Cassini Spacecraft Engineering Tutorial

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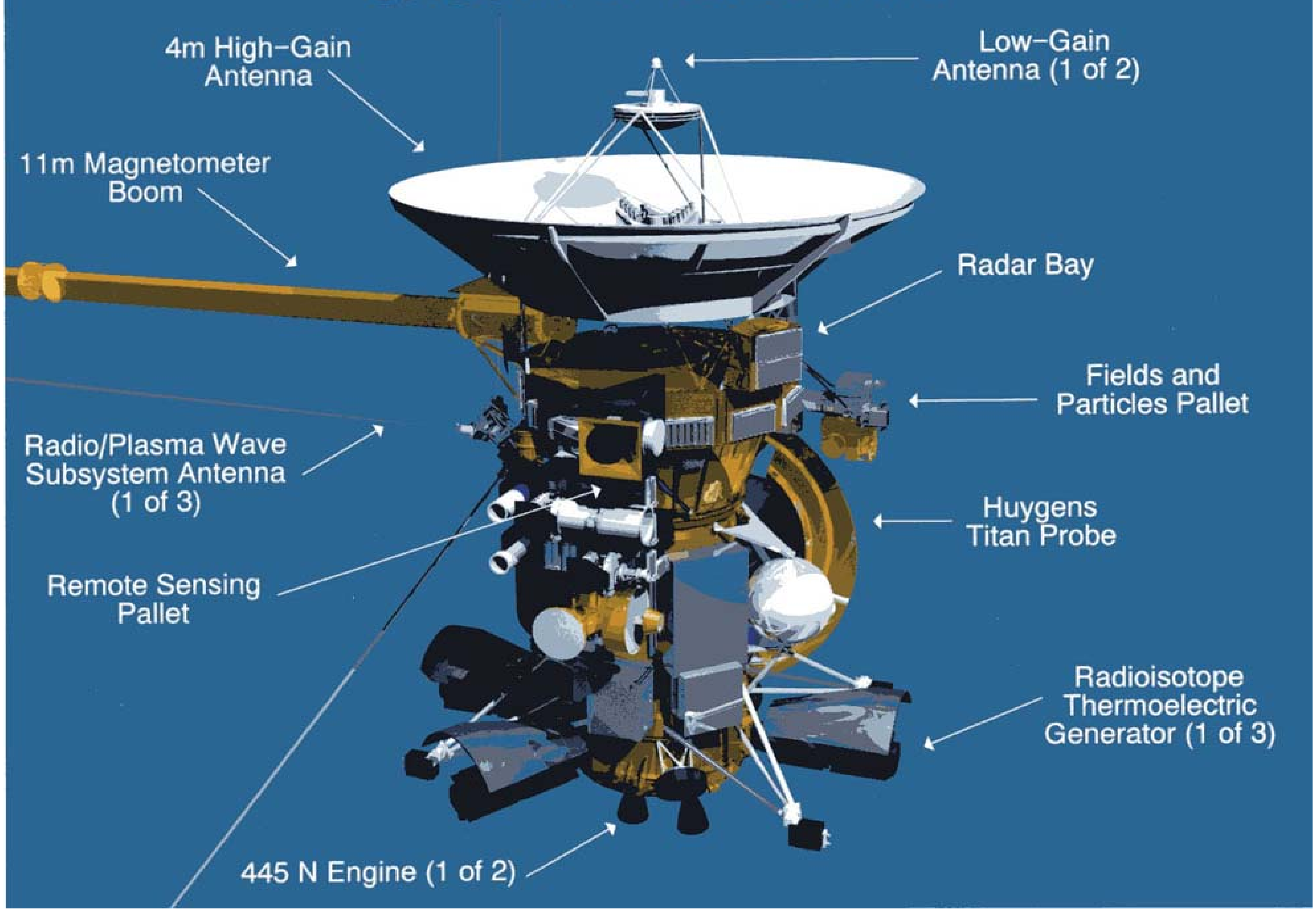
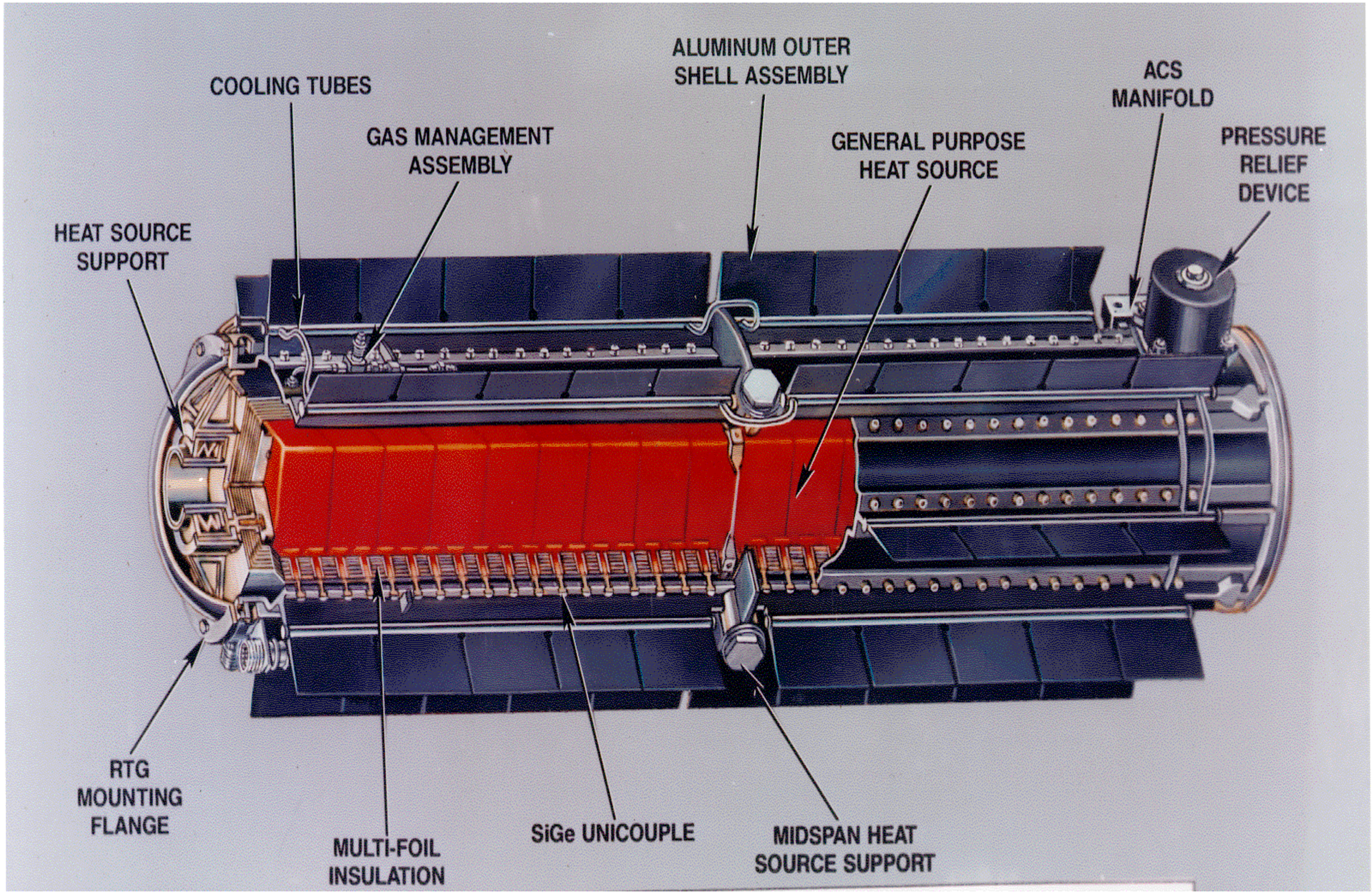
CASSINI SPACECRAFT



