III CURSO COMPLUTENSE DE INTRODUCCIÓN A LA EXPLORACIÓN ESPACIAL Y SU UTILIZACIÓN

DEL 17 DE NOVIEMBRE AL 5 DE DICIEMBRE DE 2025

Lección 6: Operaciones espaciales y comunicaciones

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20-Nov-2025

AEGORA
COMPLUTENSE
RESEARCH GROUP ON
SPACE ASTRONOMY
AND DATA MINING

UNIVERSITAS COMPLUTENSIS MATRITENSIS

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Outline

- Introduction
- Space Mission Control.
- Ground Segment.
- Mission Operations.
  - Some (hopefully) illustrative examples

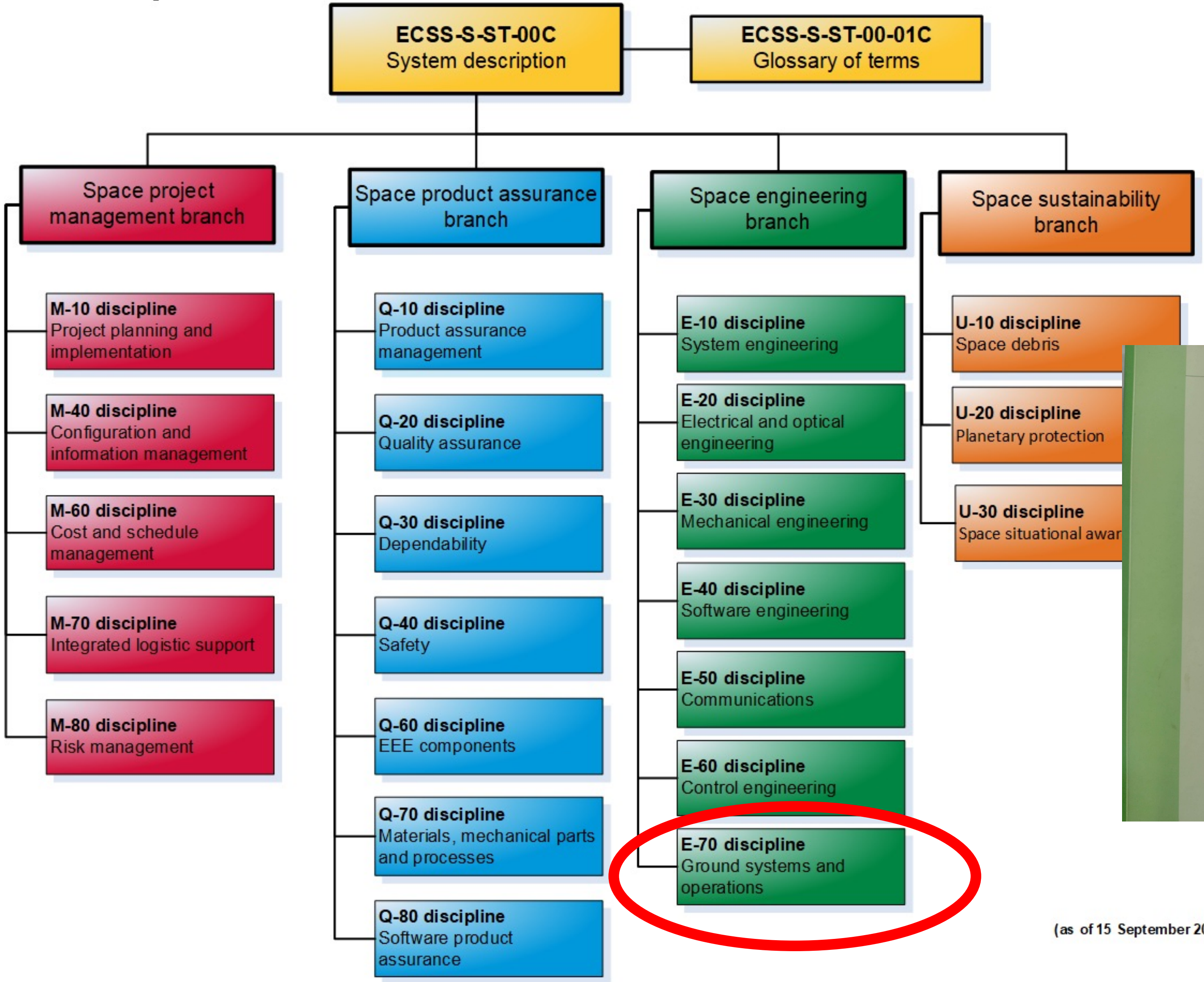
Introduction to operations

- Operations means,
  - Launch.
  - In orbit Verification and Validation.
  - Monitoring and Control.
  - Payload management.
  - Data Processing.
  - Data Distribution.
  - …

- Operations mean engineering processes, space standards, ….



ECSS Disciplines



(as of 15 September 2021)

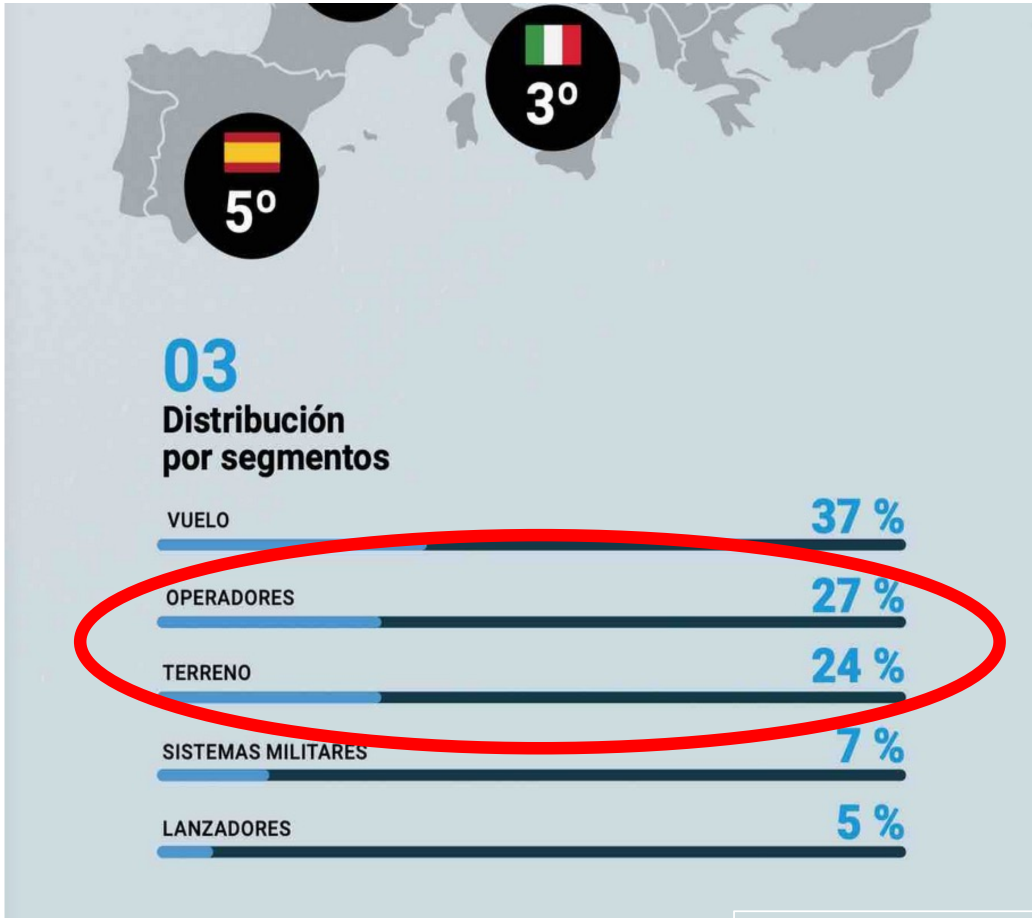
Turnover 2021

- See the previous slide.
- Operations are a minor element of space exploration?
- A significant percent of total turnover is linked to operations:
    47%

Src: TEDAE anuario 2021

Turnover 2022

- See the previous slide.
- Operations are a minor element of space exploration?
- A significant percent of total turnover is linked to operations:
    51%



Src: TEDAE anuario 2022

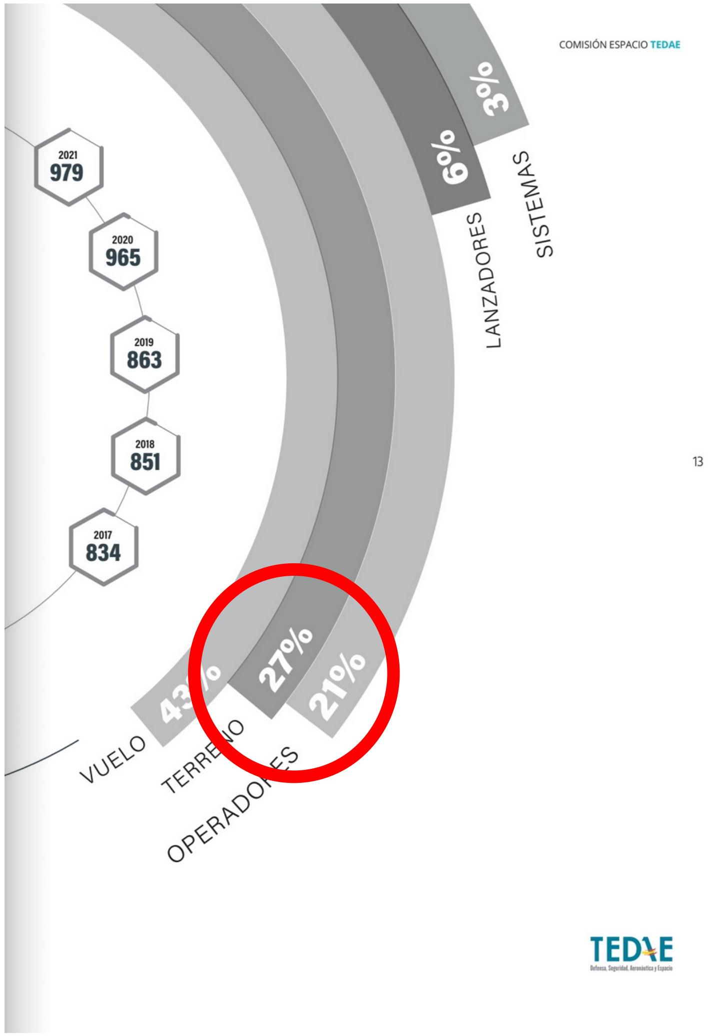
Turnover 2023

- See the previous slide.
- Operations are a minor element of space exploration?
- A significant percent of total turnover is linked to operations:
  56.1%

Src: TEDAE anuario 2023

Turnover 2024

- See the previous slide.
- Operations are a minor element of space exploration?
- A significant percent of total turnover is linked to operations:
  48%



Src: TEDAE anuario 2024

Business landmark

ESPECIALIDADES DE LAS EMPRESAS DE TEDAE

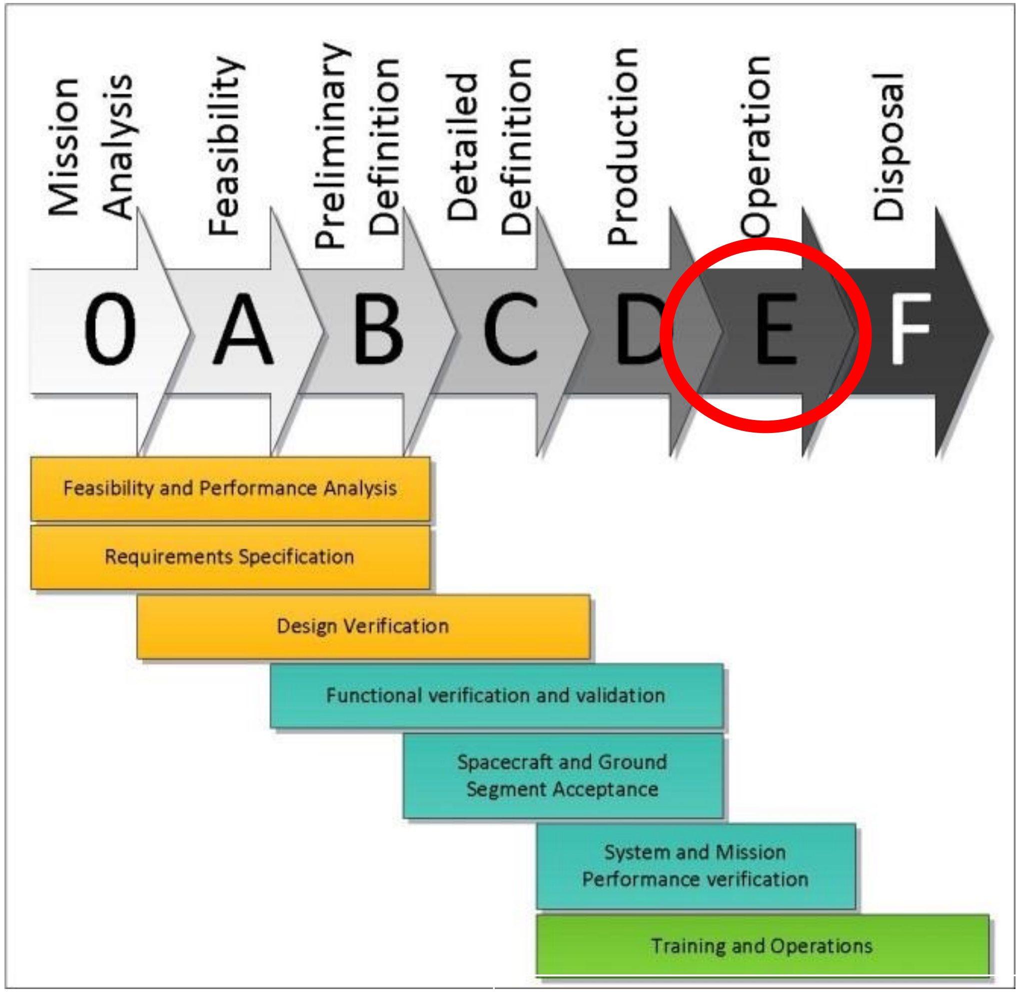
Empresa	LANZADORES	SATÉLITES	SEGMENTO TERRENO	OPERADORES DE SATÉLITES	APLICACIONES
AICOX SOLUCIONES		●	●	●	●
AIRBUS DEFENCE AND SPACE	●	●		●	
ALTER TECHNOLOGY		●	●		
ARQUIMEA	●	●	●		
AIRBUS CRISA	●	●	●		
DAS PHOTONICS		●	●		
DEIMOS SPACE	●	●	●		●
GMV	●	●	●		●
GRUPO OESÍA	●	●	●		●
GTD	●	●	●		●
HISDESAT		●	●	●	●
HISPASAT		●	●	●	
HV SISTEMAS	●	●	●		
INDRA		●	●	●	●
INSTER		●	●		●
INTEGRASYS		●	●		●
INVENTIA	●	●	●		
ORBITAL	●	●	●		●
PLD SPACE	●				
QUASAR			●		●
SATLANTIS		●	●	●	●
SENER	●	●			●
TECNALIA	●	●			●
TELESPAZIO IBÉRICA		●	●	●	●
THALES ALENIA SPACE ESPAÑA	●	●	●		

