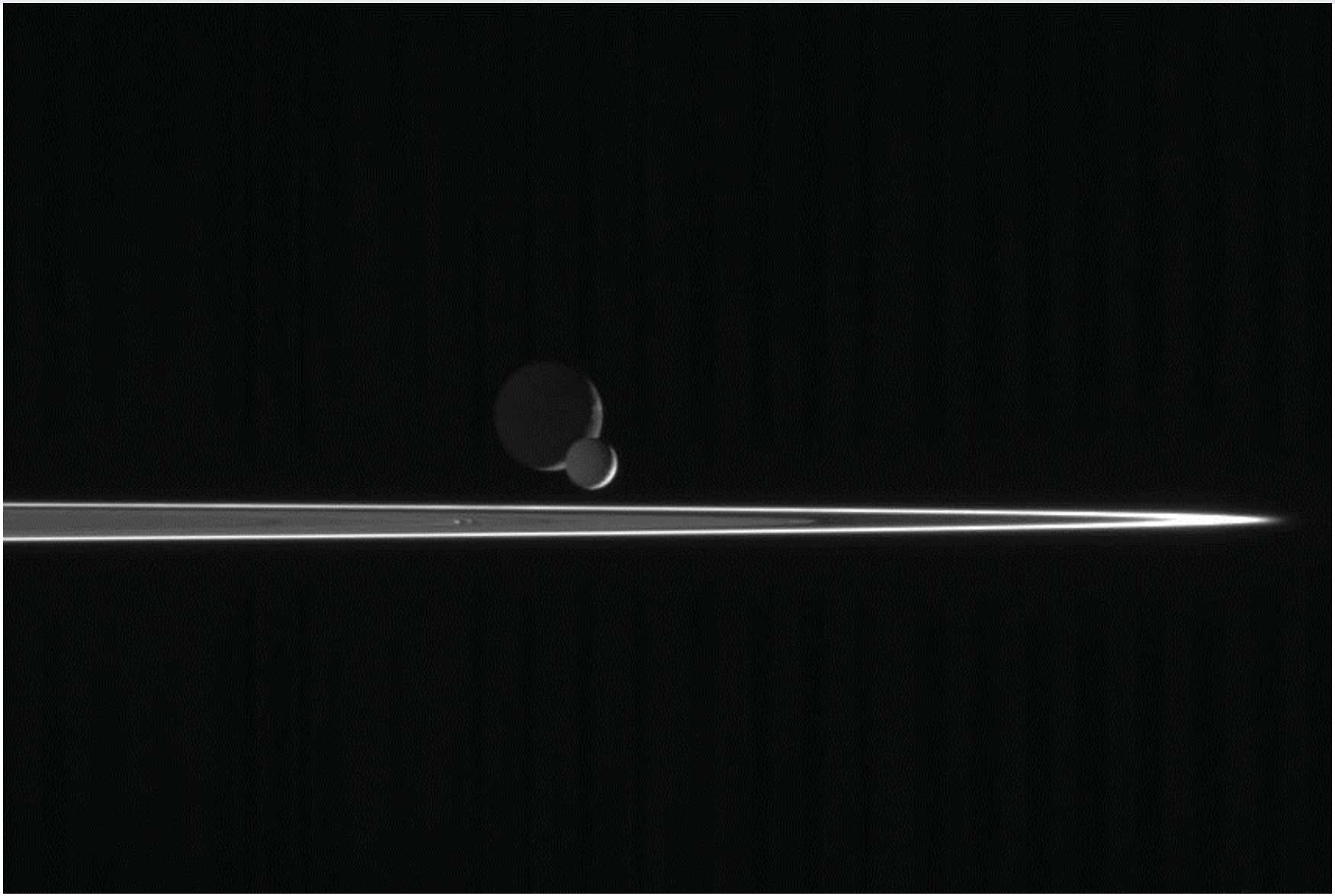
Enceladus slips in front of Dione above Saturn's F ring