Cassini/Huygens Spacecraft Overview

- **Largest outer planetary spacecraft ever built**
- **Weighed 5574 kg at Launch (3132 kg Propellant)**
  - Today’s weight is around 2710 kg with 422 kg Propellant left
  - 3 maneuvers (Deep Space Maneuver, Saturn Orbit Insertion, Periapsis Raise Maneuver) used 2083 kg of propellant
- **58 microprocessors**
- **Twelve Science Instruments**
  - Fields and Particles
    - CAPS, CDA, INMS, MAG, MIMI, RPWS
  - Optical Remote Sensing
    - CIRS, VIMS, ISS, UVIS
  - Radar
  - Radio Science
- **Huygens Probe**


ALUMINUM OUTER SHELL ASSEMBLY
COOLING TUBES
ACS MANIFOLD
GAS MANAGEMENT ASSEMBLY
GENERAL PURPOSE HEAT SOURCE
PRESSURE RELIEF DEVICE
HEAT SOURCE SUPPORT
RTG MOUNTING FLANGE
MULTI-FOIL INSULATION
SiGe UNICOUPLE
MIDSPAN HEAT SOURCE SUPPORT

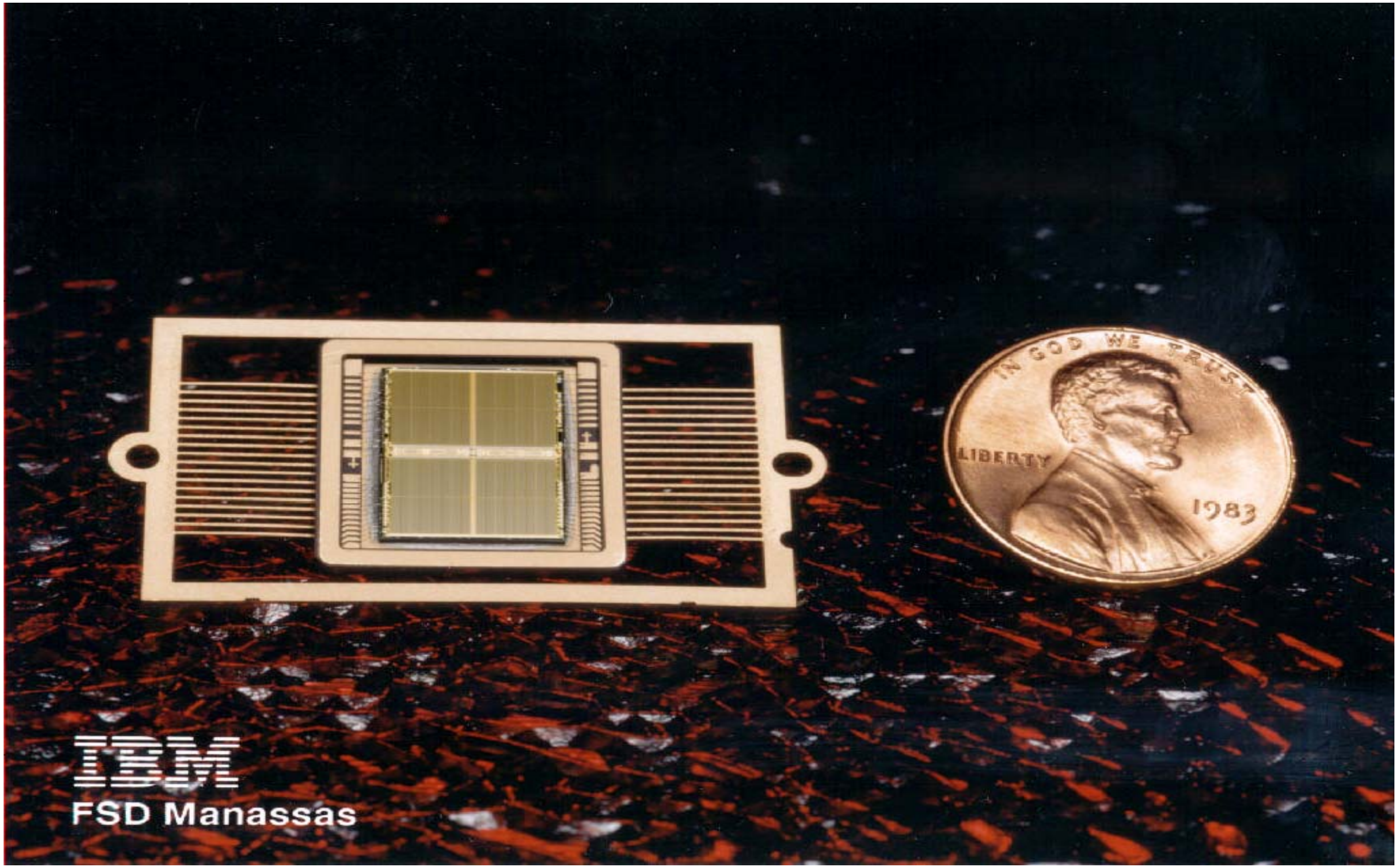
Power System

- **Power supplied by three Radioisotope Thermoelectric Generators (RTGs)**
  - 875 Watts at Launch, 692 Watts at End of Mission (July 2008)