22 23

Src: TEDAE anuario 2024

Duration

- Is it a significant percent of total project lifetime?
- Well… space projects development times are really long (20yrs might be typical).
- Operational phases are typically shorter than one (with nice exceptions).
- But not all is money and resources…



Src: Scheider Journal Interactive systems 2013

Operations

- It is when the lights are switched on and the play starts after years of preparation.

- No place to hide. There are no stops, no breaks…. When a problem arises, the show must go on.

- Hence, the human factor.

Src: palacetheatre.org

Introduction to operations

- Operations means,
  - Launch.
  - In orbit Verification
  - Monitoring and C
  - Payload man
  - Data Proc
  - Data D   n.
  - …

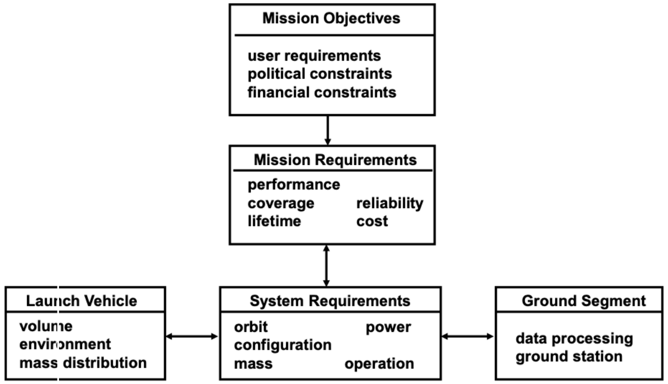
- Ope   s mean engineering processes, space standards, ….

The Human factor

Mission Control

Mission Control

- To be sure mission **deliver required products** in response to requests from users,
  - Data (e.g. science, earth observation data)
  - Services (e.g. communications, navigation)
  - Material samples processing (microgravity)
- Hence, Mission Control shall ensure:
  - Spacecraft **health** and safety
  - Implementation and maintenance of baseline trajectory/orbit and environmental **conditions**
  - **Operations** of spacecraft subsystems, payload, ground segment **for mission product generation**.



Src: Tatnall/U.Southampton/ESA 2014

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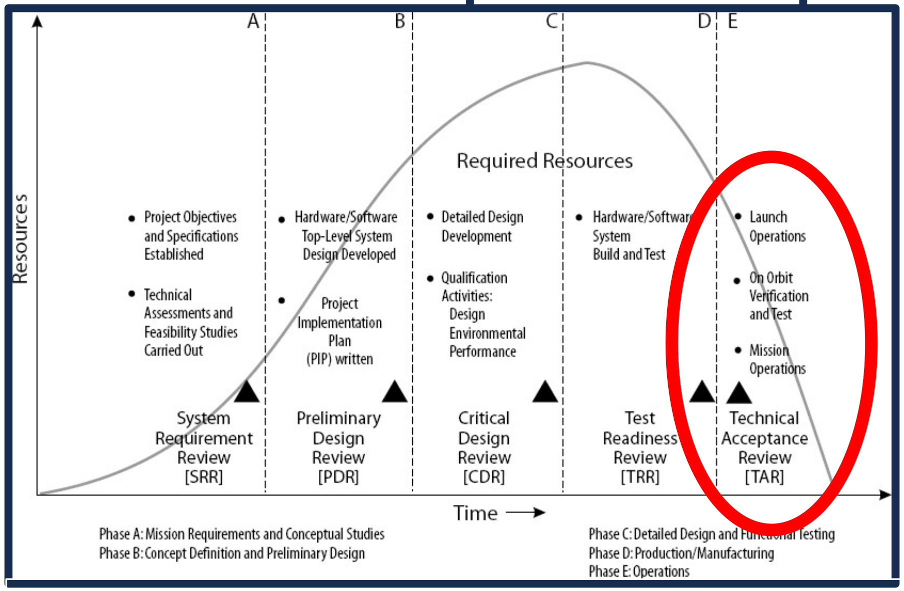
Mission success

- ‘Success’ requires contributions both from satellites and from mission control.
- Both are of about **equal importance** although their cost is significantly different:
  - Spacecraft development: typically, 85-90% of total mission cost.
  - Ground segment and operations, typically 10-15%.
  - (Launch is included?)
- launch and operations…**the final link of the chain** to achieve success.



Src: Nguyen, Project Management Institute Annual Seminars & Symposium (2000)

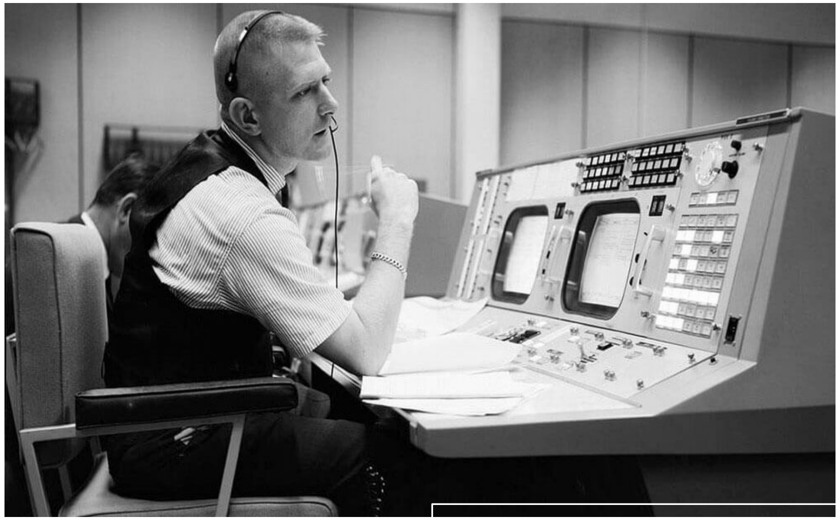
Mission goals

- User Requirements depend on type of mission (comms, sci, …).
  - High degree of mission exploitation,
    - >98.5% data product delivery.
    - >99.9% availability of communications services.
  - Minimisation of operator errors probability.
  - Rapid reaction to anomalous events.
  - Rapid adaptation of nominal operations to irreversible in-orbit failures.

- The human factor->what are the foundations to achieve the above?

Foundations of mission control

- To always be aware that **suddenly and unexpectedly** we may find ourselves in a role where our performance has ultimate consequences.
- To recognize that the greatest error is not to have tried and failed, but that in trying, we did not give it our best effort.



E.F. Kranz, Src: NASA

Foundations of mission control (II)

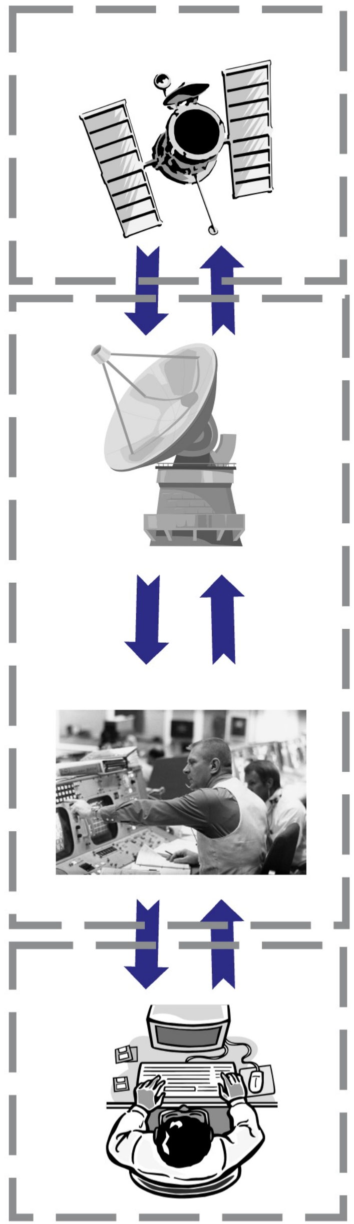
- **Discipline.** Being able to follow as well as lead, knowing we must master ourselves before we can master our task.
- **Competence**. There being no substitute for total preparation and complete dedication, for space will not tolerate the careless or indifferent.
- **Confidence.** Believing in ourselves as well as others, knowing we must master fear and hesitation before we can succeed.
- **Responsibility**. Realizing that it cannot be shifted to others, for it belongs to each of us; we must answer for what we do, or fail to do.
- **Toughness.** Taking a stand when we must; to try again, and again, even if it means following a more difficult path.
- **Teamwork.** Respecting and utilizing the ability of others, realizing that we work toward a common goal, for success depends on the efforts of all.
- **Vigilance**. Always attentive to the dangers of spaceflight; Never accepting success as a substitute for rigor in everything we do.

Ground Segment Terminology

Ground segment architecture

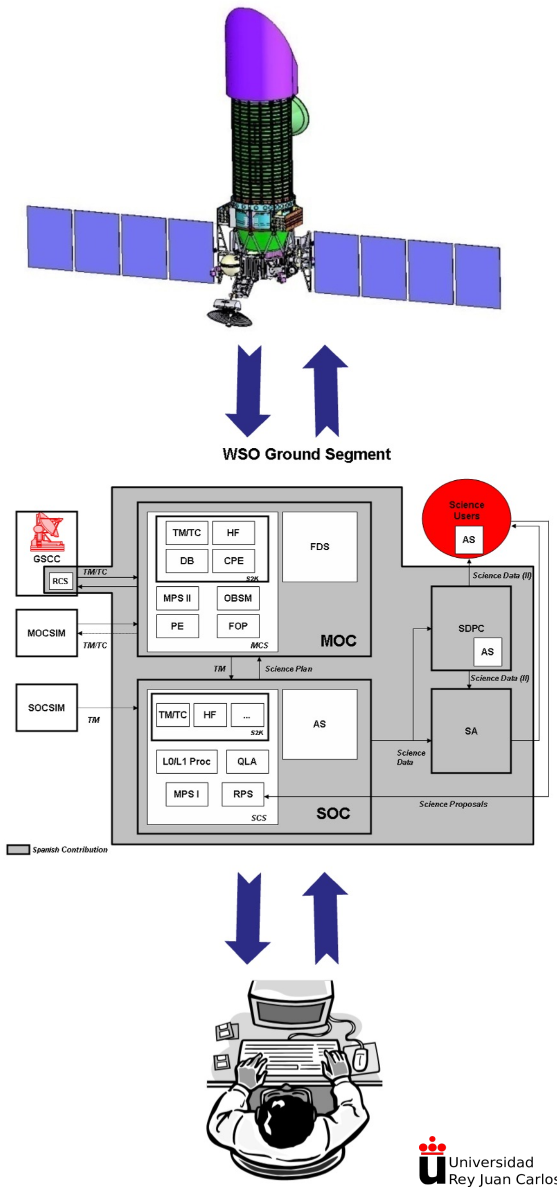
- **Mission Operations Centre**, in charge of all mission operations planning, execution, monitoring and control.
- **Ground Stations**, providing Telemetry, Tracking and Command Services, i.e. the radio link to the space segment.
- **User Support Operations Centre**, in charge of scientific/observation operations planning, Principal Investigators coordination, data archiving and scientific/observation data analysis support.
- **Local/Wide Area Comm. Network**, enabling data flow among the ground segment systems.

