Information technologie in past space missions

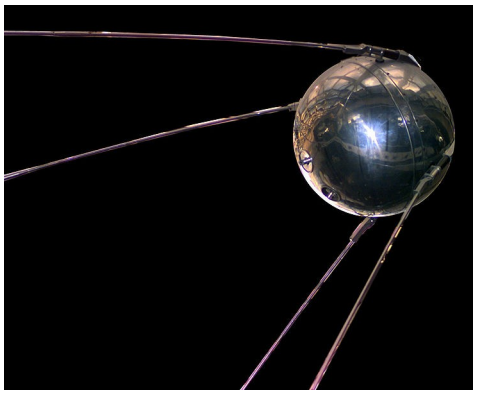
John Richardson
John.Richardson@dlr.de
DLR-RY
Deutsches Zentrum für Luft und Raumfahrt DLR
Institut für Raumfahrtsysteme
(German Aerospace Center)
Robert-Hooke-Str. 7
D-28359 Bremen
Tel. +49 421 24420 151

Outline

- IT data transfer for satellite and space missions
  - Chronological Outline of Key missions since 1957
  - Evolution of methods of data transfer
  - Onboard Data Processing and analysis
  - Data relays and satellite and ground networks
  - Storage and compression
  - LEO v Deep space missions
  - Summary

Sputnik

- Unmanned space missions in 1950s
  - First man-made objects to reach orbit
  - Sputnik 1 Launched in October 1957
  - 58cm in Diameter, ~83.6kg in weight
  - Elliptical orbit of ~96 minutes at altitude ~250km
  - Speed of 29.000km/h
  - Emitted radio signals between 20.005 and 40.002MHz to a single ground station
  - Analysis of electron density of the ionosphere

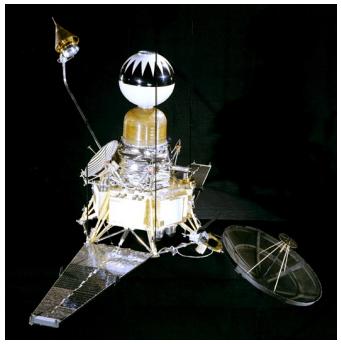


Vostok

- First manned missions
  - Vostok 1 launched on April 12, 1961
  - Single orbit of earth in ~90 minutes
  - Voice and data via UHF and VHF radio signals
  - Single ground station for VHF, several UHF
  - VHF unreliable with contact often lost outside range
  - Telegraph over HF used more often as UHF had range of only ~1500km
  - First serious thought given to dedicated GS system

Ranger Programme

- US unmanned survey missions in 1960s to Moon
  - Obtained close-up images until impact on surface
  - Rangers 1-5 communications via high gain antenna and omni-directional medium gain antenna
  - Two transmitters (0.25W & 3W) at approx. 960MHz
  - Rangers 6-9 communications via low-gain antenna and parabolic high-gain antenna
  - 60W TV channel F @ 959.52MHz, 60W TV channel P @ 960.05MHz, and a 3W channel 8 @ 960.58MHz
  - Composite video signal converted to RF signal for Tx

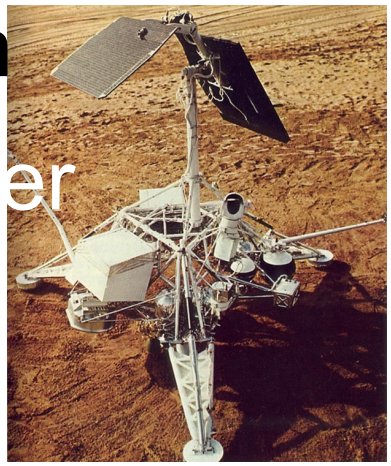


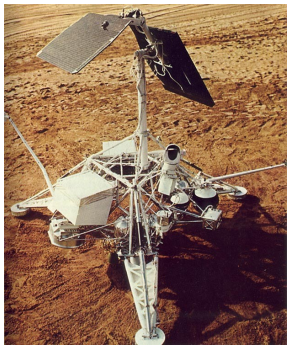
Ranger Programme

- Sufficient video bandwidth for rapid framing
- Ranger 7 F-channel began transmission at altitude of 2110km 18 minutes before impact
- Tx of 4.308 high-quality images transmitted with final image of 0,5m resolution before impact
- Ranger 9 began transmission at altitude 2363km 20 minutes before impact
- Tx of 5.814 good quality images with highest resolution of 0,3m