  - Loses about 1 Watt/month now, will slow to 9 Watts/year by 2007
  - Excess power distributed to shunt regulator/radiator

- **Power distribution using 192 Solid State Power Switches**
  - Switches act a circuit breakers in over load condition
  - Critical loads have redundant switches and automatic turn-on circuitry
  - Special Fault protection in case of SSPS “trip”

- **Not enough power to keep all instruments on all the time, so Operational Modes are used**

- **Picture shows RTG schematic**


IBM
FSD Manassas
IN GOD WE TRUST
LIBERTY
1983

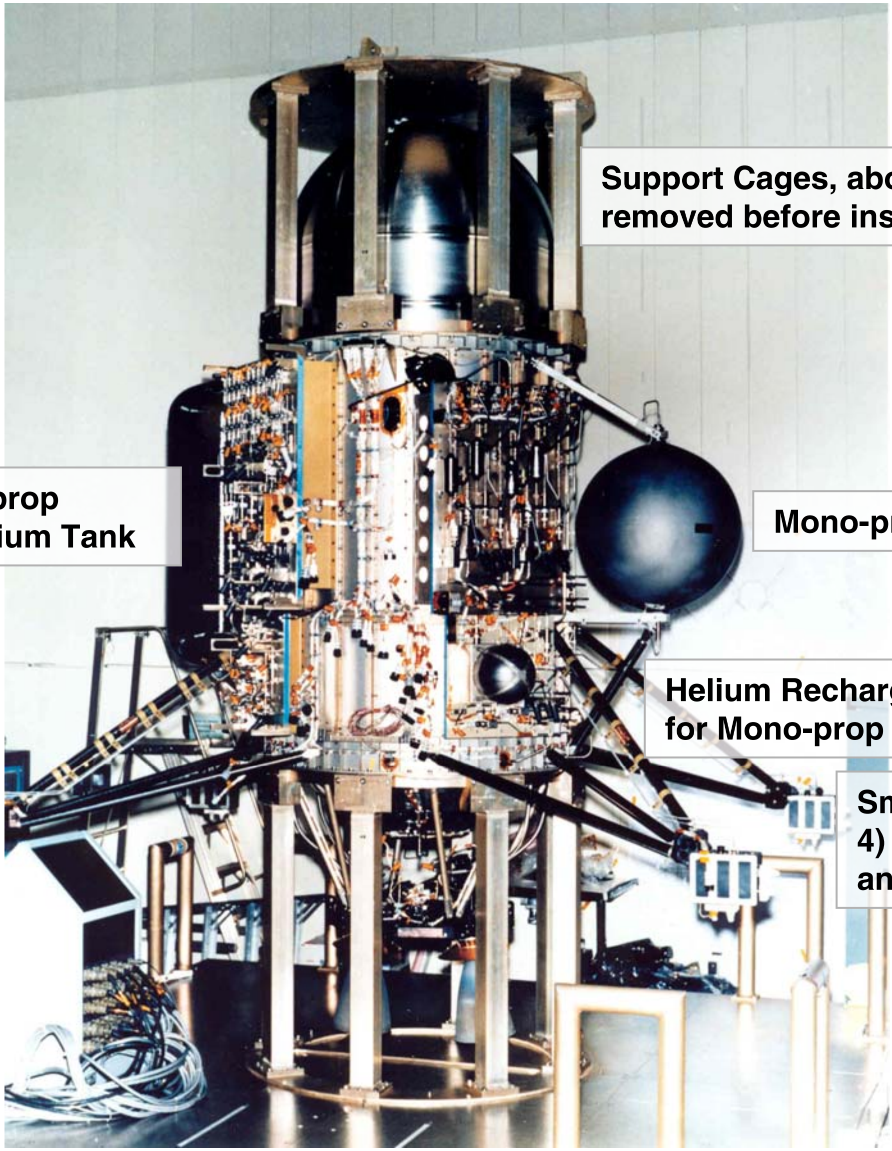
Command and Data System

- **Two redundant 1553 Buses with fully redundant hardware**
- **Flight computer (EFC) IBM 1750A architecture**
  - 512k RAM
  - ~48,000 lines of Ada and assembly source code

- **Processes all commanding for the spacecraft engineering sub-systems and instruments**
  - Background sequences uplinked every 3-6 weeks
  - “Real-time” commands are uplinked during downlink passes