….In other words, Ground Segment is the link between satellite (Flight Segment) and final user.

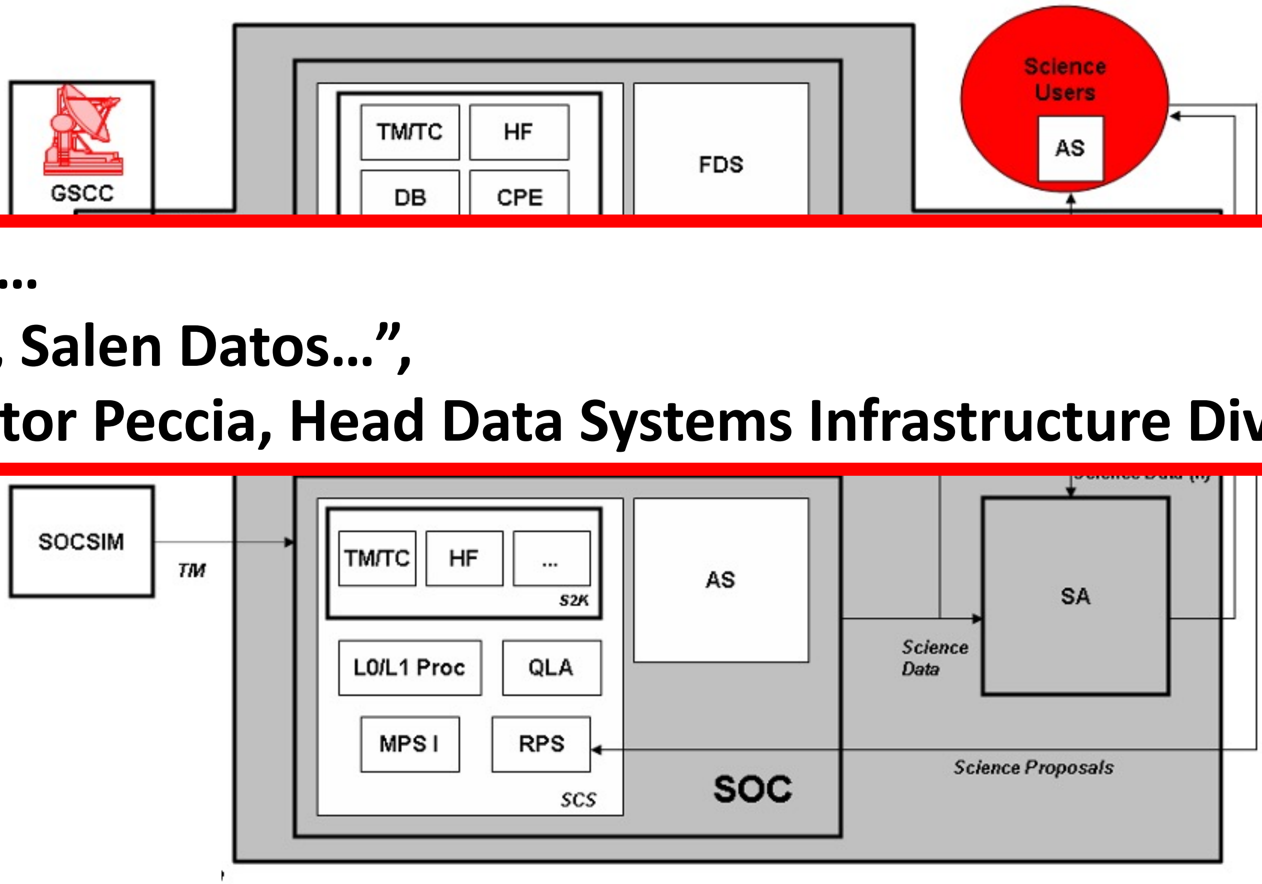


Ground segment elements

- Ground Station, antennas, base band equipment.
- Mission Operations Center (MOC), including Routing systems (DRS), Mission Control Systems (MCS), Flight Dynamics Systems (FDS).
- Science Operations Center (SOC), including Science Control System (SCS), Analysis Systems (AS), Pipelines, Archive, Disseminations Systems, …
- Platform Simulators, Science Simulators,…
- **Terminology, Roles, … depend on specific project, actual agency.**
- **Standards define everything but born to be tuned.**



Ground segment elements (II)



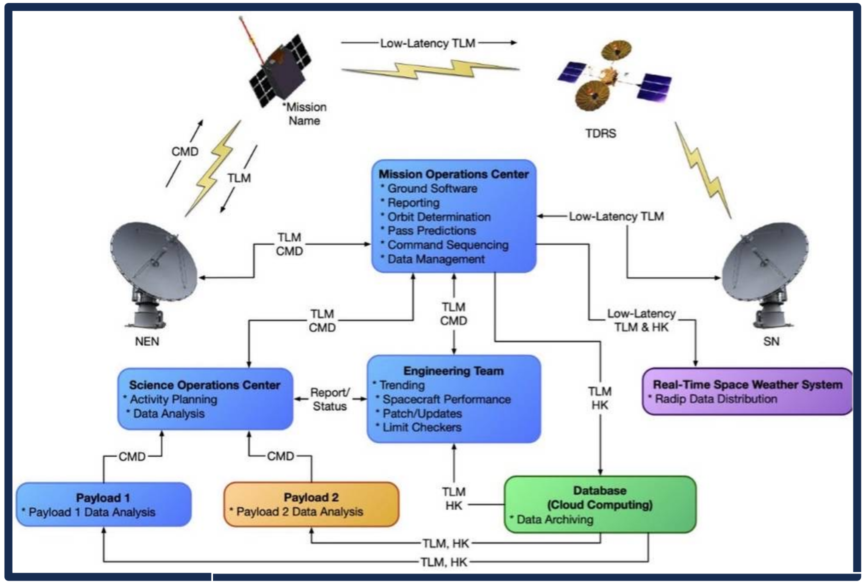
…In other words…

"…Entran Datos, Salen Datos…",

(Nestor Peccia, Head Data Systems Infrastructure Division at ESA)

Ground segment units

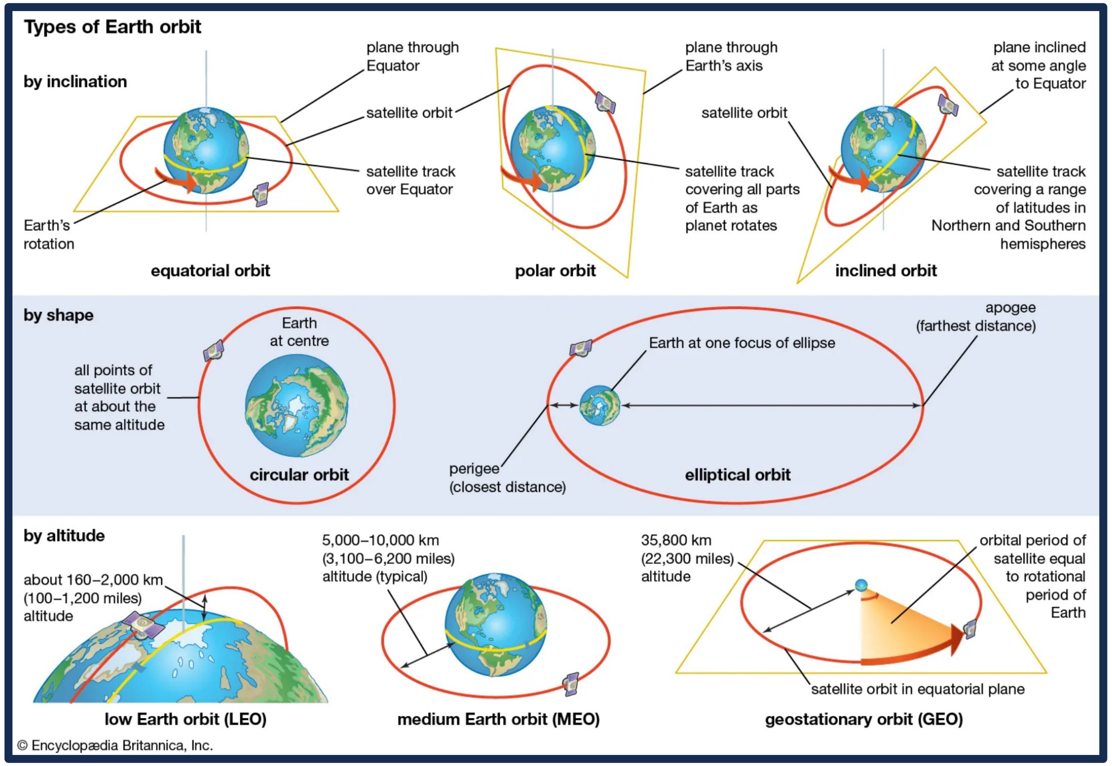
- **Spacecraft Operations**. Responsible for the definition, implementation and execution of mission operations activities.
- **Data Systems**. Responsible for specifications, develoments, implementation, integration and testing of all sw and hw pertaining the project ground data processing in accordance with user requirements. This covers in particular <u>mission control sw, simulators and payload data processing</u>.



Src: NASA, nasa.gov

Ground segment units (II)

- **Flight Dynamics**. Responsible for support to mission and s/c design with respect to mission analysis, orbit and attitude, including investigations and studies of launch window, orbit selection and evolution, maneuver strategies and optimizations, tracking and navigation, sensor and instrument performances.

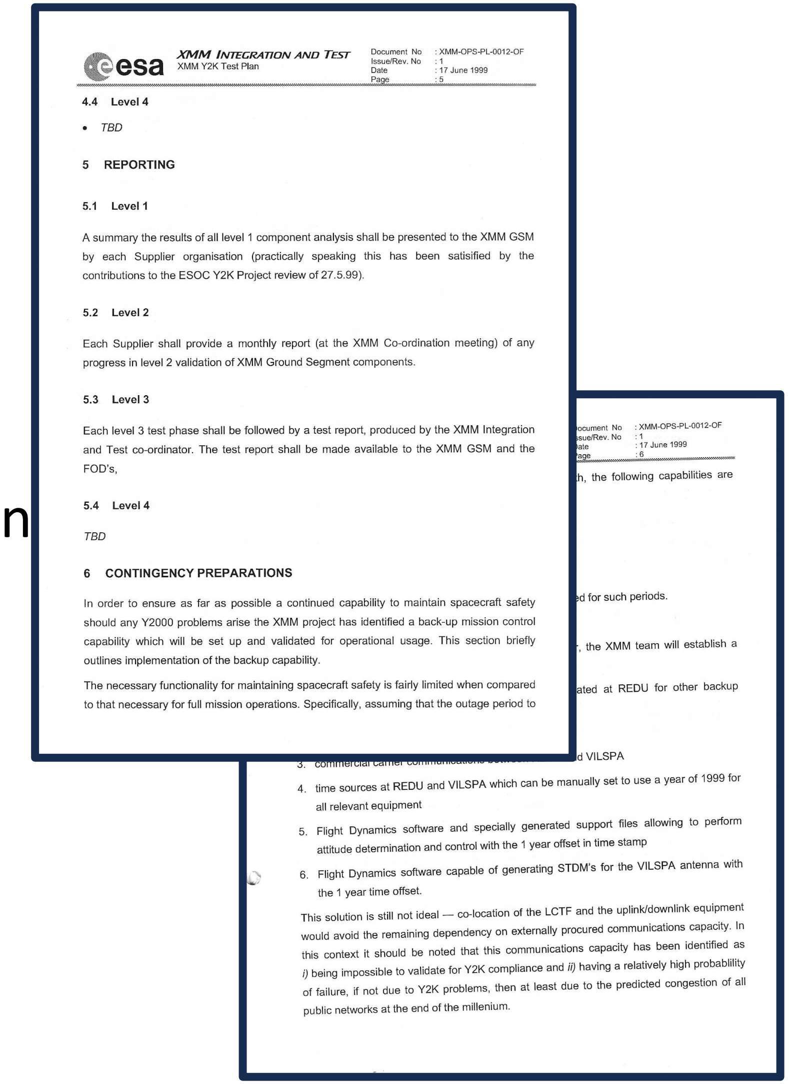


Remote operations

- **Once launched, nothing to do**.
  - Some exceptions are serviceable missions, as HST, or manned missions, ISS, …
- Indeed, SW is the only thing can be upgraded and serviced "in flight" in a typical mission.
- Therefore, we talk of operations **functional areas**:
  - Commanding Chain (Uplink chain), devoted to **telecommands**.
  - Monitoring Chain (Downlink Chain), devoted to **telemetry**.
  - **Data** Archiving and Dissemination.

Procedures

- "**Human-Machine-Procedure**" Systems:
  - Procedures are used for all **nominal** and 'foreseen' **contingency** cases.
  - Humans (i.e. experts) are used during,
    - critical phases for mission implementation and for corrective interventions as active and decision-making elements
    - during routine phases primarily for supervision and troubleshooting.
  - Machines are always present, supporting or even replacing the above.



esa XMM INTEGRATION AND TEST
XMM Y2K Test Plan
Document No : XMM-OPS-PL-0012-OF
Issue/Rev. No : 1
Date : 17 June 1999
Page : 5

4.4 Level 4

- TBD

5 REPORTING

5.1 Level 1

A summary the results of all level 1 component analysis shall be presented to the XMM GSM by each Supplier organisation (practically speaking this has been satisfied by the contributions to the ESOC Y2K Project review of 27.5.99).