Surveyor 1

- The first soft landing on the Moon by the USA
- Evolution of Ranger programme to landers
- Supported technology for later Apollo landings
- Provided data on Apollo technical compatibility
- Added scientific knowledge of the Moon
- Communications similar to that of Ranger



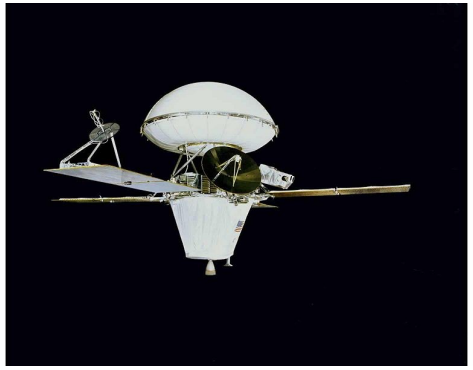


Surveyor 1 cont.

- Planar array high-gain TV antenna and two conical antennas for uplink and downlink
- Two Rx and two Tx (0.25W & 3W) at approx. 960MHz
- 10.338 photos transmitted to Earth in first days
- Data acquired and transmitted on radar reflectivity, bearing strength, and temperatures of the lunar surface
- Mission ended after total 11.240 photos Tx

Mariner 4

- Orbital satellite returning first images from Mars
- Experience of engineering capabilities for interplanetary flights of long duration
- Dual capacity S-band 7W triode cavity amp/10W TWTA transmitter and single receiver
- Total data returned > 5,2 million bits stored on tape recorder. Deferred Tx due to latency period
- Stored time-sequence commands using a 38,4kHz synchronisation frequency as time ref



Viking Programme

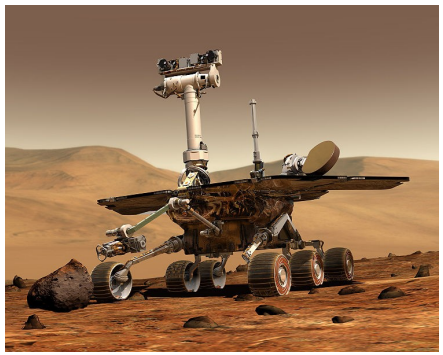
- NASA's Mars lander program (1976-1980/1978)
- Orbital recon and comms relays
- Comms via 20W S-band (2,3GHz) Tx and two 20W Travelling-wave tube amplifiers (TWTA)
- X-band (8,4GHz) downlink for science and comms. Uplink via S-band (2,1GHz).
- Data storage: two tape recorders ea. 1280Mbits
- Data processed: 6000-word memory computer

Intel 8085 processor

- An 8-bit microprocessor requiring only +5V
- Based on 8080. Used 6.500 transistors
- Rad-hard version used for NASA and ESA space missions in onboard data processors
- Examples of missions using the 8085 include:
- Mars Sojourner Rover, CRRES, THEMIS etc.
- CRRES launched into GTO for 3-year mission
- Investigating energy effects in magnetosphere

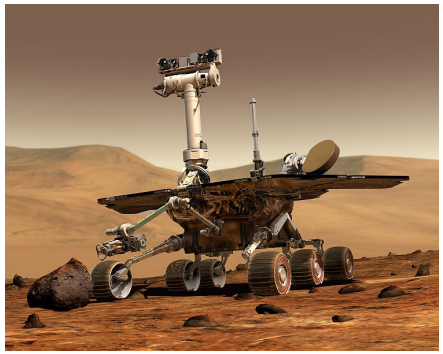
Intel 8085 processor

- The Global Geospace Science (GGS)Polar Sat
- 1996 NASA science craft observing polar magnetosphere
- THEMIS satellite constellation
- Investigating energy releases called substorms
- First time high data-rate taken during substorm
- Data compressed x2 to minimise data return time
- 256MB memory used to store data