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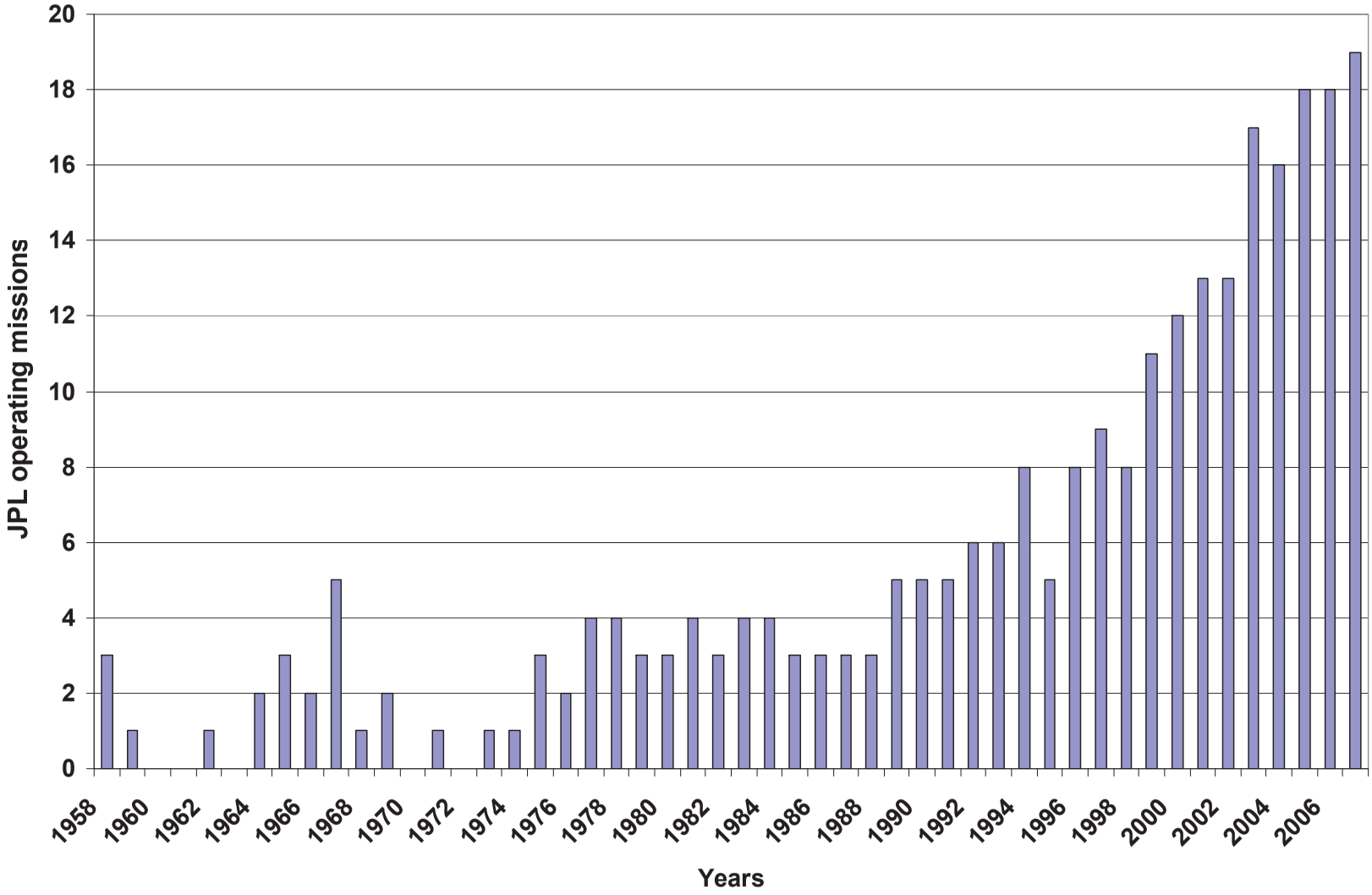
JPL MISSIONS 1958-2008

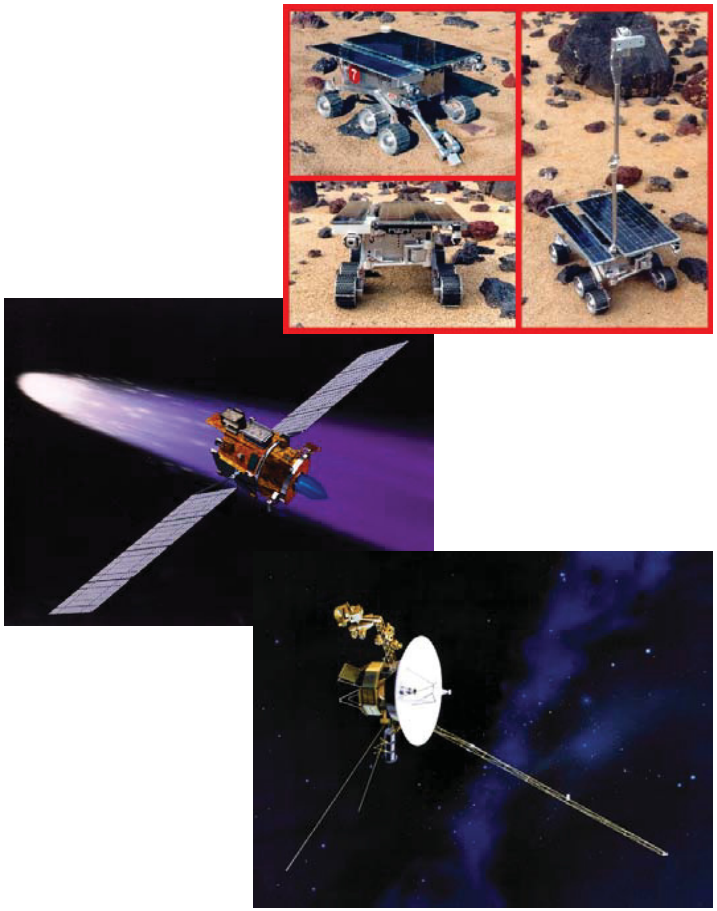


Failure overview

- Pre-launch
  - Handling and Test
  - Screening
- Launch
  - Catastrophic mission loss
- Mission
  - Early mission
  - Normal/designed
  - Extended mission

JPL Institutional Parts Program

- A minimum parts program applicable to all JPL missions
  - Is based on a minimum of "level B" parts program
  - Includes clear criteria for the utilization of COTS and PEMS
  - Targets 5-year mission life
  - Has radiation tolerance levels set by mission requirements
- Recommend using the best part levels available
- The tailored Project PPR is due:
  - Draft by the end of Phase A
  - Final by PDR