5.2 Level 2

Each Supplier shall provide a monthly report (at the XMM Co-ordination meeting) of any progress in level 2 validation of XMM Ground Segment components.

5.3 Level 3

Each level 3 test phase shall be followed by a test report, produced by the XMM Integration and Test co-ordinator. The test report shall be made available to the XMM GSM and the FOD's,

5.4 Level 4

TBD

6 CONTINGENCY PREPARATIONS

In order to ensure as far as possible a continued capability to maintain spacecraft safety should any Y2000 problems arise the XMM project has identified a back-up mission control capability which will be set up and validated for operational usage. This section briefly outlines implementation of the backup capability.

The necessary functionality for maintaining spacecraft safety is fairly limited when compared to that necessary for full mission operations. Specifically, assuming that the outage period to

4. time sources at REDU and VILSPA which can be manually set to use a year of 1999 for all relevant equipment
5. Flight Dynamics software and specially generated support files allowing to perform attitude determination and control with the 1 year offset in time stamp
6. Flight Dynamics software capable of generating STDM's for the VILSPA antenna with the 1 year time offset.

This solution is still not ideal — co-location of the LCTF and the uplink/downlink equipment would avoid the remaining dependency on externally procured communications capacity. In this context it should be noted that this communications capacity has been identified as *i)* being impossible to validate for Y2K compliance and *ii)* having a relatively high probability of failure, if not due to Y2K problems, then at least due to the predicted congestion of all public networks at the end of the millenium.

FOP

- Flight Operations Procedures
- **Validation** is required on the procedural/tools side.
- **Training** is required on the human side.

- Automation is nowadays on site
- Procedures = algorithmic
- IA = Training here now.

Satellite Flight Operations Procedure: FOP-AOCS-0010
OOP Update – Version 1.2 (10/10/2021)

Objective: This procedure is used to update the on-board propagators. This procedure updates the parameters of the STS module: Satellite, Sun and Moon orbits at specific epoch, not necessarily the three at once. In fact, satellite, Sun and Moon orbit updates shall be performed at different frequencies

Constraints: Flight Dynamics input available (SCOS2K TPF transferred to MCS)

Satellite configuration: SAT-NOM/AOCS-NOM/EPS-NOM
OBDH software is running correctly, TM packets activated: SAA_TMCSTS (SPID 258612)

Step	Label	Activity/Remarks	Telecommand	Telemetry	Display/Branch
1		Initial Checks			
1.1		Check Packets Enabled		SAA_TMCSTS	TM-AOCS-1
1.2		Check OOP Telemetry (SC)			
		Verify Telemetry X in ECI		AAAT076D	
		Verify Telemetry Y in ECI			
		Verify Telemetry Z in ECI			
2		Command OOP update			TC-AOCS-1
2.1		**Execute Telecommand SAASTS00** SET STS AAAP123H = SAT_TIME, AAAP123D = SAT_SMA AAAP123A = SAT_INC AAAP123A = SAT_RAAN AAAP123A = SAT_AOP AAAP123_ = SAT_ECC AAAP123V = DSAT_SMA AAAP123V = DSAT_INC	SAASTS00		
3		Verify OOP Update			
3.1		Verify OOP Telemetry (ECI Cartesian) AAAT0125 = SATPOSXECI		AAAT0125	TM-AOCS-2
		AAAT0125 = SATPOSYECI		AAAT0126	TM-AOCS-2
		AAAT0125 = SATPOSZECI		AAAT0127	TM-AOCS-2

Src: Introduction to Satellite Ground Segment System Engineering /Springer

Procedures =nominal and 'foreseen' contingency cases.

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Contingencies

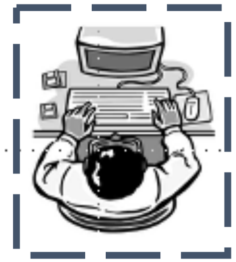
- **The real art is to think earlier, not to think faster** (Napoleon, I think?).
- Follow procedures and checklists.
- Training, learning / unconscious assimilation.

- Operators call for Support (specialists) when needed (out of procedure)
- Go/NoGo break points. (Stay/no-stay).
- **First line** means the quickest, more efficient solution, not the smartest or ultimate one.

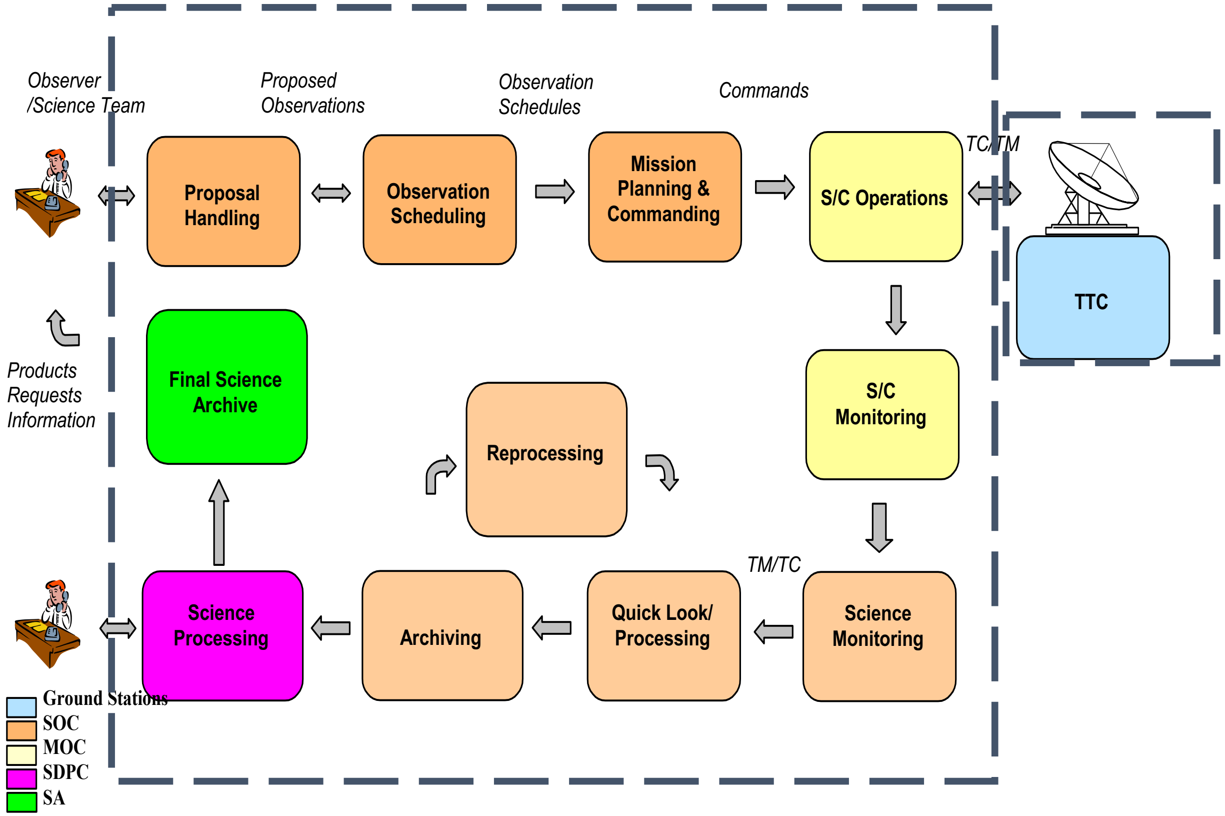
-Know how/when to apply procedure.
-Know your limitations: know what you do not know. **The first rule of flight control:** if you do not know what to do, don't do anything!

Ed Heinemann and KISS Principle (Keep it simple, stupid)

Ground Segment



Ground Segment



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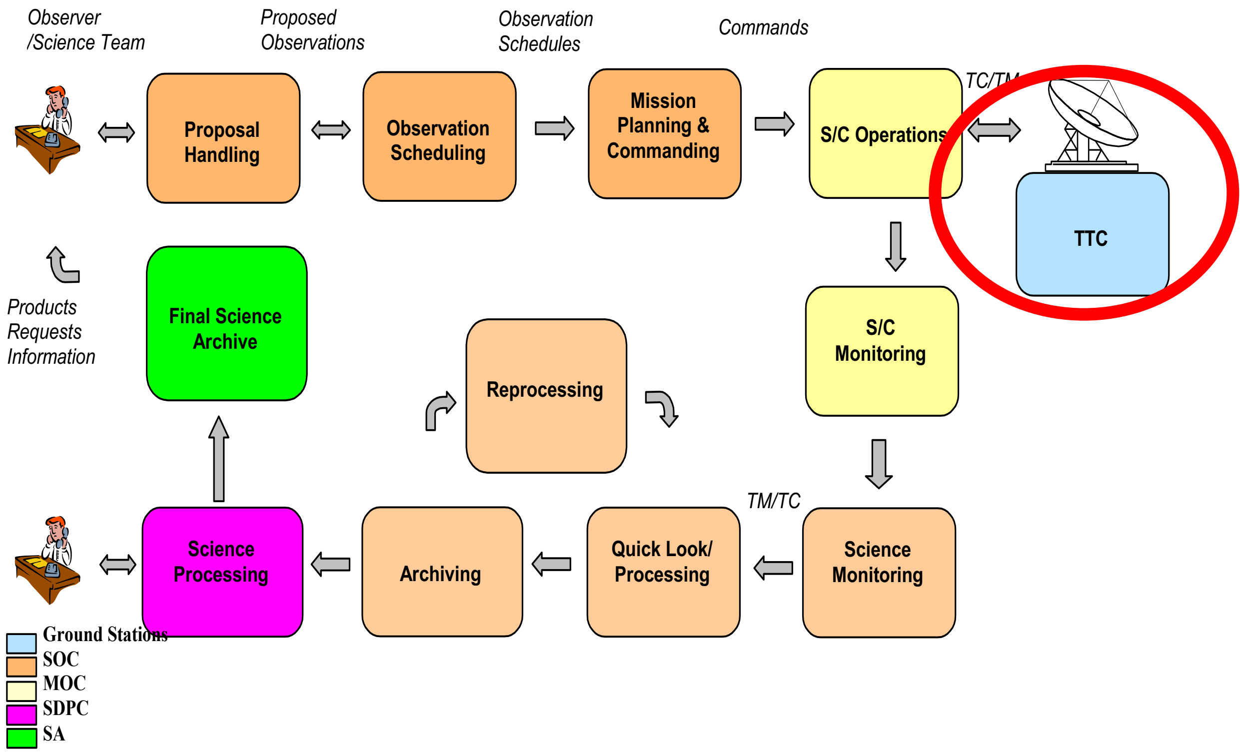
G/S and Comms

GS and Comms



Observer /Science Team
Proposed Observations
Observation Schedules
Commands
Proposal Handling
Observation Scheduling
Mission Planning & Commanding
S/C Operations
TC/TM
TTC
Products Requests Information
Final Science Archive
Reprocessing
S/C Monitoring
TM/TC
Science Processing
Archiving
Quick Look/ Processing
Science Monitoring
Ground Stations
SOC
MOC
SDPC
SA

Comms

- To confirm of the satellite survival!.

- **Telemetry,** data <u>from</u> the satellite,
  - **Housekeeping** data: Temperature, voltage, current, status, and attitude parameters.
  - **Payload** data: CCD status, images, …
- **Telecommands,** commands <u>to</u> control the satellite,.
- **Tracking**, that is getting **distance/position information,**
  - Ranging, Doppler, (LEO case: GPS/GNSS-based).

- In a first phase of space exploration, antennas were governmental owned. Nowadays, many g/s are **commercial/private, providing services** to both governments and companies.

ESTRACK

- Established in 1975, with the first 15 m-diameter station at Villafranca del Castillo, Spain, for the International Ultraviolet Explorer mission
- Tracking for all phases of a mission, from 'LEOP' – the critical Launch and Early Orbit Phase – through to routine operations, special manoeuvres or flybys and ultimately through deorbiting and safe disposal.
- All stations are operated centrally from the Network Operations Centre located at ESOC using a sophisticated remote control and automation system to reduce personnel costs and boost efficiency.

RCSGSO workshops!

ESTRACK (II)

- The **core Estrack network** comprises seven stations in seven countries (Korou, Kiruna, Redu, Santa Maria plus 3 DS stations) .
- DS Stastions: In 1998 ESA established its own network for tracking deep-space probes (New Norcia, Cebreros, Malargue).
- The ESA-owned and operated core Estrack network is complemented by the **augmented network**: commercially operated stations provided thru **service contracts** with organisations.

- The smaller stations communicate using radio frequencies in a mix of S- and X-Bands (2025-2300 MHz, 7145-8500 MHz, respectively), while the three 35-m deep-space stations primarily use X-band.