Sojourner Mars Rover

- Micro rover 65 x 48 x 30 cm weighing 10,5kg
- Operated for 83 sols (Martian days)
- Transferred 550 photos and 16 soil analyses
- Embedded computer system using 8085
- Computational resources limited due to higher demands to withstand rad and temp changes
- Autonomy software allowed decision-making based on observation of surroundings



Mars Rovers

- Autonomy software becoming more advanced
- Sojourner – 20 3D points; MER ~15-40k 3D

Comparison of embedded computer systems on board the Mars rovers			
Rover (mission, organization, year)	CPU	RAM	Flash solid state storage
Sojourner Rover (Pathfinder, NASA, 1997)	100 kHz Intel 80C85	512 KB	176 KB
Pathfinder Lander (NASA, 1997),,,,,,,,,,,	20 MHz MFC (RAD6000	128 MB	6 MB (EEPROM)
Spirit and Opportunity (Mars Exploration Rover (MER), NASA, 2004)	20 MHz RAD6000	128 MB	256 MB
Curiosity (Mars Science Laboratory (MSL), NASA, 2011)	200 MHz RAD750	256 MB	2 GB

Operation issues with rovers (1)

- Direct tele-operation with Mars not possible
- Round-trip communications 8-42 min with DSN
- Entire sol of operations accumulated and sent
- January 2004 comms failure of *Spirit* lander
- Tx received but indicated it was in fault mode
- Serious but recoverable if it was a software or memory problem and not hardware problem
- *Spirit* transmitted low-bitrate messages of 73Mb

Operation issues with Rovers (2)

- *Spirit* responding but at risk of total failure
- Ordered to suspend until a given time (ignored)
- Stuck in reboot loop (reboot if fault onboard)
- If fault occurred at reboot → reboot forever
- Error not RAM but FM, EEPROM or H/W (fatal)
- Rover could reboot without touching FM
- *Spirit* rebooted and reboot cycle was broken

Operation issues with Rovers (3)

- FM SW confirmed as primary problem
- Flash HW believed to be working correctly
- File Management module not robust enough
- Software bug was to blame and not faulty HW
- Unneeded in-flight data files on FS
- Files deleted and FMS reformatted
- Feb 6 (Sol 33) Rover restored and activities resumed

Spirit software upgrade

- Jan 2007 – rover onboard computer upgraded
- New systems allowed for autonomous rover decisions such as image transmission and arm movements to examine specimens
- Decreased dependence on Earth scientists
- Saved time due to latency period decisions
- *Opportunity* upgrade increased photography
- Images compressed with ICER, stored, Tx

ICER compression software

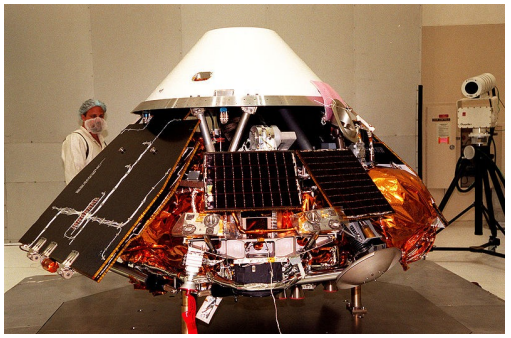
- Wavelet-based image compression file format
- Used by Spirit and Opportunity rovers
- Lossy and lossless modes for downlink
- Most of MER images compressed with ICER
- Rest compressed with LOCO s/w submode
- Trade-off between quality and compression
- Compression necessary for deep space Tx
- Quantity and amount specified by byte quota