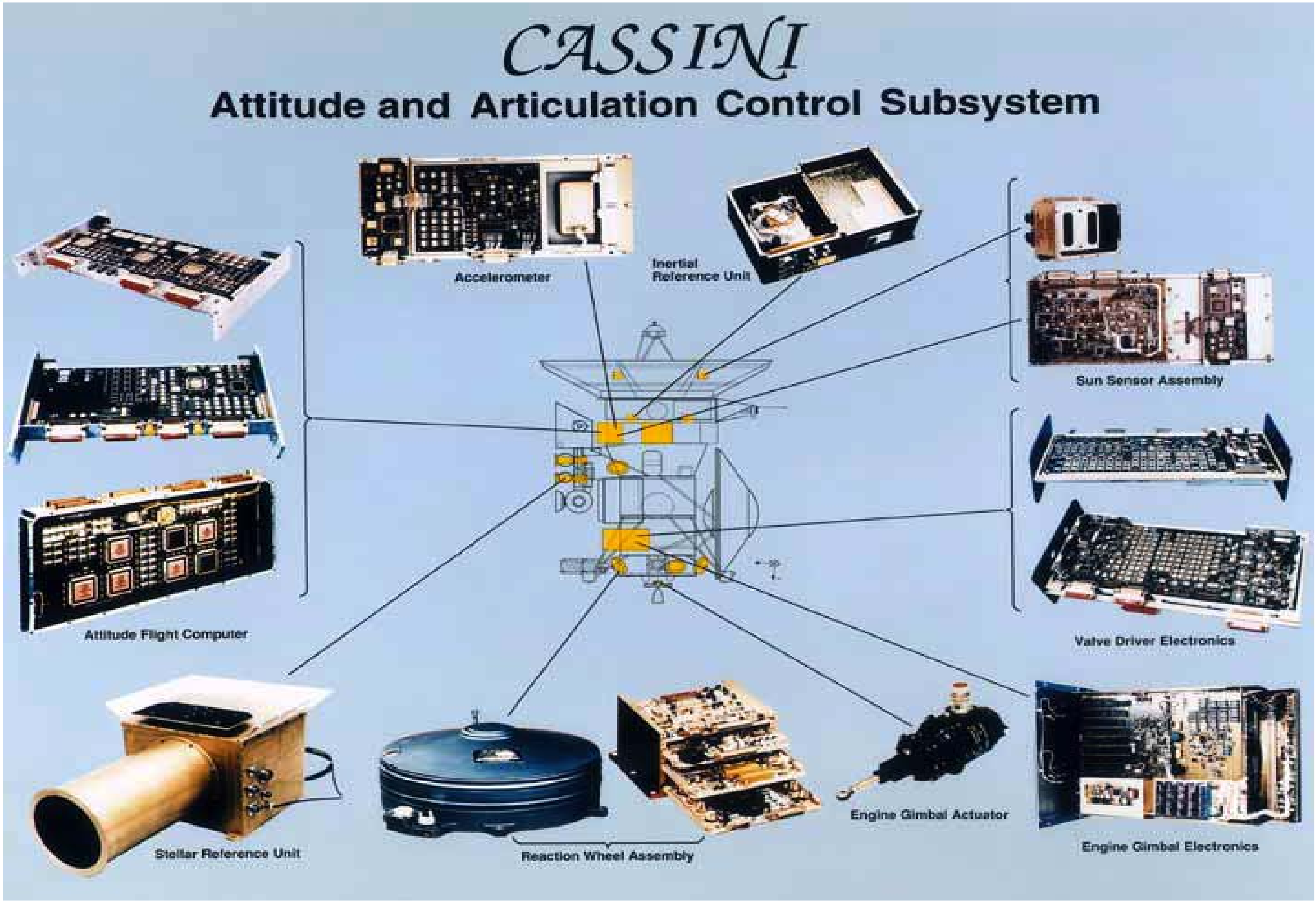
- **Processes all telemetry for the spacecraft engineering sub-systems and instruments**
  - On-board data storage and playback using 2 Solid-State Recorders
    - 2.3 Gbits total, 2.1 Gbits available for telemetry (each SSR)

- **Picture is the IBM 1750A processor chip**


Support Cages, above and below removed before installation
Bi-prop Helium Tank
Mono-prop Hydrazine Tank
Helium Recharge Tank for Mono-prop
Small Thruster Cluster (1 of 4) with nozzles facing down and out
Main Engine (2)

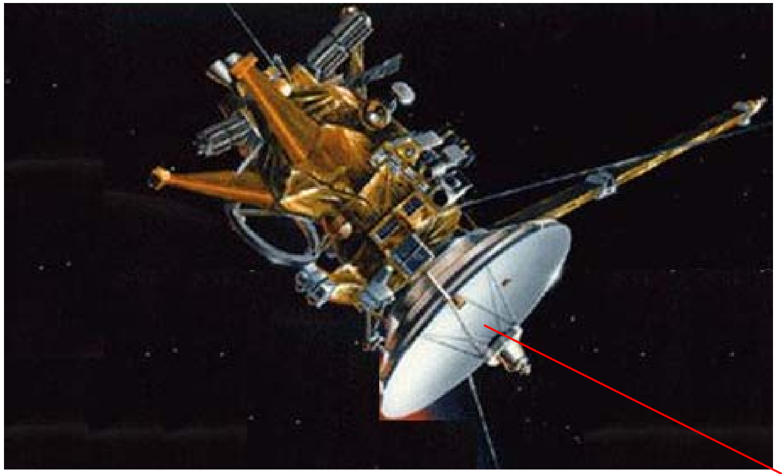
Propulsion System

- **Two completely isolated systems**
  - Monopropellant System - Hydrazine (H_2N_4)
    - 16 Redundant ~1 Newton thrusters, 4 per "cluster"
    - Used for attitude control and small (< 0.3 m/s) trajectory control maneuvers
    - Blow-down mode
    - Single Helium pressure recharge - will be done 4/10/06
  - Bipropellant system- Nitrogen Tetroxide (NTO)/Monomethyl Hydrazine(MMH)
    - Main (445 Newton) engine for propulsive maneuvers
      - Burns can be blow-down or pressurized (with Helium)
    - Engines are protected from micrometeoroid particles by articulating cover
    - Redundant main engine (never used in flight)
- **Picture shows Propulsion Module as delivered from Lockheed-Martin Astronautics**