Bands

Step	Information Required
1. Identify Requirements	Mission type and orbit (LEO or GEO), Data amount and update frequency
2. Select Frequency	Type: Amateur or experimental or commercial, bandwidth, modulation
3. Select and Design Hardware	Antenna spec. TX/RX spec.
4. Select Data Protocol	Data packet format Error correction method
5. Identify Link Budget	Link margin

Src: KiboCUBE Academy

Band	Frequency
HF	3 to 30 MHz
VHF	30 to 300 MHz
UHF	300 to 1000 MHz
L	1 to 2 GHz
S	2 to 4 GHz
C	4 to 8 GHz
X	8 to 12 GHz
Ku	12 to 18 GHz
Ka	27 to 40 GHz
V	40 to 75 GHz
W	75 to 110 GHz
mm	110 to 300 GHz

Data rates vary greatly depending on the mission, direction (uplink or downlink), distance and other factors, but typically range from 256 Kbit/s (kilobits per second) to 8 Mbit/s (megabits per second).

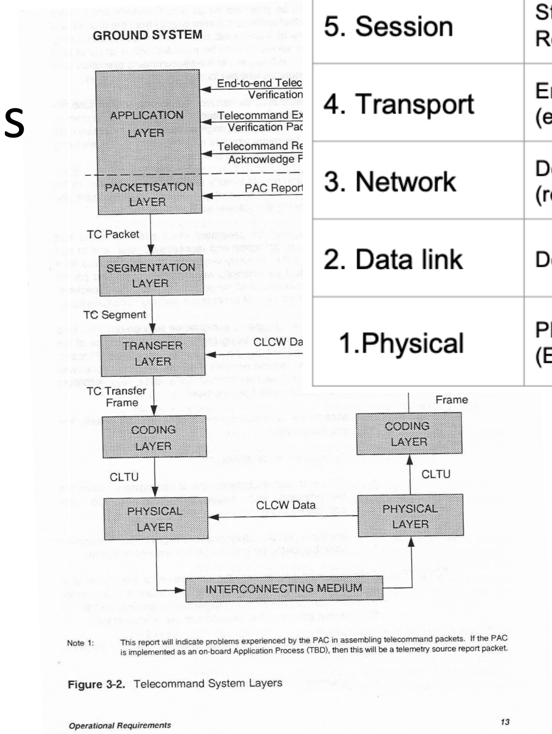
Digital Signal Packet Design

- Open Systems Interconnection model (OSI model), Developed by the International Organization for Standardization (ISO) to classify and clarify the roles of the many protocols used in computer networks.

- Defines communication functions (communication protocols) in seven layers.

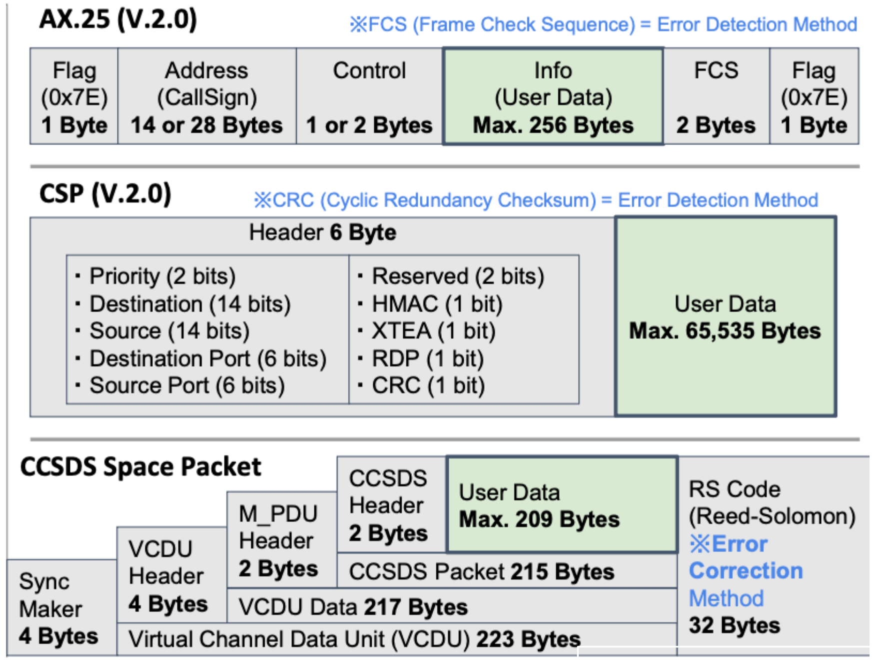
Layer Name	Description
7. Application	Specific services (Ex. E-mail, HTTP, FTP)
6. Presentation	Data presentation style (Ex. ASCII Code)
5. Session	Starting and terminating management, Reconnection management
4. Transport	End-to-end communication management (error correction, retransmission control)
3. Network	Decides which physical path the data will take (rooting)
2. Data link	Defines the format of data on the network
1.Physical	Physical (electromagnetic) signal connection (Ex. wired: RS-232, 10BASE-T, wireless: wifi)

Src: KiboCUBE Academy



Data Packet Protocols

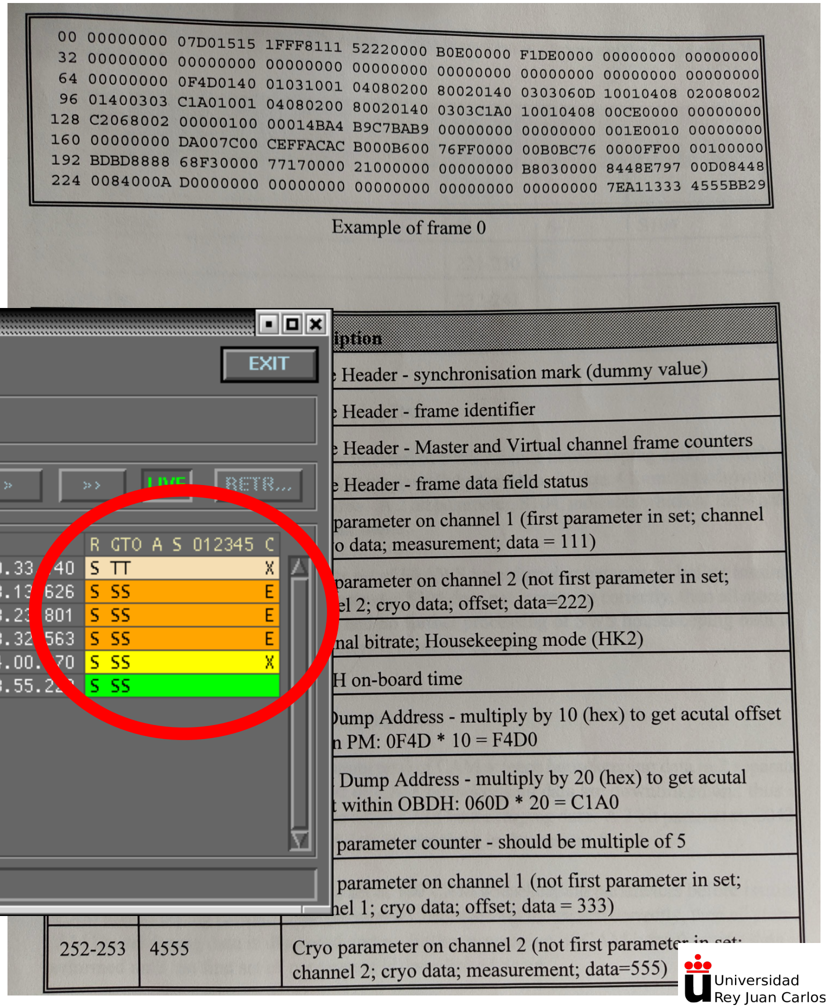
- **Amateur** AX.25, originally derived from layer 2 of the X.25, protocol suite and designed for use by amateur radio operators in 1984. It occupies the data link layer, the second layer of the OSI model
- **CSP**, CubeSat Space Protocol, developed by a group of students in 2008.
- **CCSD**S, Consultative Committee for Space Data Systems, Space Packet Protocol, with error correction.

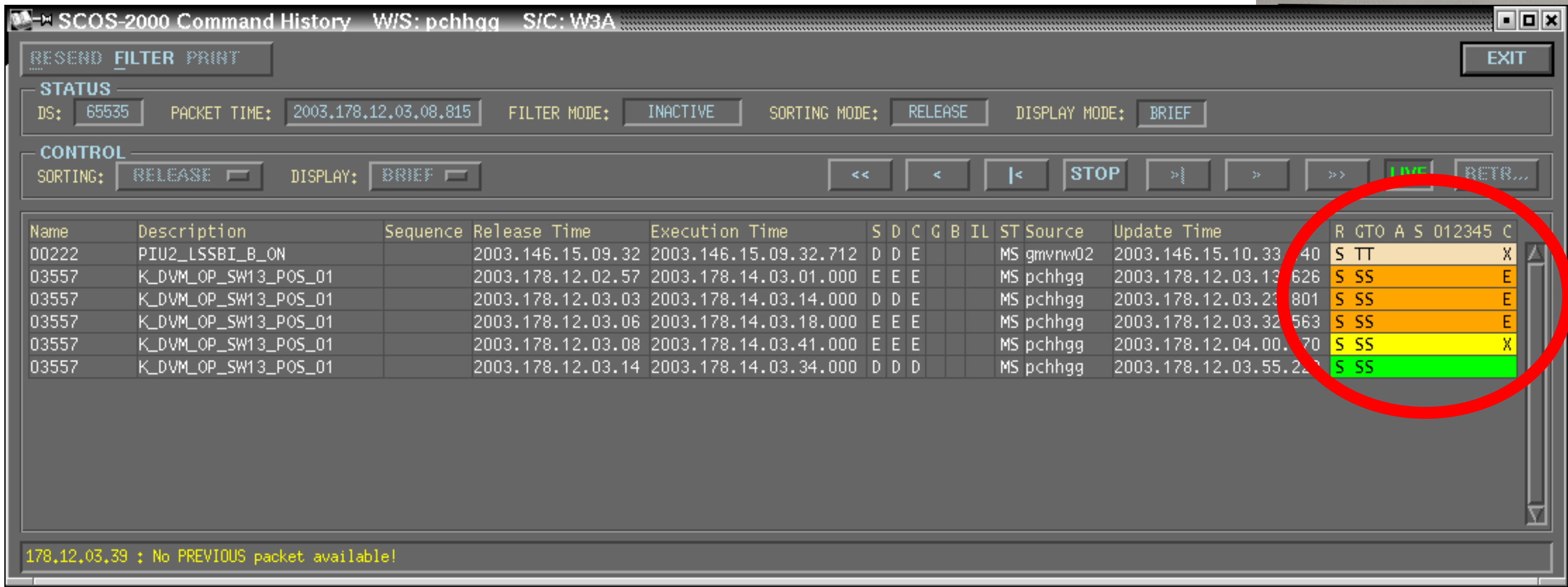


Src: KiboCUBE Academy

Data Packet Protocols (II)

- ICDs are key for development and operations.
- Some staff can read this!!!





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Comms issues

- Dedicated frequencies means frequency licensing.
- RF communication frequencies are protected.
- UHF -> S-band-> X-band -> Optical

- Some issues to be tackled elsewhere: beware from RFI, Radio interferences.
- Beware of Starlink?
- Optical comms on development.

IUE, Satan UHF antenna - Src:

Comms issues (II)

- Antennas usually located at remote areas or at least, r/f isolated areas, somehow protected from outside interferences.
- (This can change as the time goes).

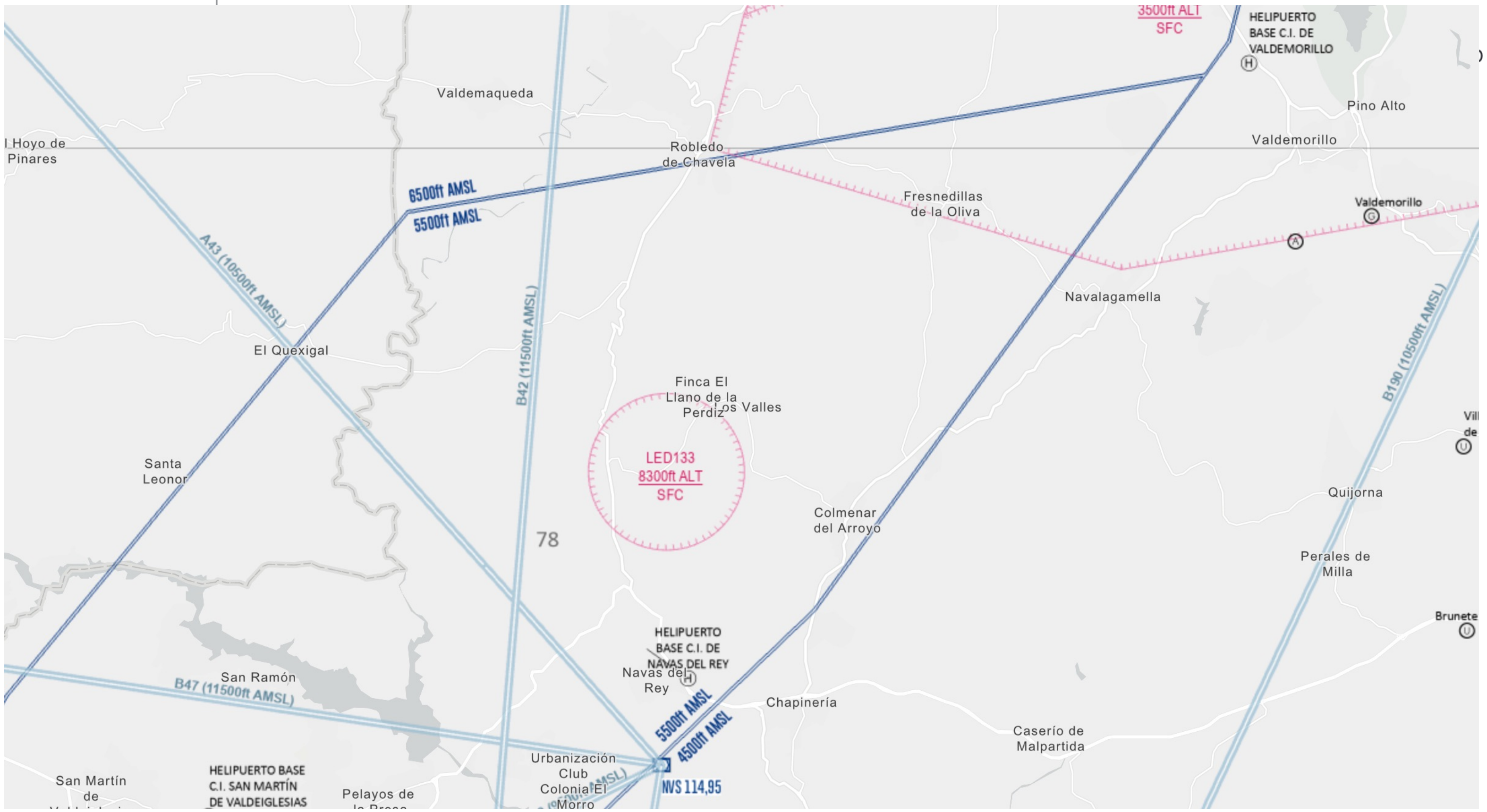
- At the same time, the antennas can produce some interferences in the area.