ICER compression software

- Compressed bitstream in separate segments
- Segments are rectangular regions of images
- Compression traded against packet loss
- Images compressed using 4 to 6 regions
- Monochrome compression = colour
- Spectral+ICER mode offers lower rate distortion levels with ICER images
- Wider implementation as standard with NASA

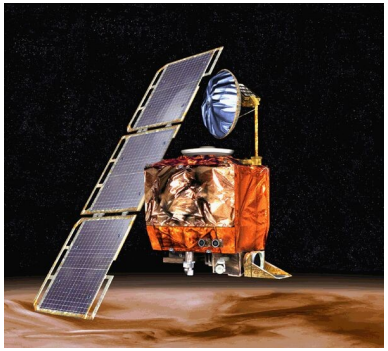
The IBM RAD6000

- Rad-hard version of RSC 1.1 million tran. Prcsr.
- Max clock rate of 33MHz. Speed of 35 MIPS
- 128MB of ECC RAM running on VxWorks
- Flight board clock rates of 2.5, 5, 10, 20 Mhz
- Used on variety of NASA missions
- Mars Rovers, Deep Space1, Mars Polar Lander
- Deep Space 1 tested payload of advanced high-risk technologies



Mars Polar Lander

- Part of Mars Surveyor Programme with MCO
- Both MCO and MPL used RAD6000 processor
- Failure of unit following MCO disintegration
- X-band comms using Cassini DSTs
- 15W RF solid-state high gain Tx/Rx for uplink and downlink, medium gain Tx, low gain Rx
- 10W UHF system for 2-way comms with MCO

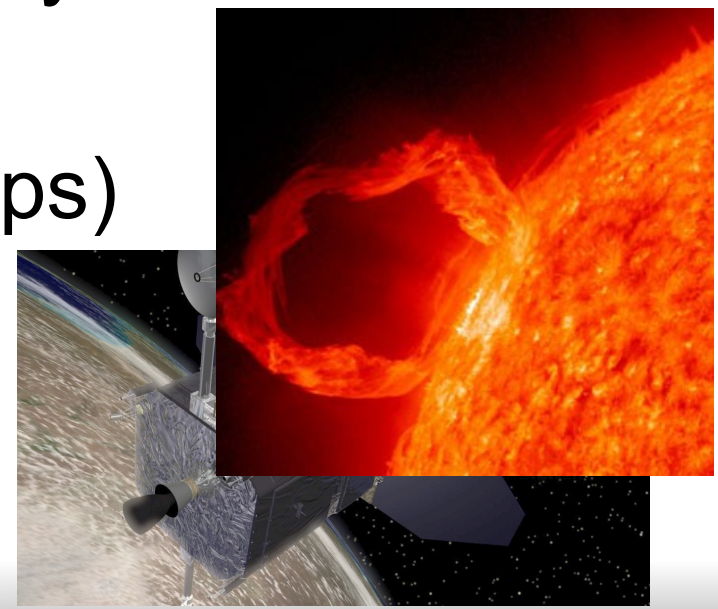


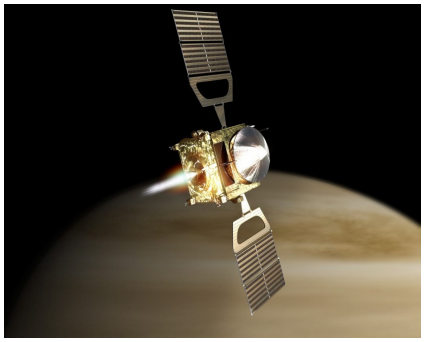
Mars Climate Orbiter

- MCO was to support MPL for first 3 months
- 8-10 passes of 5-6 mins each day over MPL
- 128 kbit/s limited 2-way UHF data relay
- Uplink comms to Earth via medium-gain DTE
- MCO was to act as UHF relay for 2001 mission
- Failed due to Incorrectly used measurements
- Orbit altitude set at 140-150km. Flew at 57km
- Stress break up of spacecraft at low altitude