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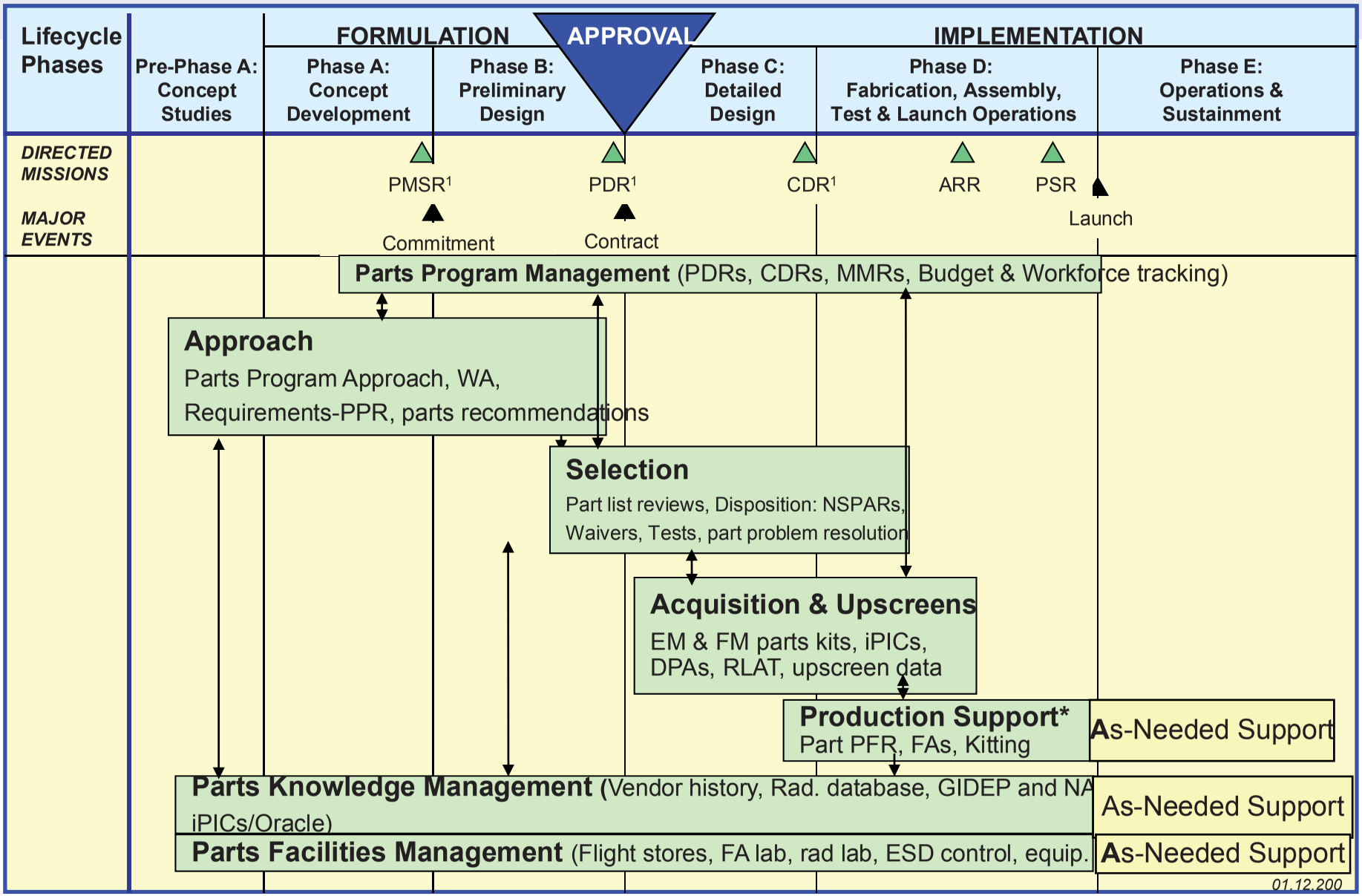
JPL Electronic Parts Life Cycle



Pre-launch Electronic Parts Failures

- One year sample of part types to JPL Failure Analysis Lab
- Screening escapes and integration failures
  - All technologies are represented

1.5V DC-DC Converter Hybrid	EEPROM
16 Channel Analog Mux	Hex Inverter
2.5V Voltage Reference	Ka Band LNA
256Mb NOR Flash	MESFET
25 Amp relay	MOSFET
32-bit SPARC Processor	Octal Buffer
Tantalum Capacitor	Resolver-to-Digital Converter
4Mb SRAM	RF amp module
Analog Mux	Schottky diode
CCD	Surface mount resistors
Ceramic chip resistor	Tunnel diode
Dual Comparator	Voltage reference