CASSINI
Attitude and Articulation Control Subsystem
Accelerometer
Inertial Reference Unit
Sun Sensor Assembly
Attitude Flight Computer
Valve Driver Electronics
Stellar Reference Unit
Reaction Wheel Assembly
Engine Gimbal Actuator
Engine Gimbal Electronics

Attitude Control System

- **Two redundant 1553 Buses with fully redundant hardware**
- **Flight computer (EFC) IBM 1750A architecture (same as CDS)**
- **Attitude determination**
  - Attitude determined by Stellar Reference Units
  - ~3500 Star on board catalog, picking the 4 or 5 brightest stars in the field of view at any given time
  - Attitude rates supplied by Hemispheric Resonator Gyros (HRGs), aka Inertial Reference Units
- **Attitude Control**
  - 3 axis stabilized using thrusters or 3 reaction wheels (RWAs)
    - Small (1 Newton) thrusters used when pointing isn't as important or when faster turns are needed
    - RWAs provide pointing stability better than 100 microradians over 1000 seconds
- **Propulsive maneuvers**
  - Uses small thrusters or main engine (445 Newton) for trajectory control
- **Picture shows various components of Attitude Control System**



The spacecraft turns to Earth for a typical 9 hour tracking pass, to downlink telemetry data and receive commands.
The DSN radiates an X-Band uplink signal which the spacecraft locks to (just like your FM radio receiver) and then the spacecraft multiplies the uplink signal by a exact (880/749) amount to form the coherent downlink carrier. This gives Navigation and Radio Science very precise two-way coherent Doppler and ranging tones for spacecraft location.

Deep Space Network –
3 complexes: Barstow, Ca, Madrid, Spain and Canberra, Australia
Each complex has a 70 meter antenna, and multiple 34 meter antennas.

Telecommunications System

- **Antenna**
  - 4 meter High Gain Antenna (HGA) used for main communications
    - HGA is a multi-aperture antenna used jointly for Telecom (X-Band), Radio Science (S, X (same as Telecom) and Ka-Band), RADAR (Ku-Band) and Probe mission (S-Band, different frequencies than Radio Science)
    - HGA was used as a Sun shield during Inner Cruise
  - 2 Low Gain Antennas used for emergency X-Band emergency communications
    - LGA-2 located below Probe was used only during Inner Cruise
- **Cassini Deep Space Transponder**
  - Receives uplink X-Band signal (and commands) from DSN
  - Downlinks
    - Ultra-Stable Oscillator (USO) used for 1 Way Doppler
    - Voltage Controlled Oscillator (VCO) used for 2 Way Coherent Doppler
  - Ranging channel for Navigation
- **20 Watt X-Band downlink Traveling Wave Tube Amplifier**
- **Data Rates**
  - Uplink nominal rates at 250 or 500 bps
  - Emergency rate is 7.8125 bps
  - Downlink nominal tour rates from 22.12 - 165.9 Kbps
  - Depends on Deep Space Network antenna and Earth-Saturn range
  - Emergency downlink is 5 bps

- **Picture 1 taken during Assembly, Test and Launch Operations - shows HGA, LGA-1 and Upper Equipment Module.**

Thermal System

- **Thermal System designed to withstand the Sun's heat at Venus distances and the cold of 0.1 Sun at Saturn distances**

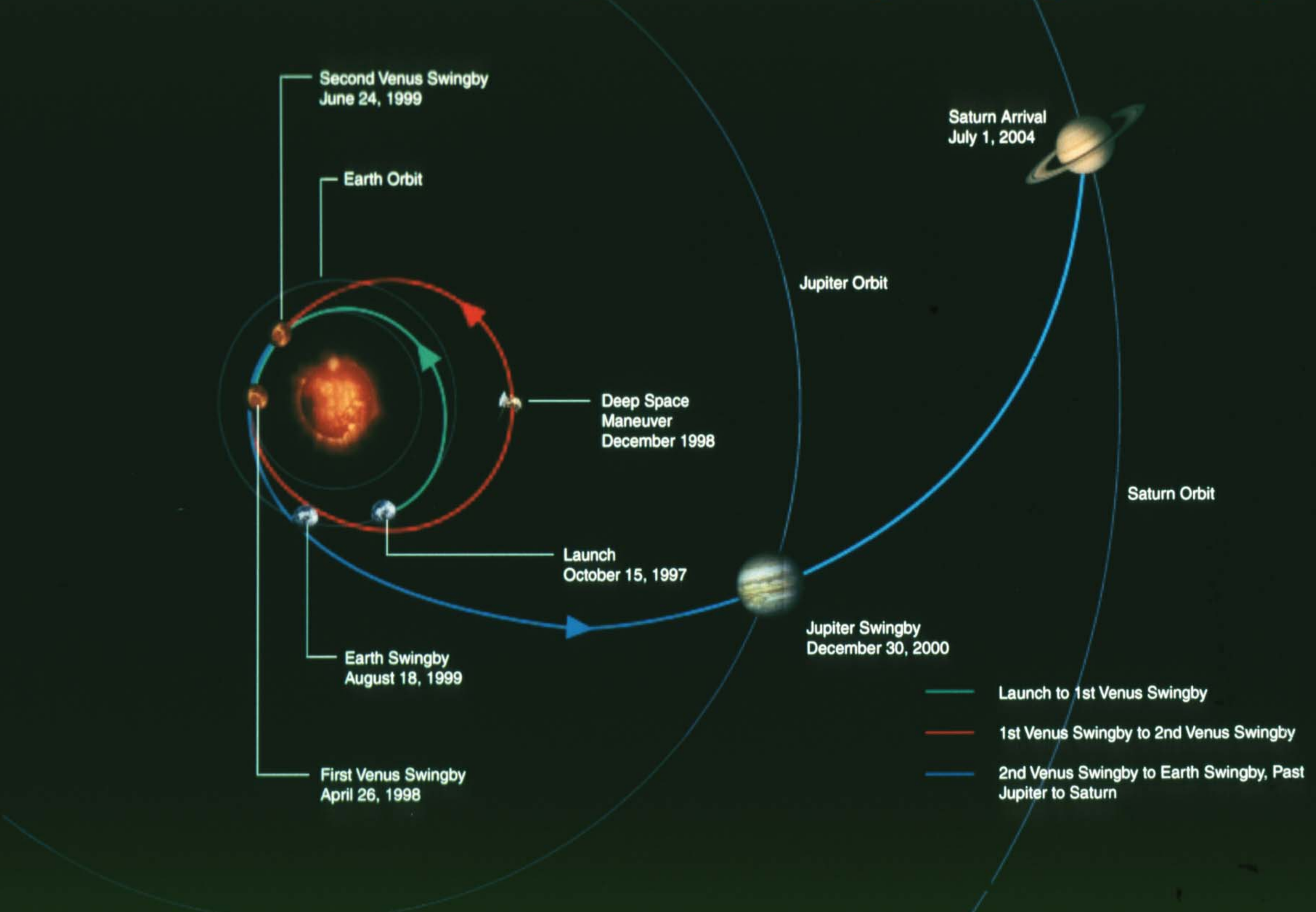
- **Passive components**
  - Blanketing and surface treatments
  - Radio-isotope Heater Units (RHUs) used in some locations
  - Instrument radiators that face "cold sky"