Solar Dynamics laboratory (SDO)

- NASA mission of five years to observe the sun
- Launched Feb 2010 into GSO
- Data rate of 130Mbps on 26 Ka band with 150Mbps with overhead, 300Msymbols/s with rate ½ convolutional encoding
- 1,5 TB data daily (150 million bps)
- Data download via K-band
- Telemetry via S-band



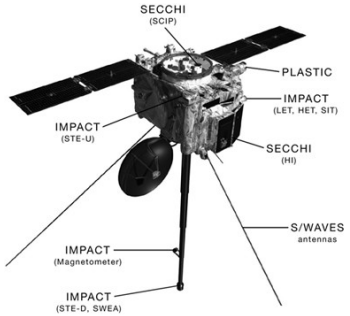


Venus Express

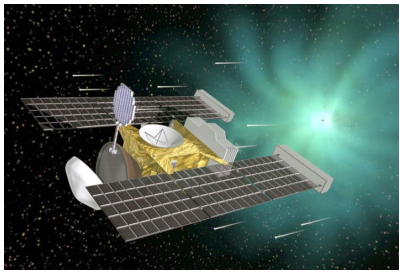
- ESA mission to explore Venus environment
- Modified Mars Express bus. Ready in 4 years
- Polar orbit of ~400km-~330.000km in April 2010
- Telecomms with Cebreros GS
- S-band and X-band Tx with max d/l of 228kbps
- Onboard SSMM data storage of 12 Gbits
- High capacity necessary to analyse and store data from seven optical and radio instruments

MESSENGER probe

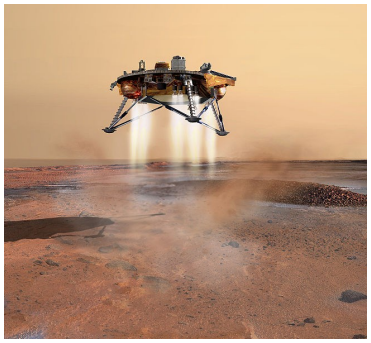
- MErcury Surface, Space, ENvironment, GEochemistry and Ranging launched in 2004
- Integrated Electronics Module combined CA
- Consists of one 25MHz IBM RAD6000 main processor for data analysis and storage and one 10MHz fault protection processor
- Two solid-state data storage recorders of 1GB each
- Data Tx to Earth when capacity is reached



IBM RAD6000 missions



- Solar TErrestrial RElations Observatory
- Launched in 2006 to HE-GCO
- Running two 25MHz processors @ 720kb/s d/l
- Stardust mission to investigate comet Wild2
- Seven year mission travelling 5.10^9km
- Running VxWorks OS on 32-bit processor
- Data storage is 128MB for programme and data



IBM RAD6000 missions

- Phoenix Robotic exploration mission
- Lander descended to Mars surface in May 2008
- Comms via X-band during cruise and separation
- UHF for remainder of mission compatible with all other Mars missions (MRO, Odyssey, Express)
- Interconnections via Proximix-1 Link Protocol
- Provides two-way 400MHz band comms between lander & orbiter giving reliable data rate

Data & Communications Networks

- Changing nature of Data transfer and comms
- Space needs variety of reliable networks
- Tracking stations and satellite/orbiter links
- NASA's Manned Space Flight Network (MSFN)
- Spacecraft Tracking and Data Acquisition Network (STADAN), Deep Space Network (DSN)
- Spaceflight Data Tracking Network (SDTN)
- NASA's TDRSS and ESA's EDRS network

Evolution of Comm Networks

- MSFN - Set of tracking stations to support US missions from Mercury to Skylab (1961-1979)
- STADAN – Tracking unmanned LEO sats
- DSN – Tracking distant unmanned missions
- MSFN & STADAN → SDTN (1979) → TDRSS
- Deep space missions need fewer, but larger, TS
- LEO more but smaller (DSN has three – 03/2010)
- DSN antennae larger to deal with weaker signals