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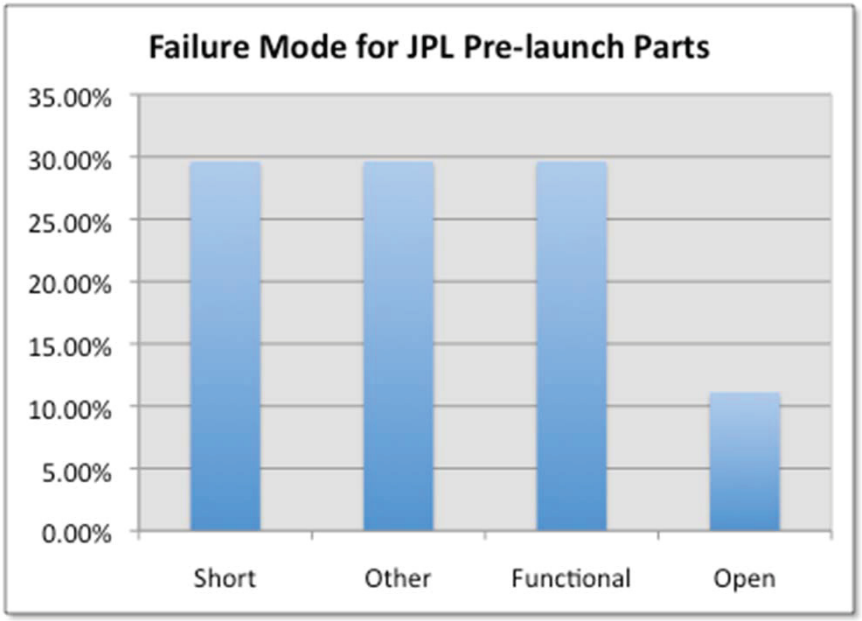
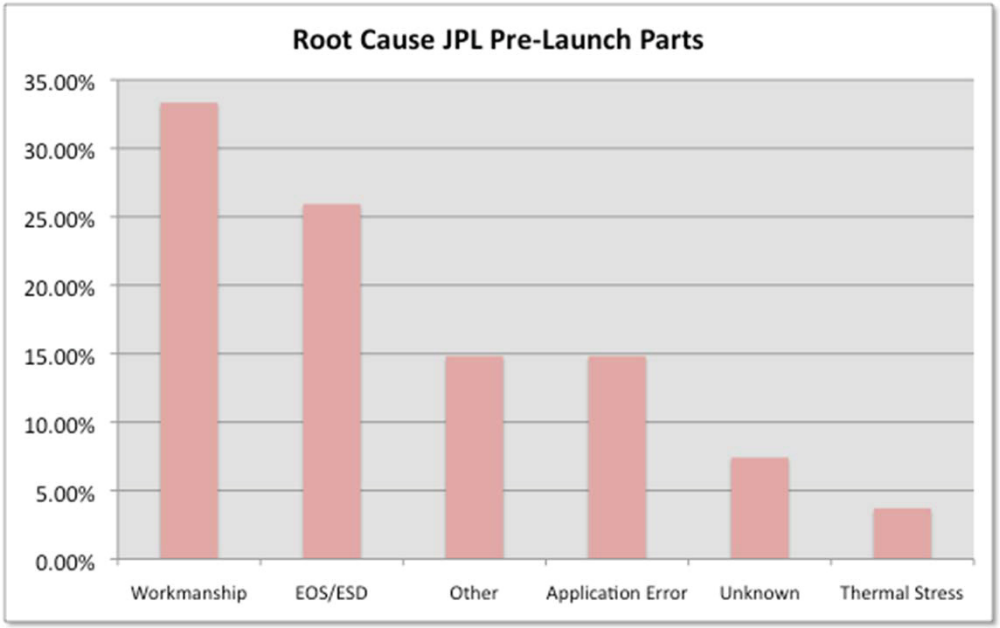
Pre-launch Electronic Parts Failures



- Failure modes dominated by shorts and functional failures (60%).
- Parts failing open only occurs about 10% of the time.
- "Other" includes visual/materials defects.

- Manufacturer's workmanship is the number one issue.
- Continuous improvements in supplier QA and JPL IQA required.
- EOS/ESD failures reflect challenging spacecraft assembly and test environment.



System vs. Circuit ESD

- All EEE parts are screened for minimum 2000V HBM ESD
  - Parts with exceptions are noted and discouraged
- Continued ESD failures during implementation indicate lack of correlation between integrated circuit ESD and system ESD
- Ethernet/network users have developed Cable Discharge Event/Model to account for long and (often) untwisted pair cables
  - A large amount of charge with a low source impedance vs. high impedance/low capacitance models (MM, HBM, CDM), similar to discharge of a transmission line
  - Charge accumulation due to triboelectricity and electromagnetic induction
  - Materials with very low dielectric leakage with ability to retain charge for long periods of time
- Custom system level models need to be considered/developed to ensure ESD success