VILSPA ca. 1978 - src:wikipedia

Comms issues (III)

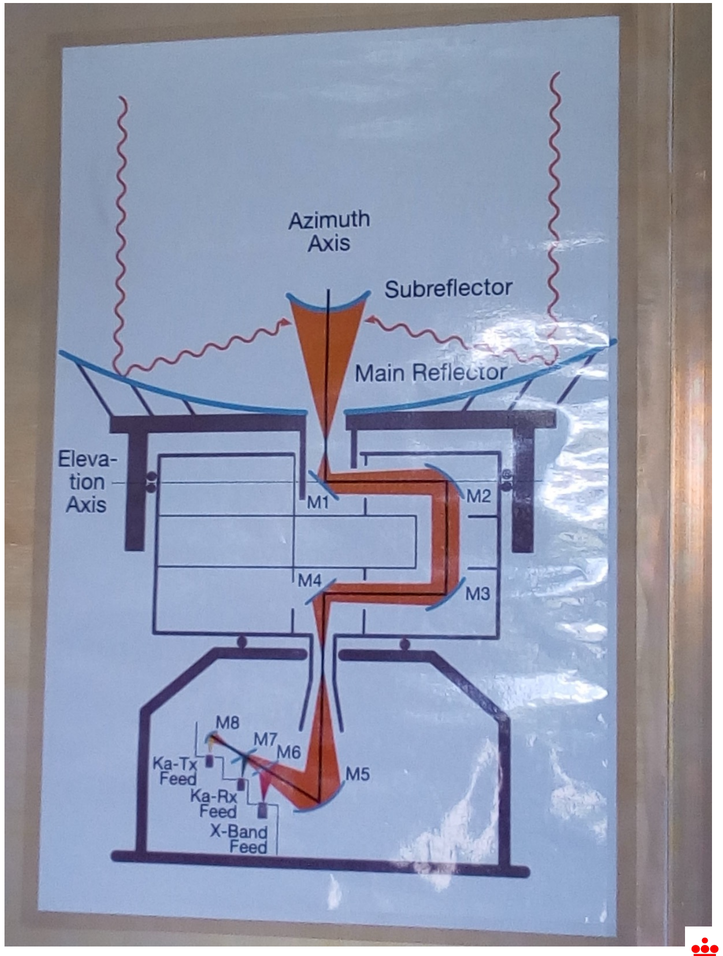
activities announced by NOTAM.

LED133 ROBLEDO DE CHAVELA (Madrid) Círculo de 1 NM de radio centrado en // Circle of 1 NM radius centred on 402552N 0041453W.	8300 ft ALT SFC	Actividad anunciada por NOTAM // Activity announced by NOTAM. Campos eléctricos radiales de alta intensidad // High intensity radial electric fields.

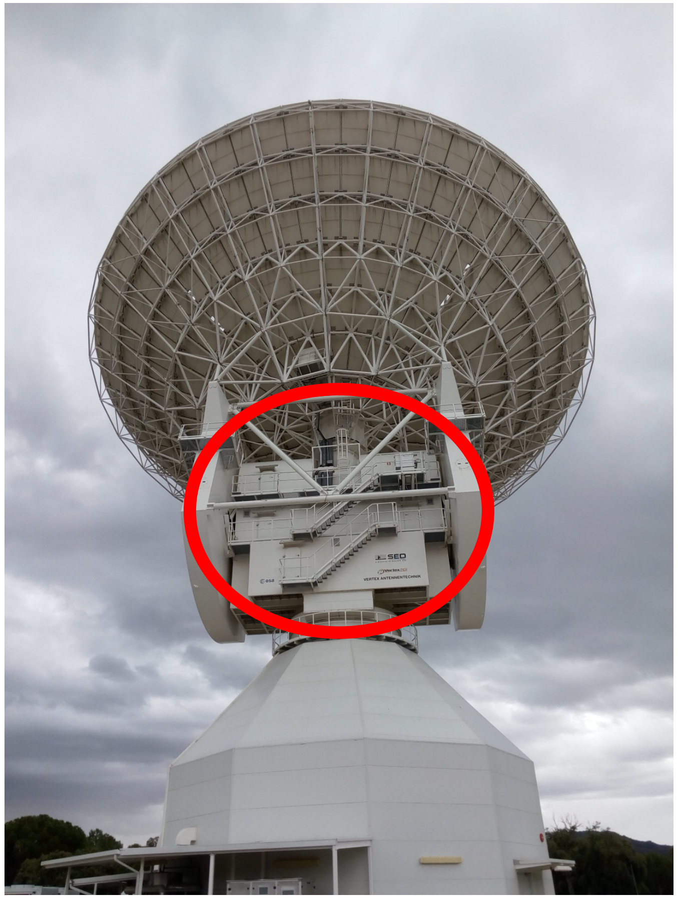


Deep Stations requirements

- Reliable communication with the spacecraft over **very large distances.**
- Very precise radiometric data.
- In turn, this requires,
  - Large dish (>35m diameter),
  - High-gain antenna, narrow beam width.
  - Consequently, high pointing accuracy requirements.
  - Sensitive receivers, powerful transmitters.
  - Advanced digital baseband technology.



Deep Space Network DSN -ESA



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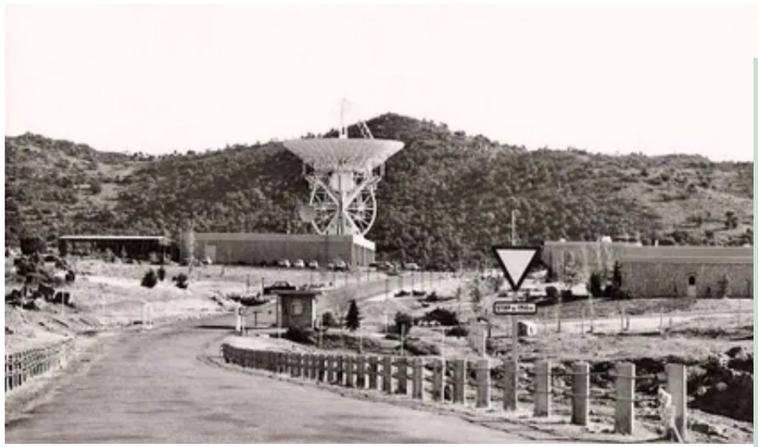
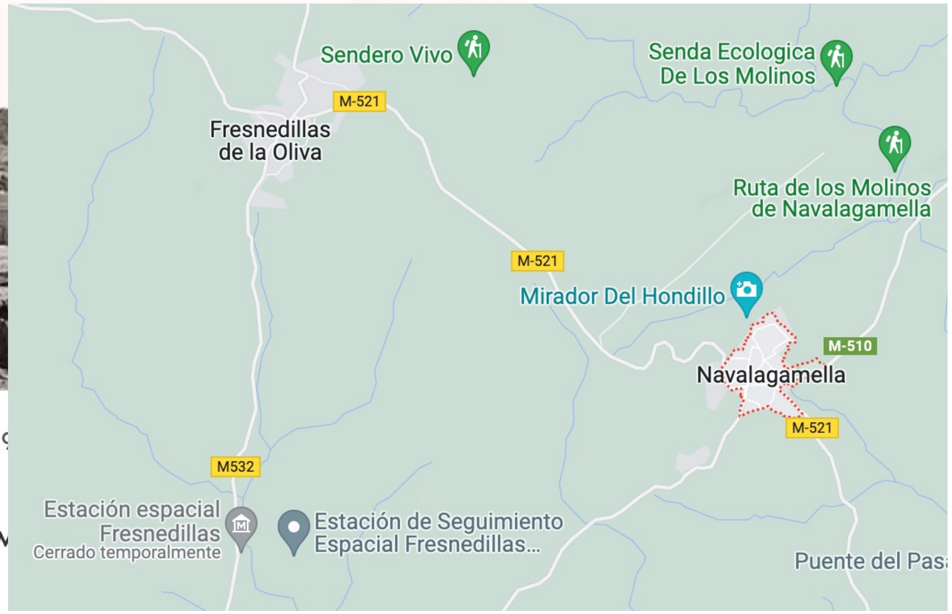
Historical Note

- NASA operations are also Spanish operations (!).
- Fresnedillas de la Oliva, first g/s in receiving Earth photo from apollo 8 and first in receiving **lunar landing** Neil Armstrong’s words (do not believe what some films say).



Carretera de acceso a la Estación Espacial de Fresnedillas en 19
26 metros y a a derecha el cartel original.

FOTOGRAFÍA DE LARRY HAUG, WIKIMÉDIA COMM



Deep Space Network DSN - NASA

- DSN services include:
  - Command Services.
  - Telemetry Services.
  - Tracking Services.
  - Calibration and Modeling Services.
  - Standard Interfaces.
  - Radio Science, Radio Astronomy and Very Long Baseline Interferometry Services.
  - Radar Science Services.
  - Service Management.

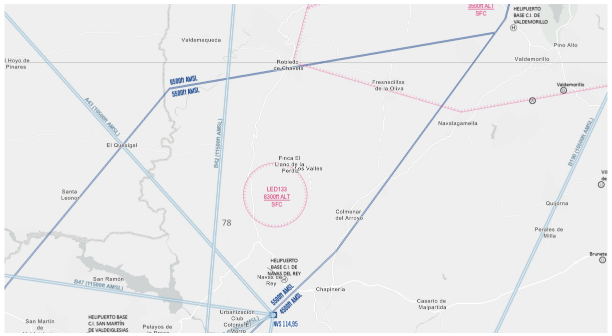
Table 11-6: DSN Customers, Mission Characteristics, Frequencies, and Services

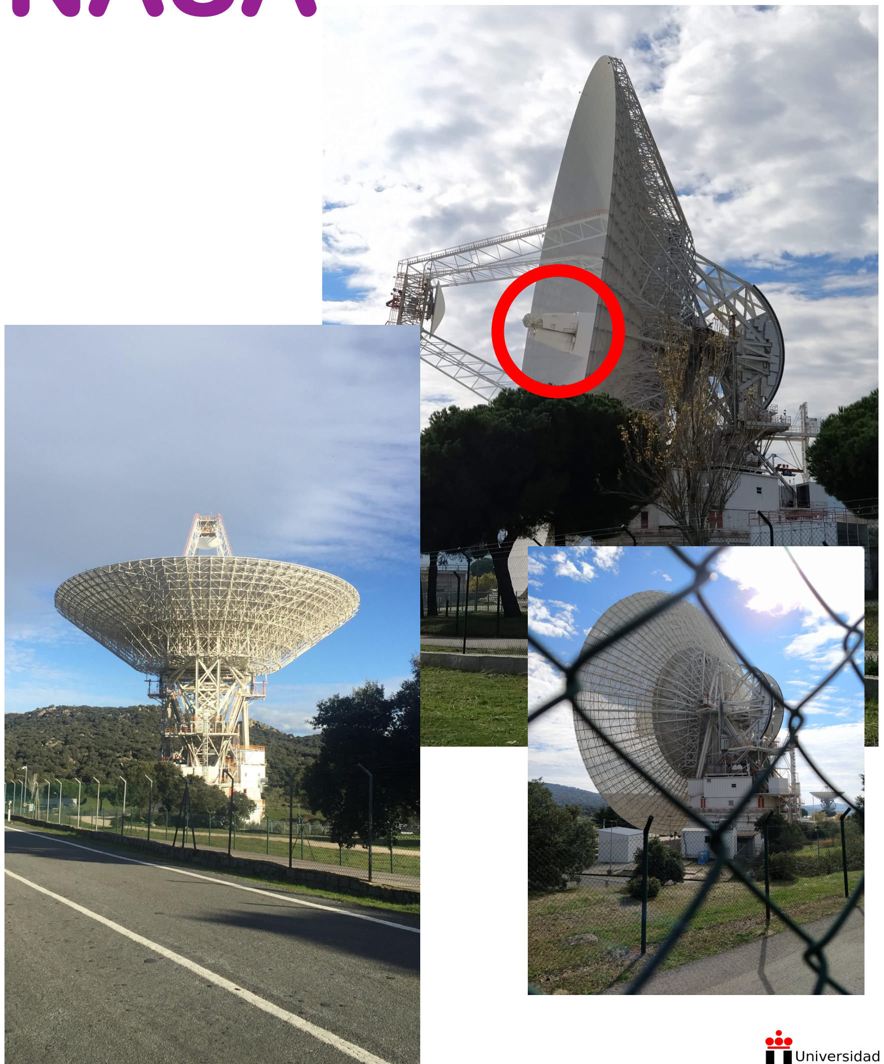
Customers NASA Other Government Agencies International Partners	**Mission Phases** Launch and Early Orbit Phase (LEOP) Cruise Orbital In-Situ
Mission Trajectories Geostationary or GEO HEO Lunar LaGrange Earth Drift Away Planetary	**Frequency Bands –** Includes Near-Earth and Deep Space Bands, Uplink and Downlink, Command, Telemetry, and Tracking Services S-Band (2 GHz) X-Band (7, 8 GHz) Ka-Band (26, 32 GHz)

Src: NASA, nasa.gov

Robledo Deep Space - NASA

- Madrid Deep Space Communications Complex (MDSCC) has eight large parabolic antennas.
- DSS-63 weighs 8000 tons, 70m diameter.
- DSS-63 has a reflecting surface of 4,180 square metres. Operators need solar protection!