Tracking stations

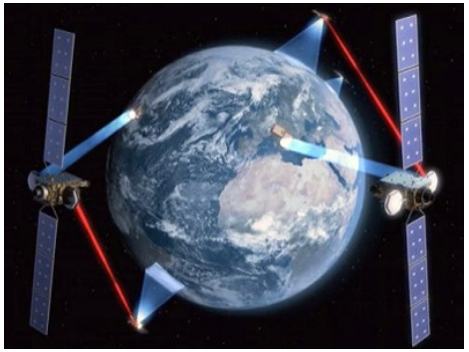
- LEO tracking and comms antennae track quickly
- Mission-optimised networks became the TDRSS
- Primary network was MSFN (used for Apollo)
- Required range and range-tracking system
- Large 26m paraboloid high-gain antennae for tracking and communication
- Extended land, ship, and aircraft TS and GS
- Sub-horizon antennae (26m) < 16.000km

Deep Space Network

- Contributed to communication and tracking of Apollo although in a secondary role to MSFN
- Two large antennae to track orbiter and lander
- Large antennae provided tv coverage of landings and emergency comms for Apollo 13
- Antennae were switched between missions constantly so as not to compromise each other
- DSN maintained its original purpose

TDRSS

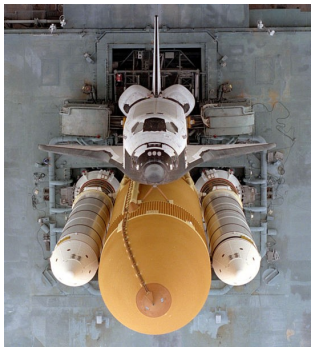
- NASA network of comms sats & ground stations
- Increase comms time and improve data transfer
- Two primary GS located in Continental USA
- Nine orbital sats (three primary) inc. Backups
- Constantly expanded primarily for ISS and STS
- HST & Landsat relay their data through TDRSS
- Primary comms system for Polar stations
- Extended use for interplanetary missions



EDRS

- Being introduced due to ESA mission increases
- Similar in design to NASA TDRSS
- Includes two comms sats and one dedicated s/c
- Near-global coverage for LEO from GSO sats
- LEO → GEO → GS reducing downlink time
- Priorities - Environment and Security monitoring
- Replaces existing ARTEMIS laser comms satellite in 2013

Space Shuttle Comms



- Tracking and communications through TDRSS
- MC in Houston → 23m White Sands Antenna
- WSA → Tracking and Data sats in GEO
- These signals are relayed to Space Shuttle
- Signals are relayed also in the reverse direction
- S-Band for voice, commands, data and telemetry
- Ku-band for video and two-way data files

Space Shuttle Flight Systems

- Earliest system to use fly-by-wire in 1980s
- Uses five identical embedded IBM 32-bit GPCs
- Four run Primary Avionics Software System
- Fifth runs Backup Flight System
- Together they are the Data Processing System
- BFS runs only of the first four fail during flight
- Number of lines of code minimal → < 1MB RAM
- Ensures that software has never failed