- **Active components**
  - Louvers on some of the electronic bays
  - Variable Radio-isotope Heater Units (VRHUs) used in some locations
  - Autonomous (thermostatic) Thermal Control of key selected components
  - Replacement and supplemental heaters for the instruments - necessary because the instruments are turned on or off by Operational Modes

- **Picture show spacecraft being readied for Solar Thermal Vacuum Test**

Launch October 15, 1997

Cassini Interplanetary Trajectory



Getting to Saturn

- **Launch and TCM-1**
  - Performed flawlessly on 10/15/97
  - CDS and AACS were nominal
    - Switched prime CDS and AACS computers in first week (to change from launch to cruise parameters)
  - Telecom performance was above predict for LGA-2
    - HGA used as sunshade, so low bit rate early mission was necessary
  - TCM-1 executed within 3% error (well within errors for uncalibrated TCM)
    - MEA Cover closed after launch, opened for TCM-1, closed after TCM-1
- **Early Checkout 10/97 - 3/98**
  - CAPS, CIRS, MIMI, CDA launch latches released
  - UVIS membrane puncture
  - RPWS antennas deployed
  - Performed AACS checkout
    - Inertial Reference Unit-B and Engine Gimbal Assembly-B
  - Probe Checkout
  - Instrument checkout
    - Only INMS and RFIS (requiring HGA) not seen
    - All checkouts were nominal

Getting to Saturn (continued)

- **Venus 1 flyby on 4/26/98**
    - Altitude 284 km
    - RADAR and RPWS performed science calibrations
- **Deep Space Maneuver (TCM-5) performed on 12/3/98**
  - 90 minute regulated burn, just like SOI!
- **Instrument Checkout on 1/99**
  - 25 days on HGA allowed instruments to perform real calibrations with high rate science data
  - RFIS saw Ka-Band and S-Band for first time
  - ORS imaged Spica
  - DFPW rolls performed
- **Venus 2 flyby on 6/24/99**
    - Altitude 603 km
    - CAPS, CDA, MAG,MIMI, RPWS, ISS, UVIS and VIMS performed science calibrations

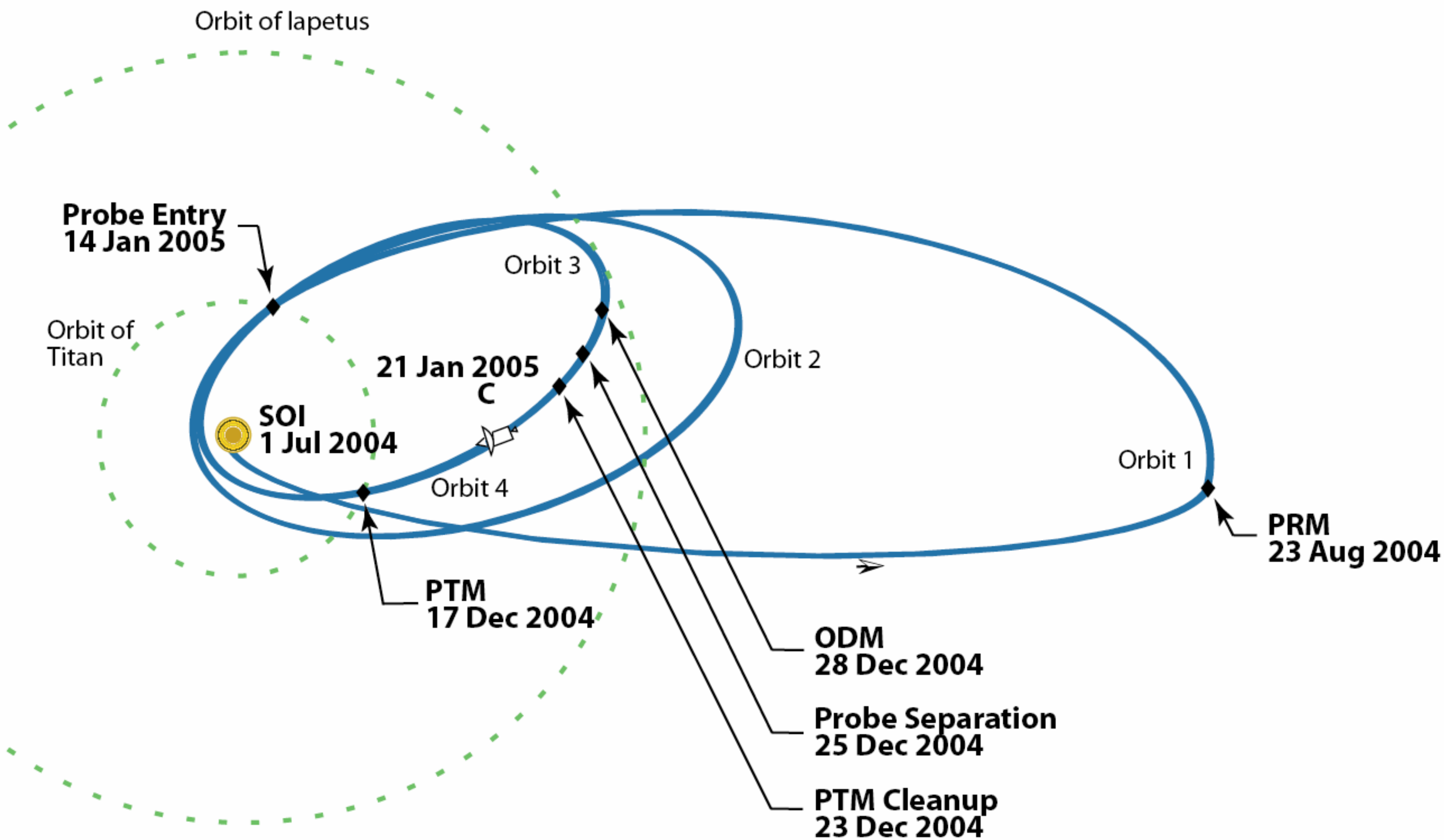
Getting to Saturn (continued)