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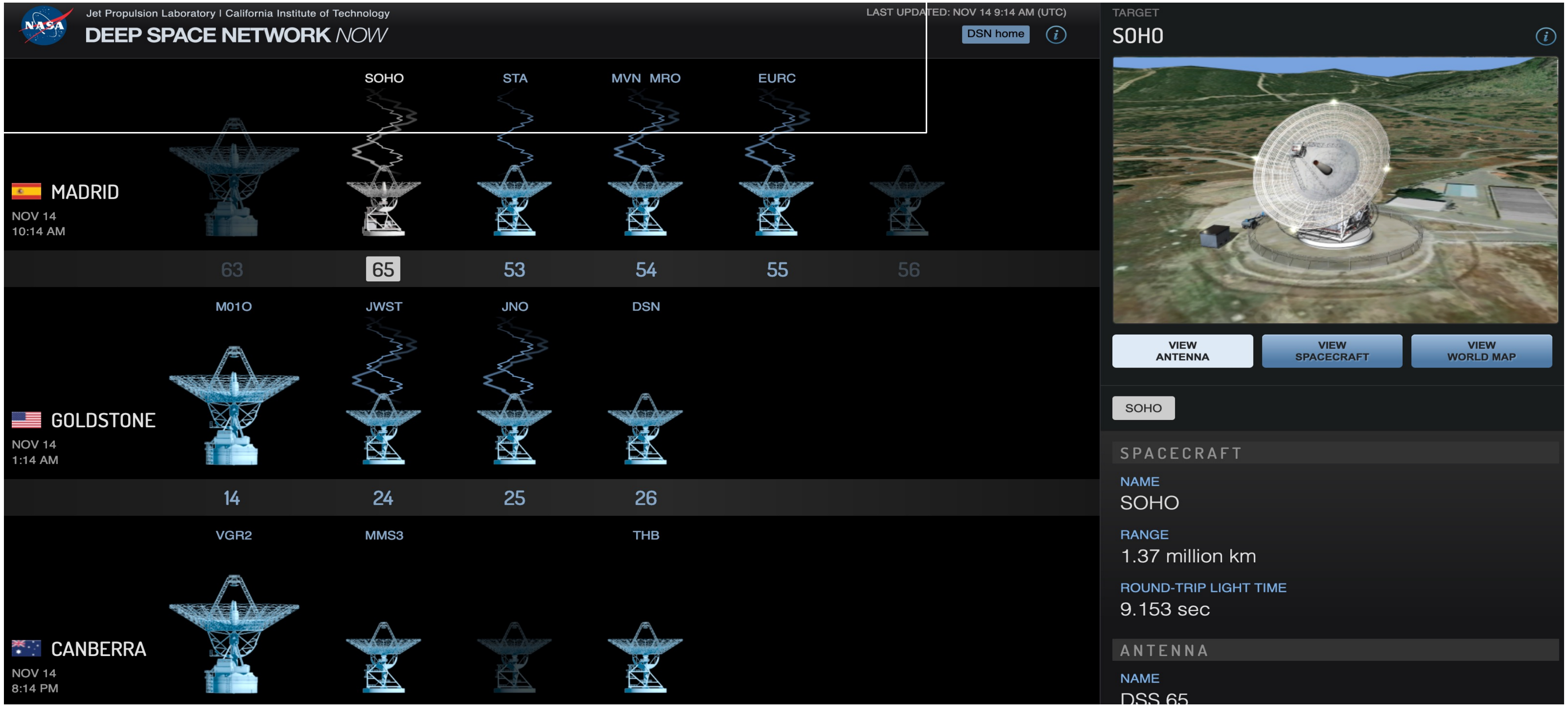
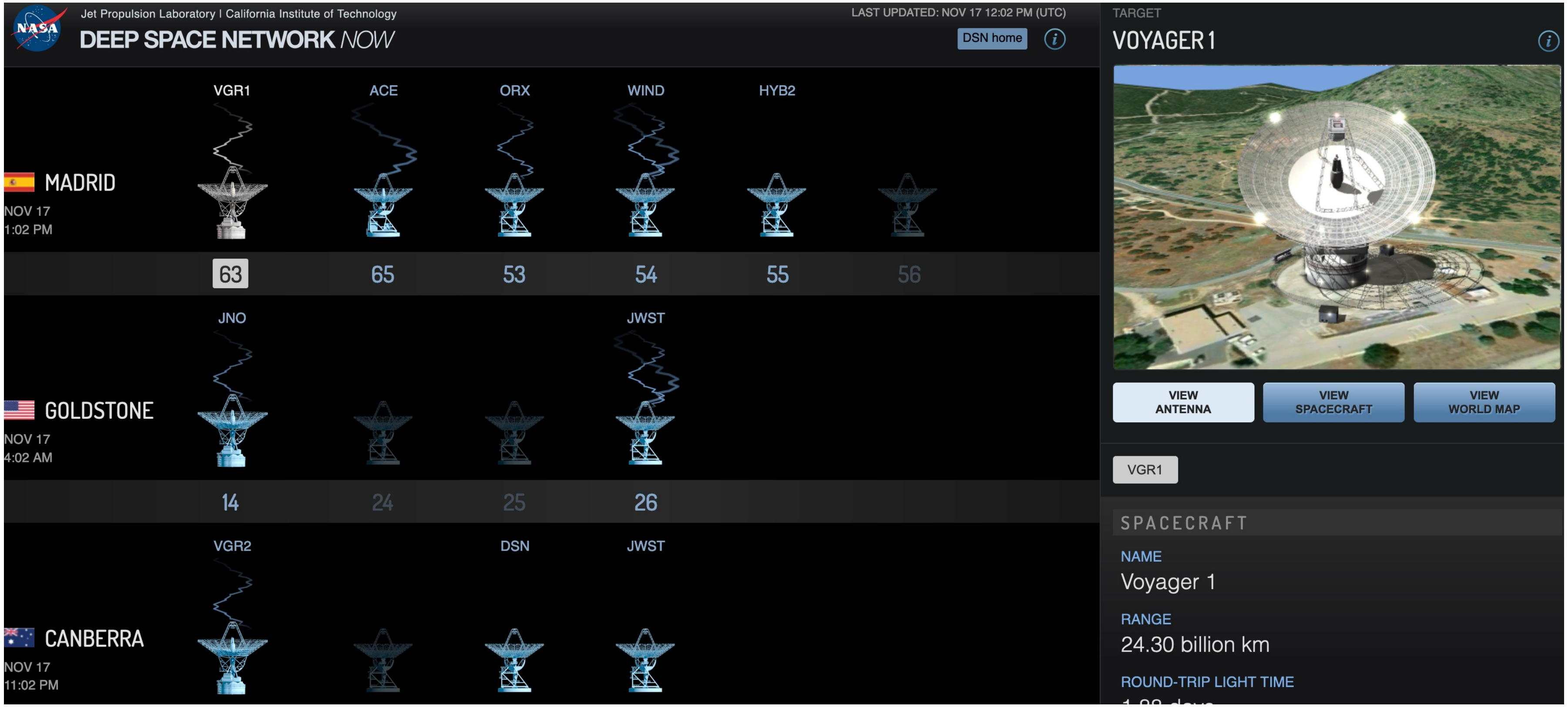
Robledo Deep Space - NASA

- https://eyes.nasa.gov/dsn/dsn.html



Robledo Deep Space - NASA

- https://eyes.nasa.gov/dsn/dsn.html



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Spanish footnote

- Private consortia conduct operations of Spanish governmental satellites.

- MoD pays for a service within a frame contract.
- MoD oversee for industrial return and service provision.
- MoD is not the operator.

- Just some examples…

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Hispasat

- Four Control Centers (Arganda del Rey, Tres Cantos, Las Palmas y Flamengo).
- There are other g/s for TM/TC and monitoring (Maspalomas/España, Guaratiba/Brasil, Balcarce/Argentina, Ciudad de México/México, Bogotá/Colombia, Arica/Chile, Laredo/USA y Hauppauge/USA).

Src: https://www.hispasat.com/es/flota-de-satelites/centros-de-control

Hisdesat

- Two main control centers located in geographically separate areas,
  - Madrid-Arganda.
  - Gran Canaria-Maspalomas.
- TTC stations and antennas in two different bands (X and S).

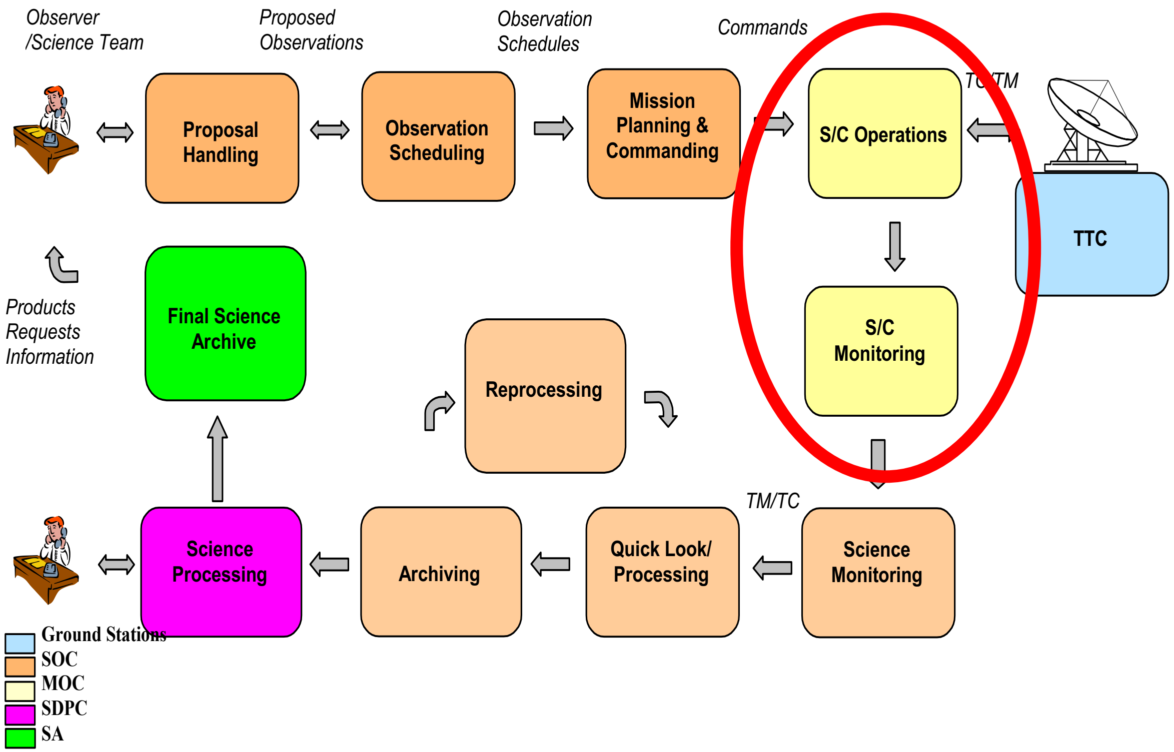
- Otawa G/S for Xtar-Eur.