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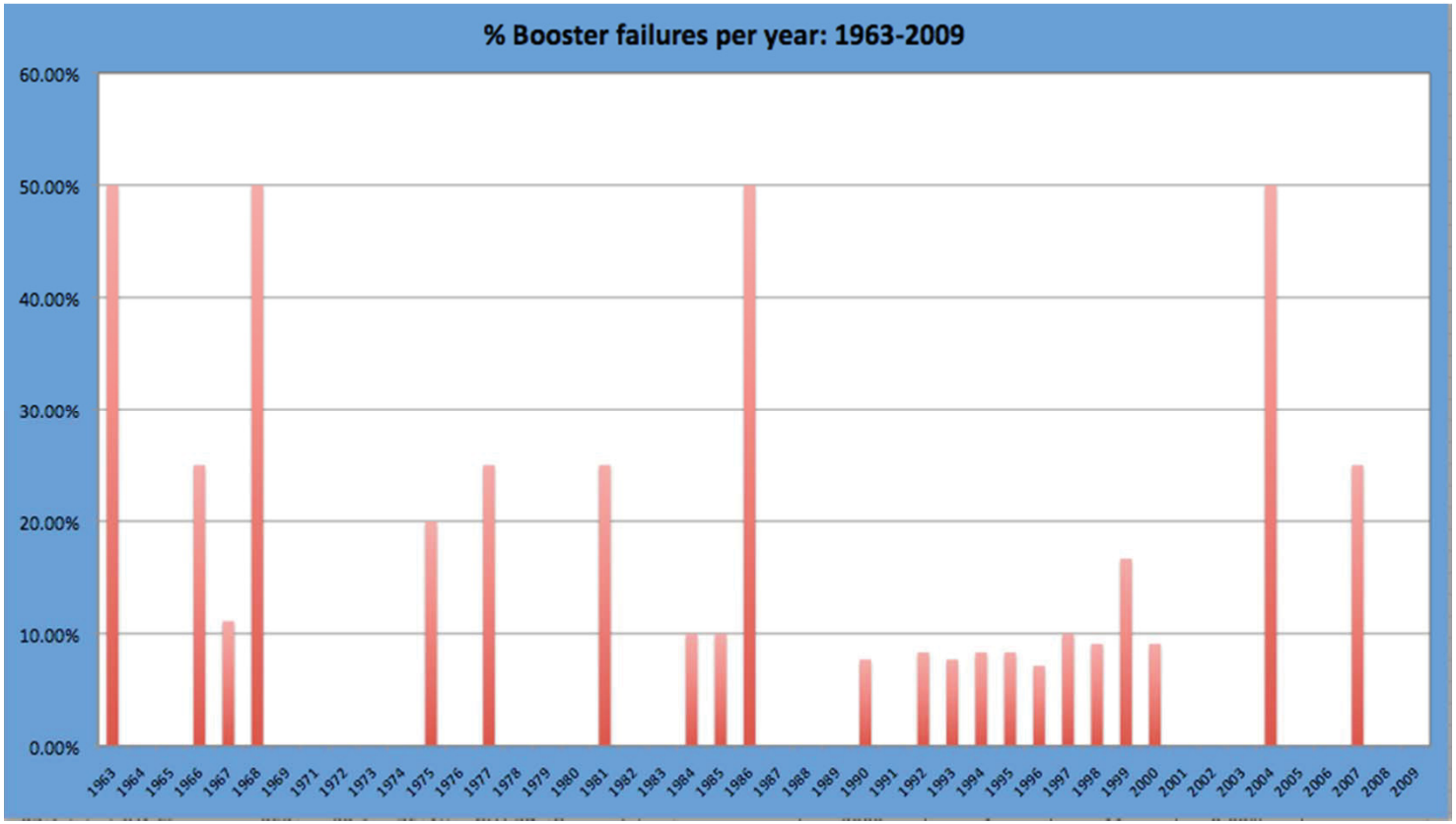
Launch Failures – Boeing Data
46 years of data



Launch is still a very risky undertaking – 46 year average is 9.4% chance of failure per year during launch

The space environment

Environment	Definition	Issues
Neutral Thermosphere	Atmospheric density, composition, atomic oxygen	Surface erosion, drag and decay
Thermal Environment	Solar radiation, albedo, radiative transfer	Passive/active thermal control, power allocation
Plasma	Ionospheric plasma, auroral plasma	EMI, charging/arcing
Meteoroid/Debris	Flux, size, mass and velocity distributions	Collision avoidance, crew survivability, material degradation
Solar Environment	Solar physics, storms	Lifetime/drag, reentry heating
Ionizing Radiation	Trapped protons/electrons, GCR, solar particles	Electronics parts dose, SEE, human dose levels
Geomagnetic Field	Natural magnetic fields	Induced currents on large structures
Gravitational Field	Natural gravitational field	Orbital mechanics

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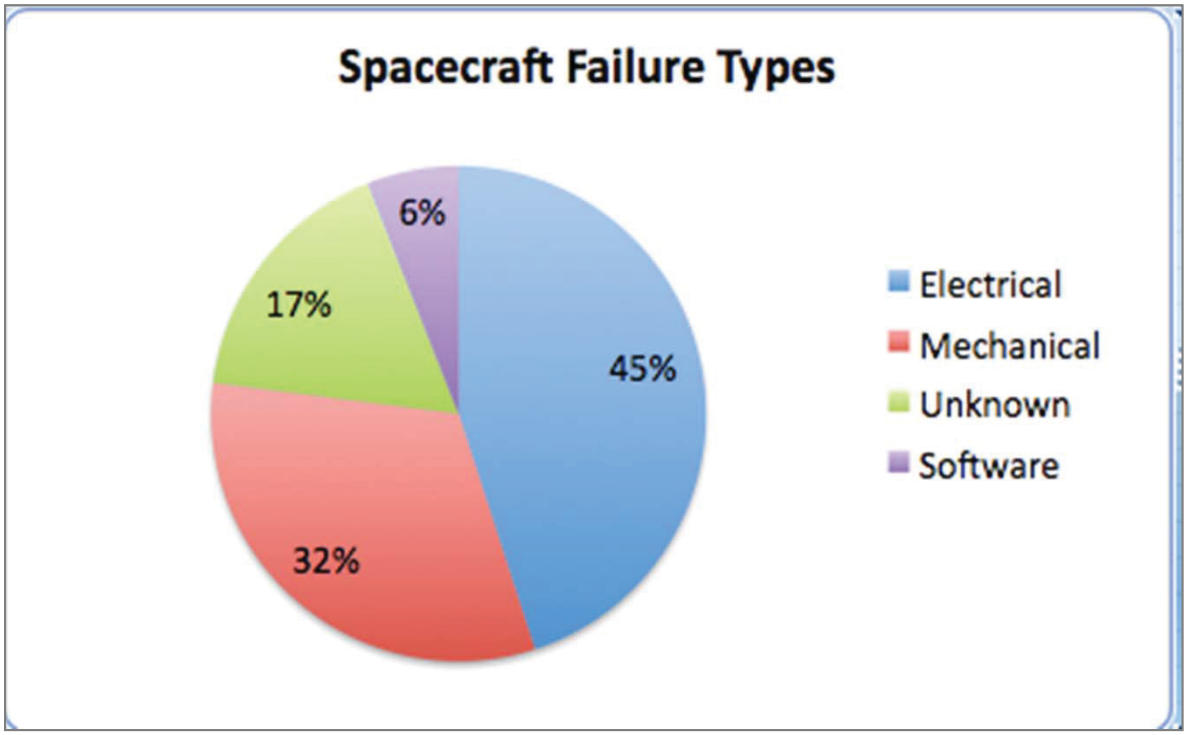
On-orbit failures 1980 to 2005