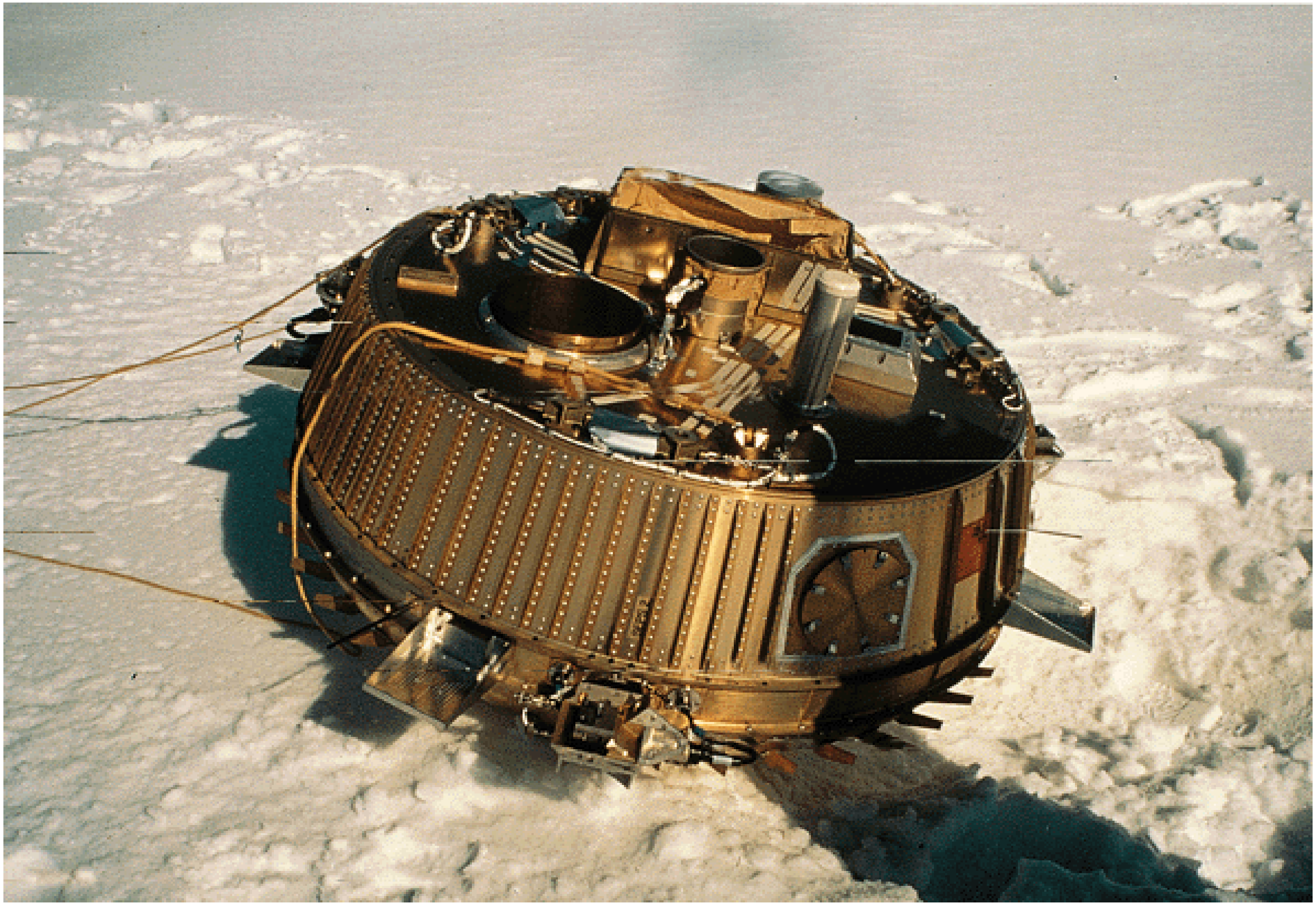
- **Earth Flyby on 8/18/99**
  - 4 TCMs prior to flyby done for Earth avoidance
  - VIMS Cover release
  - MAG Boom Deploy
- **Switch to permanent HGA on 2/1/00**
  - Real science data rates now could be used!
- **New AACS FSW loaded March 00**
  - RWA capability finally in place
- **New CDS FSW loaded August 00**
  - Dual SSR ping-pong in place for Jupiter activities
- **Jupiter Encounter (closest approach 12/30/00)**
  - 6 month campaign with all instruments but INMS participating
  - Extensive science data taken
  - Demonstrated many tour science sequencing capabilities

Getting to Saturn (continued)