Space Shuttle Computer Systems

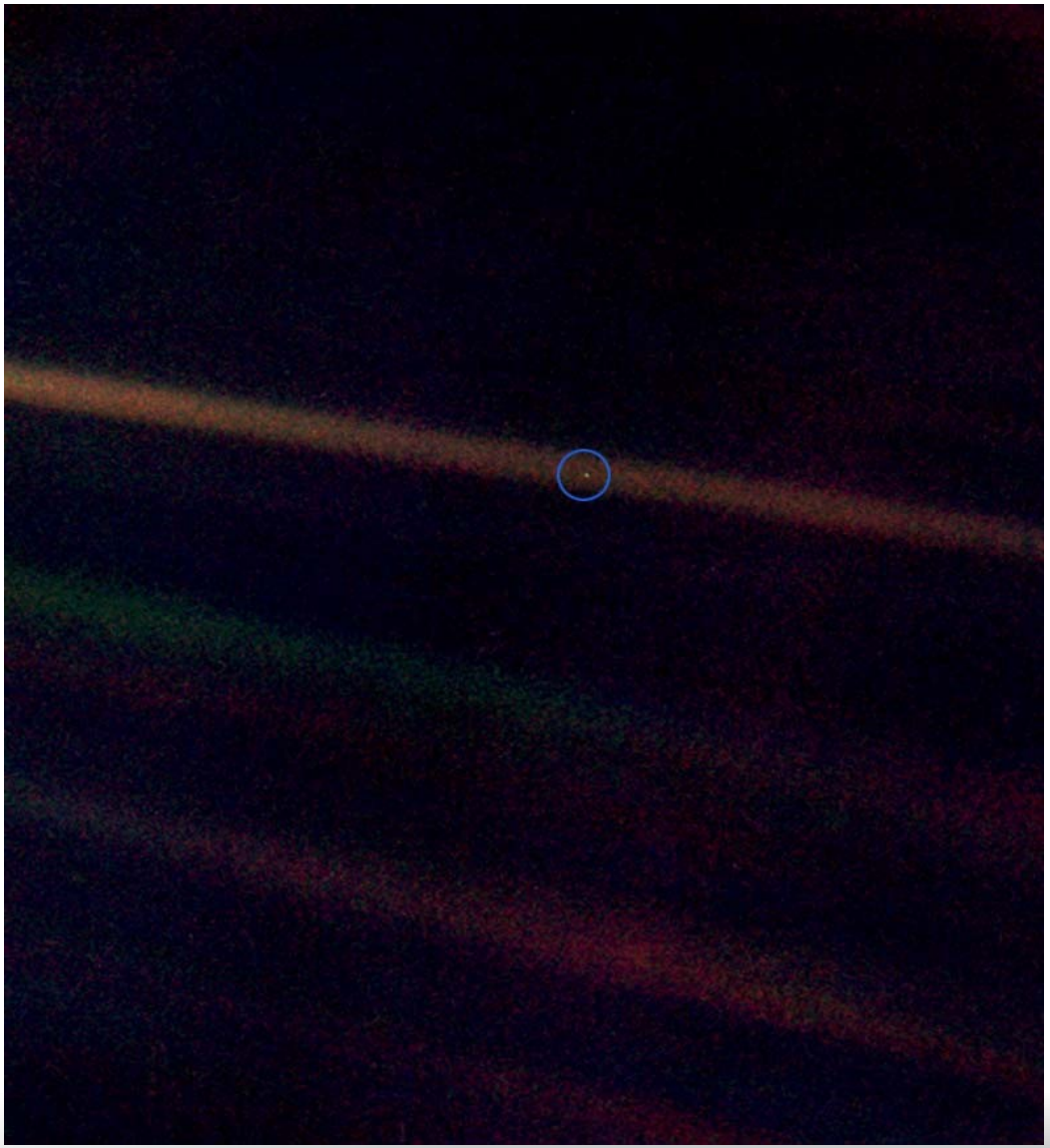
- Software written in high-level language HAL/S
- Similar to PL/I. Real-time embedded system
- ~424KB magnetic core memory (400.000ips)
- Upgraded in 1990 to 1MB and 1.2 million ips
- No HDD. Magnetic tape used for storage
- Memory upgraded from Magnetic core to Semiconductor

Voyager systems

- 1970s NASA deep-space mission
- FDS operates and configures instruments
- CCS controls functions and sequencing
- Uplink communications via S-Band (16b/s command rate) and X-band (160b/s or 1.4kb/s for playback or plasma wave data)
- Voyager outside Heliosheath as of 2010
- Data transfer < 3w. Images from outside SS.

Pale Blue Dot

- Taken from Voyager at extent of Heliosheath
- The earth appears as a pale blue dot
- The furthest photo taken from earth



End of Presentation

Thank you for your attention!!!!

Any Questions????