[Tafazoli 2008]



- 156 civilian and military on-orbit failures from 1980 to 2005
- Electrical failures are the single largest type of failures
    - Solar panels are included as electronic systems
- There are more electronic systems on modern spacecraft than there are mechanical systems.
- Found 41% of all failures occur in 1st year of operation.

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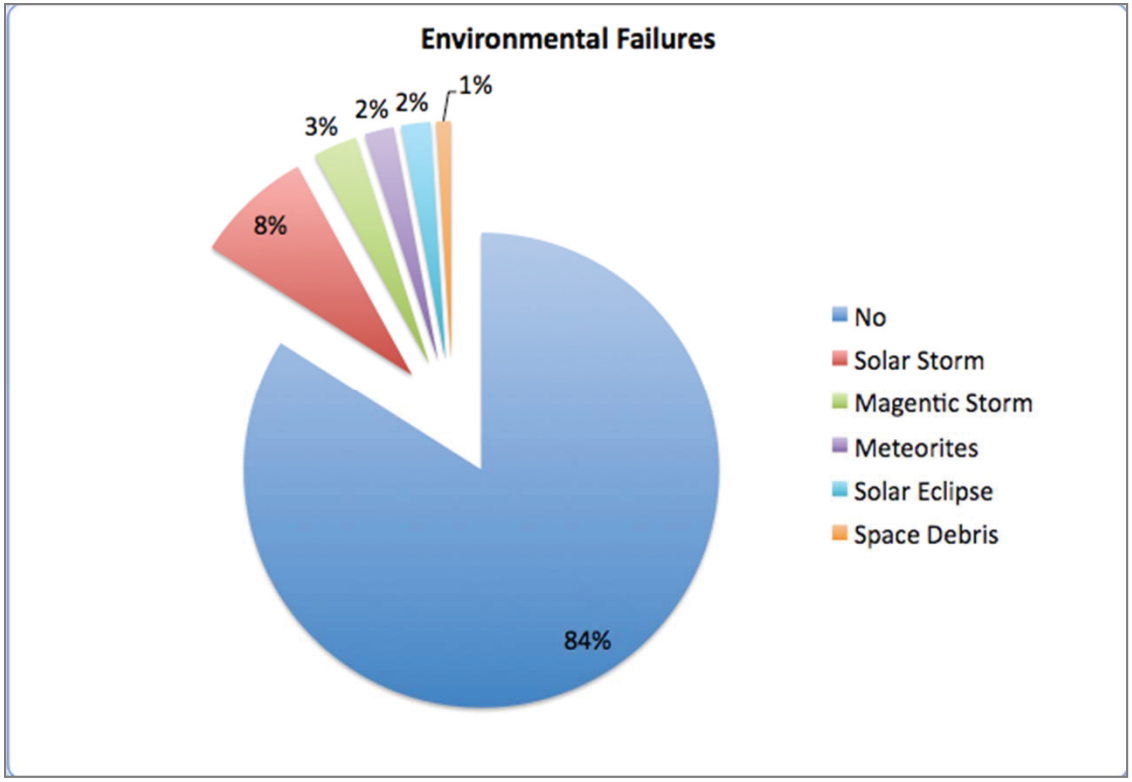
On-orbit failures due to environment

[Tafazoli 2008]