- **New AACS FSW (A8) loaded February 03**
  - Rotating Coordinates Probe tracking
  - Tracking for SOI (yaw steering)
  - IRU-B and SSA-B checked out
- **New CDS FSW (Version 9) loaded March 03**
  - Dual record for Probe Mission enhancements
  - SSR IEB capability for instruments
  - HGA Response algorithm
- **Switched to Articulated RWA-4 to replace RWA-3 07/03**
  - RWA-1,2,4 prime for “rest of Mission”
- **A8.6.5 FSW uplinked 02/04**
- **A8.6.7 FSW uplinked 04/04**
- **TCM-20**
  - First fully pressurized burn since DSM 5/27/04
- **SOI 07/01/04!**

SOI to Huygens Entry





Huygens Probe

- **European Space Agency Mission**
  - Six instruments
  - Designed to study the surface and atmosphere of Titan
  - Released on December 25, 2004
  - Landed on Titan January 14, 2005

- **Orbiter services to Probe Mission**
  - Power for Probe Receiver
  - S-band telemetry link
  - Probe Relay Data storage and playback

- **Picture is Huygens probe engineering test model after being drop tested**

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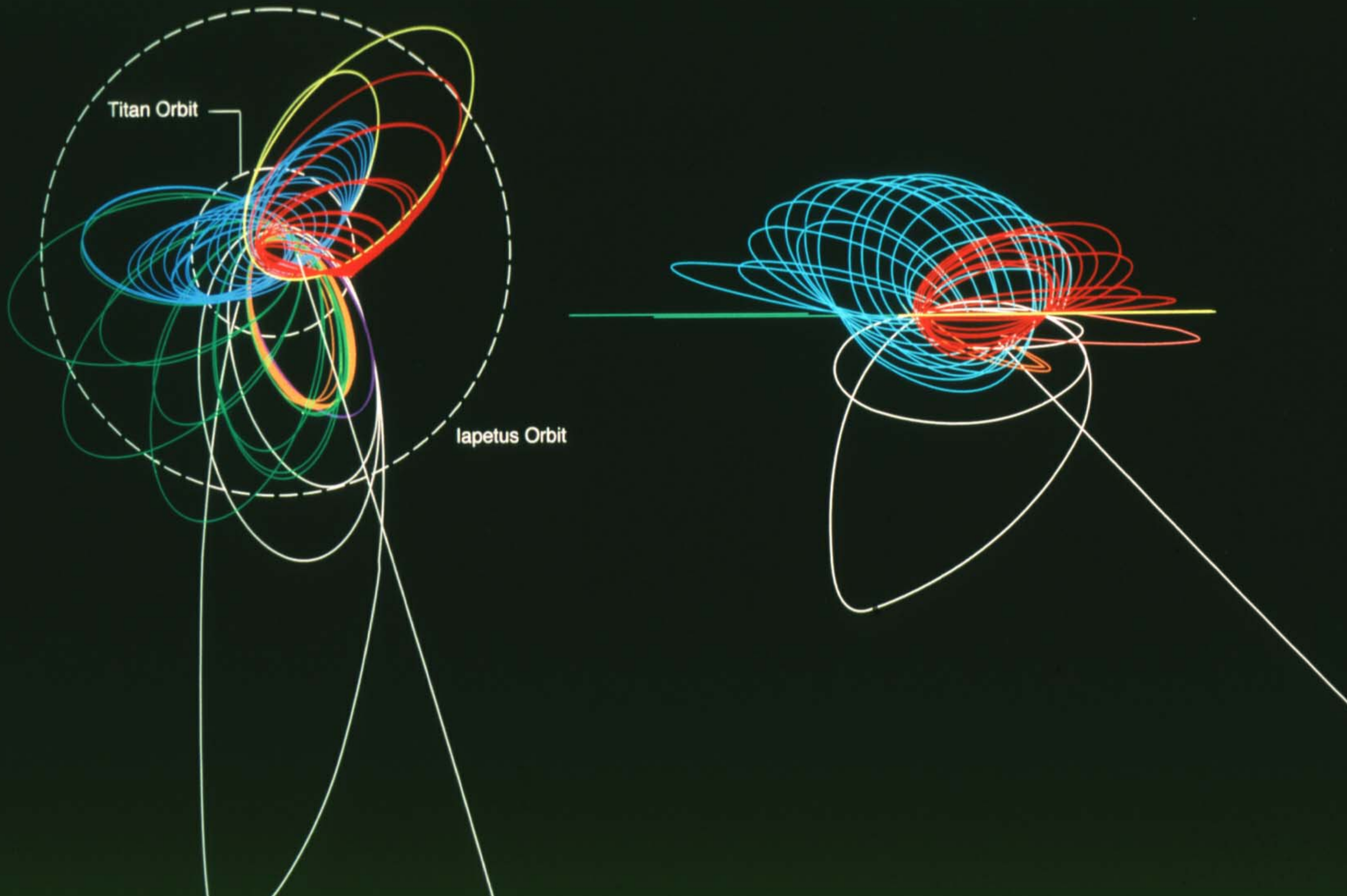

Staying on Tour

- **Each orbit around Saturn takes 3 maneuvers (Orbit Trim Maneuvers)**
  - Titan - 3 days (Approach maneuver)
  - Titan + 3 days (Clean-up maneuver)
  - Apoapsis (used for next Titan and/or to change orbit size/angle)
- **"Live Updates" for Saturn or moon encounters**
  - Better position knowledge means we update the vectors
- **Periodic Engineering Maintenance**
  - Exercise "moving" parts to keep things lubricated
- **Dust hazards**
  - If the dust hazard is great enough we close the engine cover and turn the HGA to dust hazard
- **Conjunction**
  - Once per year, spacecraft and Earth are on opposite sides of the Sun
    - Quiet period on spacecraft because telecommunications is disrupted

For more information about the
Cassini Huygens mission
http://saturn.jpl.nasa.gov

Also, see “Basics of Space Flight”
available for JPL Public website