- 16% of all failures are due directly to the space environment

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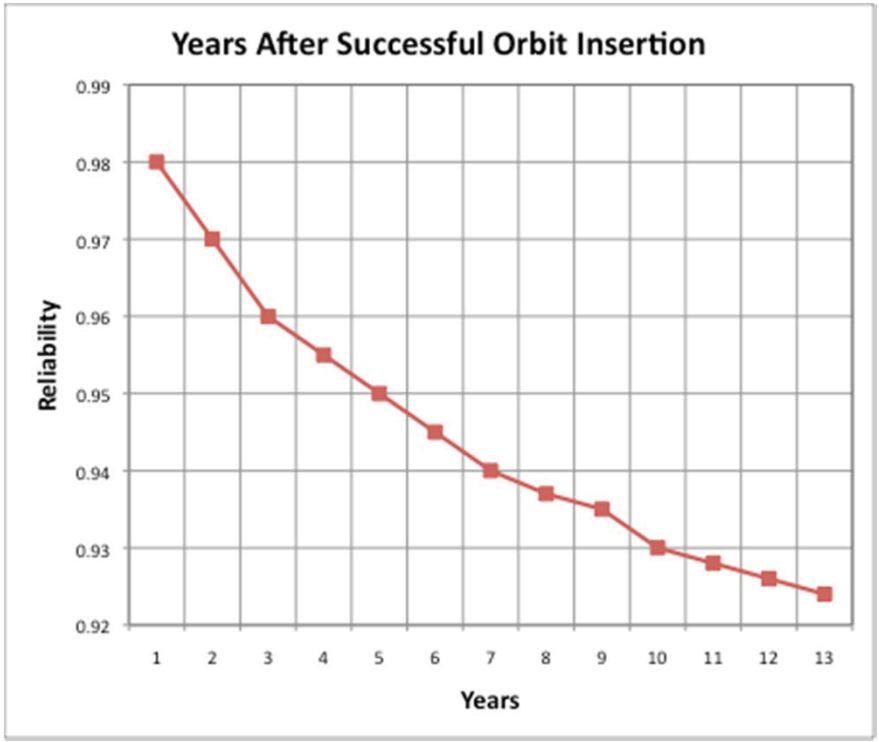
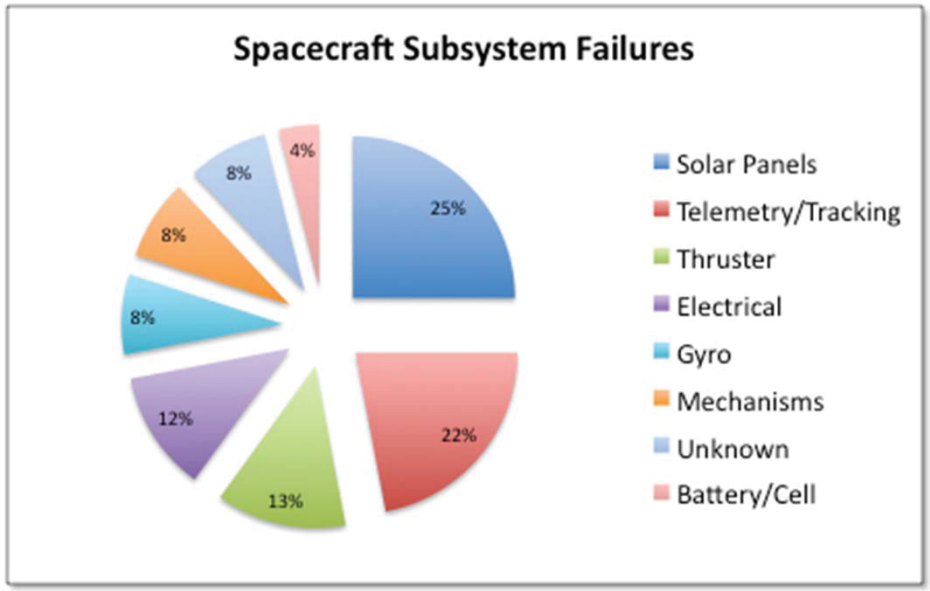
Statistical Analysis of 1,584 Earth Orbiting satellites [Castet & Saleh 2009]



- Infant mortality shaped curve with Weibull fit
  - *Shape parameter ~ 0.4*
- Telemetry and gyro/reaction wheel failures dominate
- Historical HDBK-217 constant failure rates unrealistic

Class 1 failures only
= retirement of the satellite

Data from 1990 to 2008



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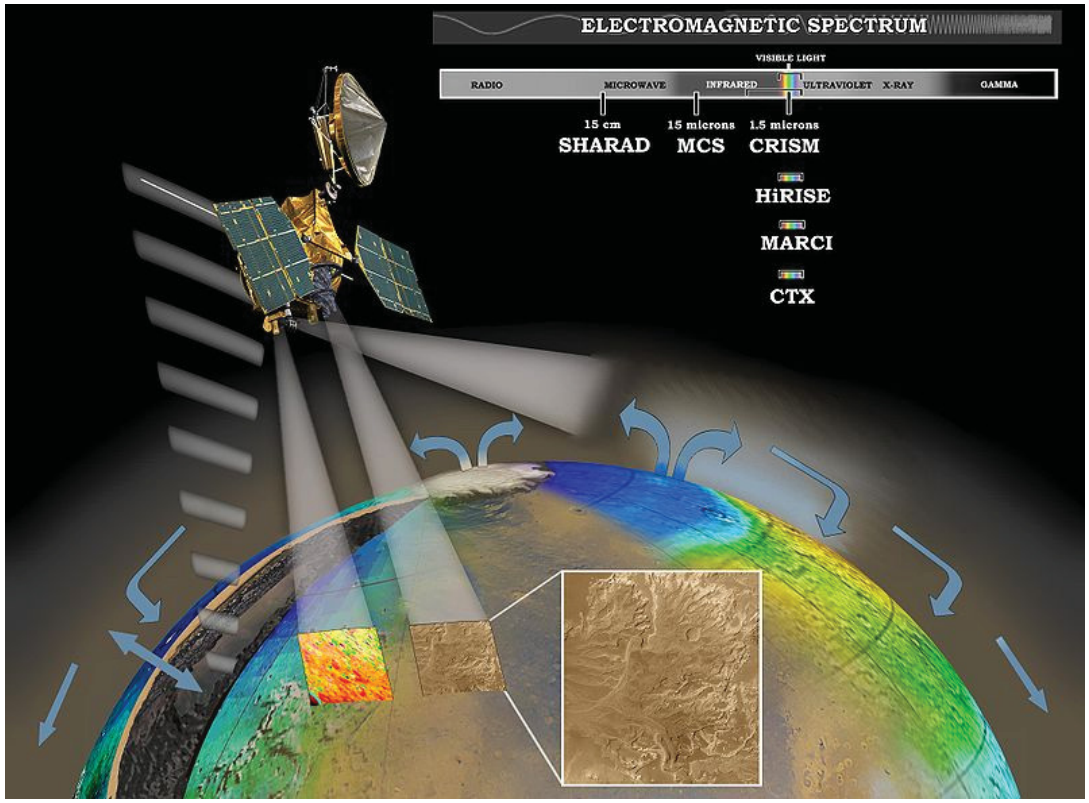
Mars Reconnaissance Orbiter - MRO



- Launched August 2005, arrived Mars March 2006
- 1,000 kg dry mass
- Wide variety of science instruments:
  - Cameras/Spectrometer/Radio meter/Radar
  - UHF Comm/Optical Navigation
- Study Martian climate and geology
- Act as telecom relay for future landers and current rovers

Table of MRO Anomalies [Bayer 2008]

Description	Details	Part	Cause	Fix
Single Event Upsets – Memory	Corruption noted in C&DH SW	SRAM	Known soft memory to protons	Upload additional CRC protection
Warm Reset	Loss of downlink	Flight software in processor	SW bug, triggers O/S task suspension	Upload patch
Ka-band Exciter	Large increase in power in SDST	MESFET amplifier	Short, failed die/package eutectic bond	Use as is with limitations
RF transfer switch	Switch failed to actuate	Waveguide Transfer Switch	Debris induced RF breakdown and pyrolysis	Use as is with limitations
Pixel loss	IR channel degradation	ADC	Incorrect termination & inputs cause erroneous reads	Warm up focal plane array prior to use

Conclusions

- Electronics failures are the number one failure mechanism for on orbit spacecraft.
- Existence of significant infant mortality situation implies testing, screening and design need to be improved.
- Pre launch electronics failures indicate need for continued robust quality screening and monitoring.
- Cable discharge like conditions appear to degrade even robust ESD capable electronic devices.
- Assembly, test, flight and operation of spacecraft remains a highly challenging electronic parts reliability activity.

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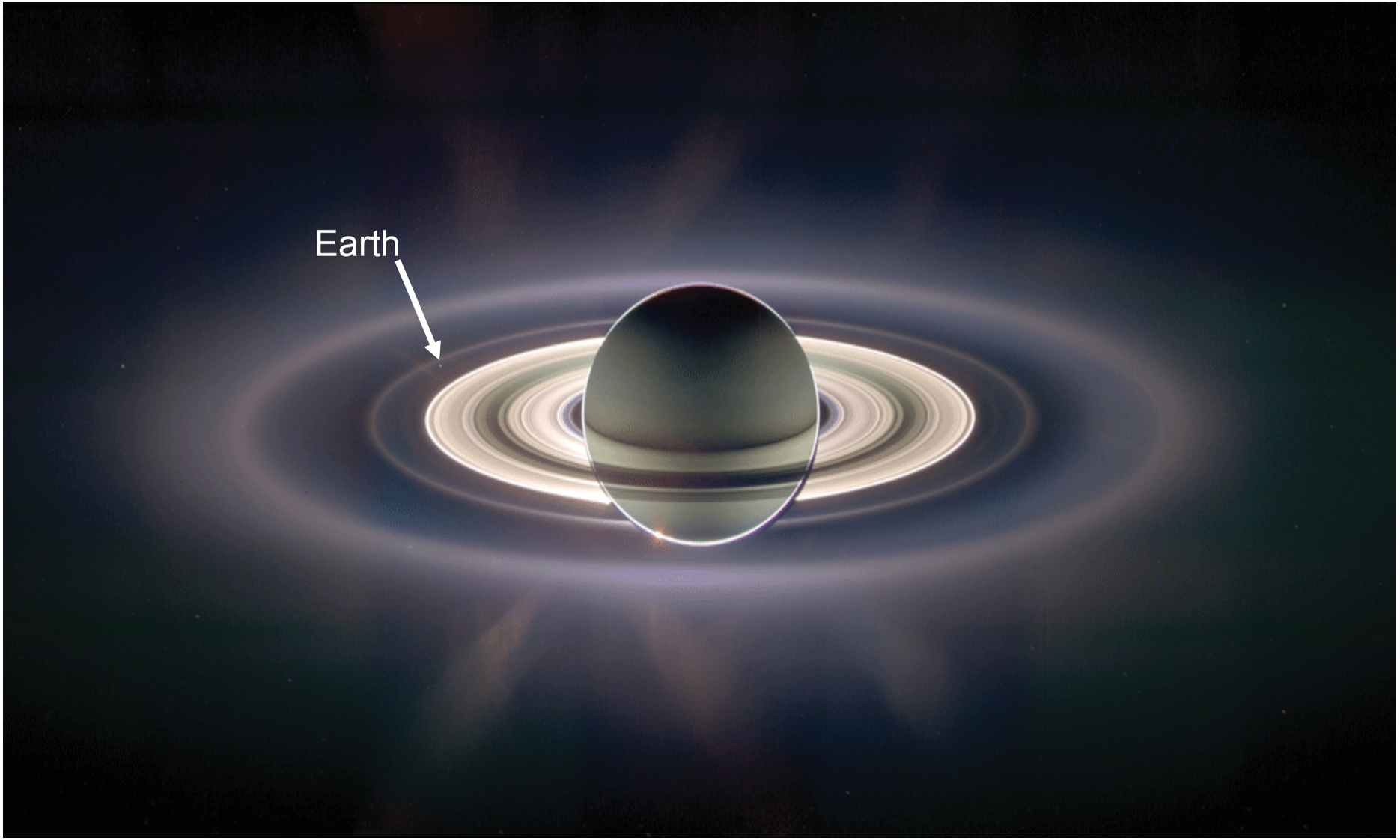
…and finally: Earth from Saturn – we live in a very unique place