Src: https://www.hisdesat.es/en/segmento-terreno/

Src: Satnews/ESA

Control Centers

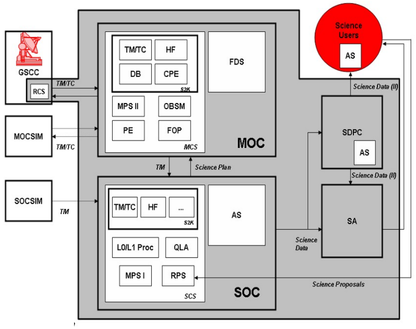
Mission Control Center (MOC)



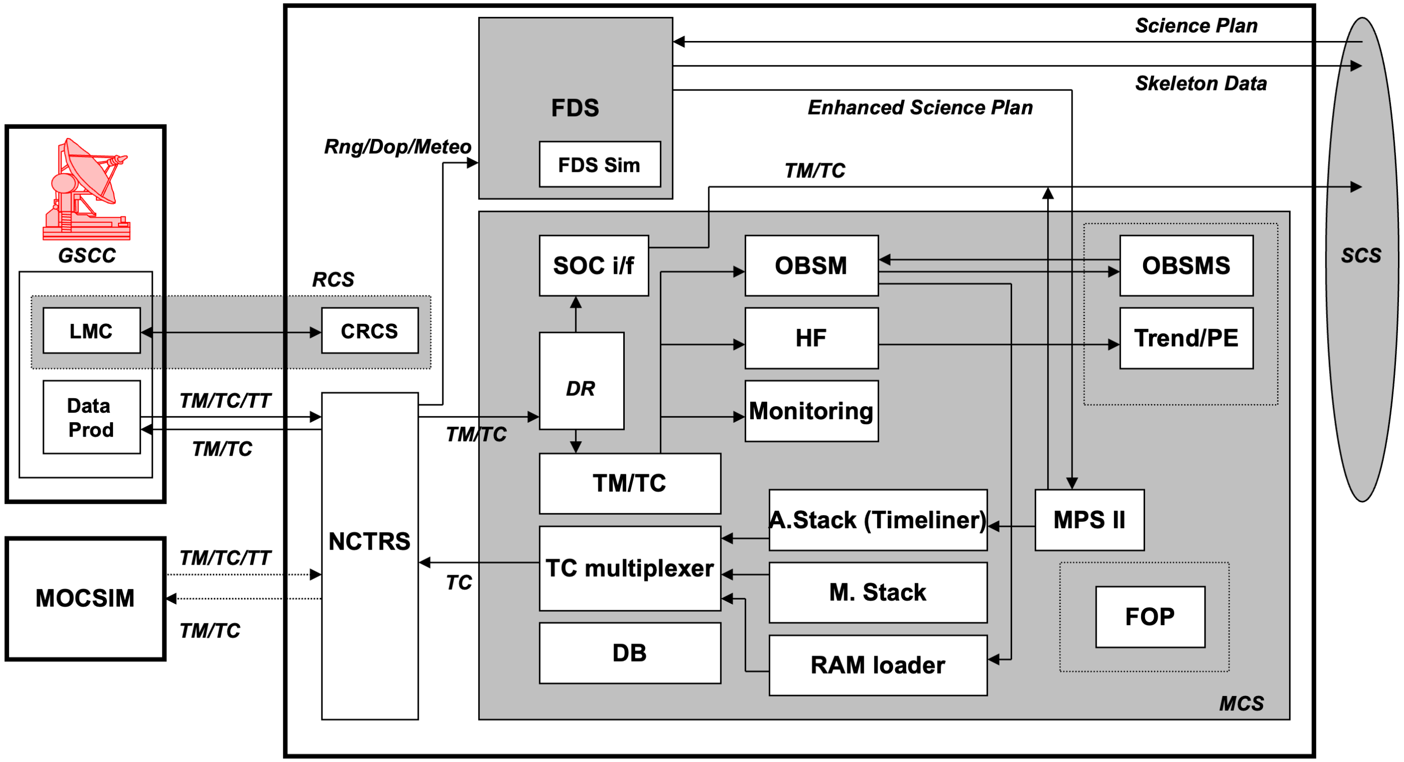
Mission Control Center (MOC)

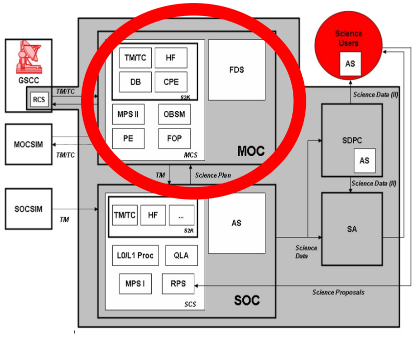
- The Mission Control System (MCS).
- The Flight Dynamics System (FDS).
  - EU FDS!=RUS FDS, the 'Ballistic Center'
- The Ground Network Control Centre.
- The Data Disposition System (DDS), which provides controlled access to spacecraft related data to MOC external users.
  - Old-days, ops networks fully isolated.
  - Nowadays, layered networks.

- We will see some of these elements (not all at all!)



MOC data flow

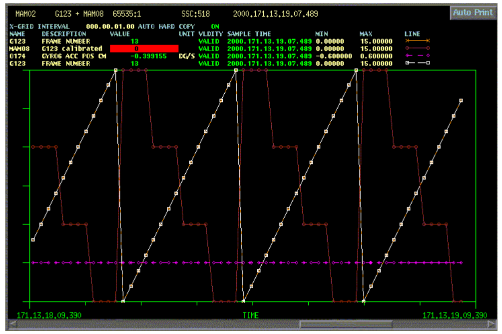


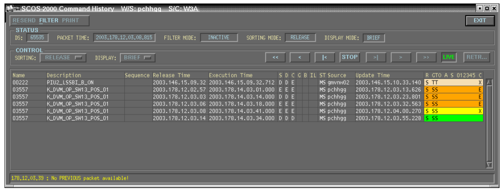


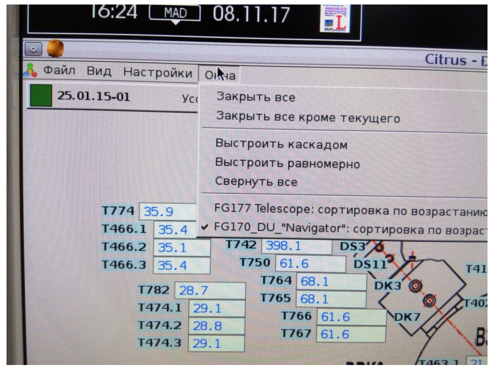
MOC data processing

- Platform monitoring, HK TM.
- Mission Planning Phase II/TC uplink.
- Downlinked/Real time TM.

- Derived Parameters.
- Trend analyses.
- Statistical reports.
- Quality reports.







ESOC

- European Space Operations Centre.
- Engineering teams that control spacecraft in orbit, manage tracking station network, and design/build/operate the MOC systems.
- Main control room for critical phases.
- Mission dedicated rooms for routine operations.
- The human factor: COVID19 handling.

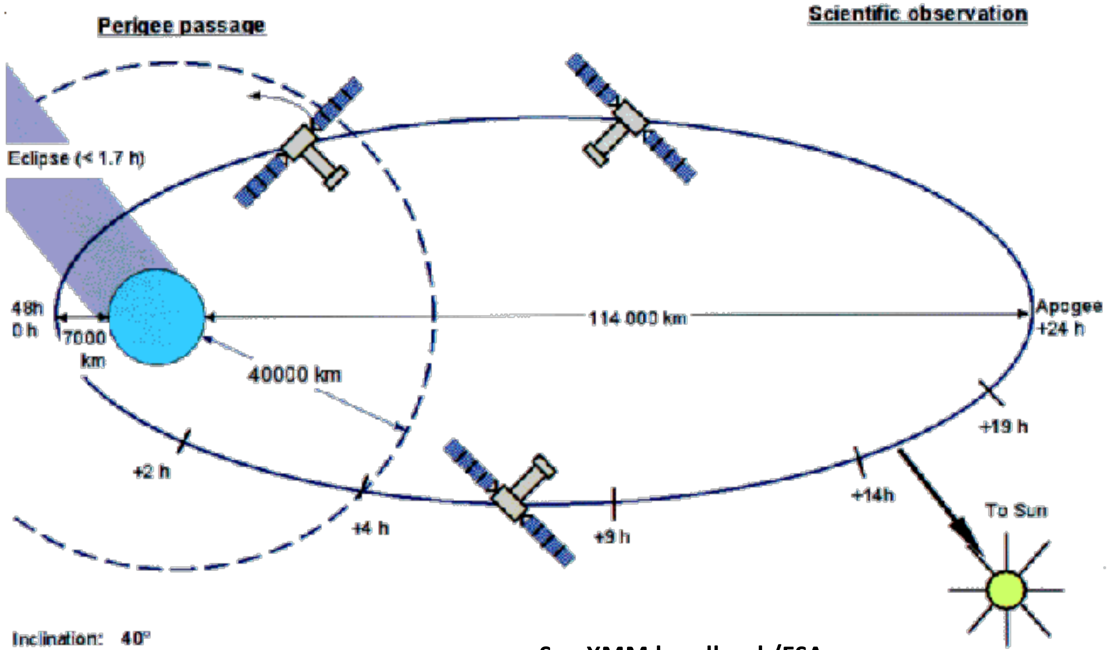
Src: ESA

ISS Control Centers

- ISS has two Flight Control Centers, Houston and Moscow.

Flight Operations Plan

- The sequence of operations conducted by the controller, the sequence of all FO procedures.
- Example: what/when to do for avoidance of radiation belts: close instruments, check TC were ok, what to do if not, …



Src: XMM handbook/ESA

OBSW management

- SW handles system complexity
- Flight SW implements critical space system **requirements**,
  - Mission and vehicle management (Spacecraft Modes and Mission Management, Failure Detection Isolation & Recovery).
  - Management of vital subsystems (e.g. AOCS, power and thermal control).
  - Acquisition, processing and distribution of payload data.

Emergency autonomous handling (ISAM mode)

OBSW management (II)

- Storage and On-board processing vs limited downlink capabilities/passes resources. Hence, it can increase mission planning efficiency.
  - **Huge dedicated control rooms are not required any longer!**
- Increasingly complex missions require on-board autonomy provided by SW.
  - Remote planetary explorations.
- The only part of the spacecraft that can be modified after launch.← hence, included in this talk.

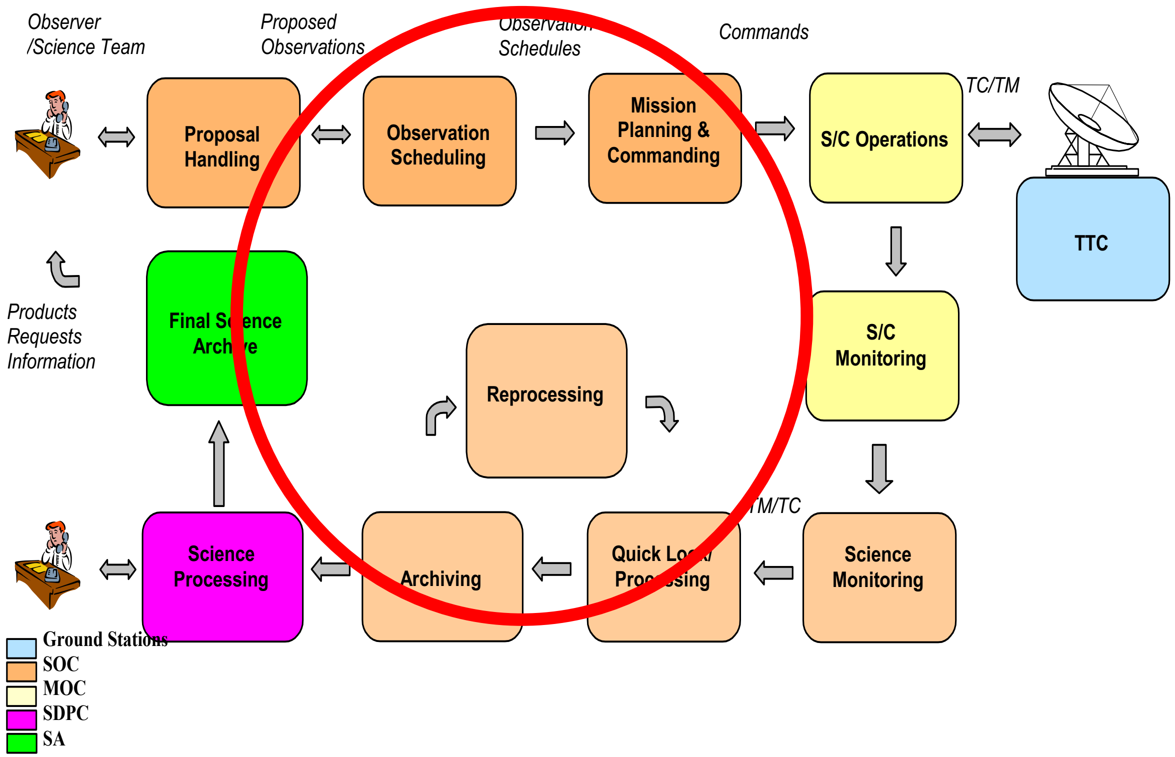
SW aspects unique to space segment

- Finite Processing Power and Memory (embedded) from radiation hardened processors.
- Longlife missions -> obsolete hardware.
- Timing constraints (real-time)
- Single Event Upsets, affecting Memory and Databus Communications.

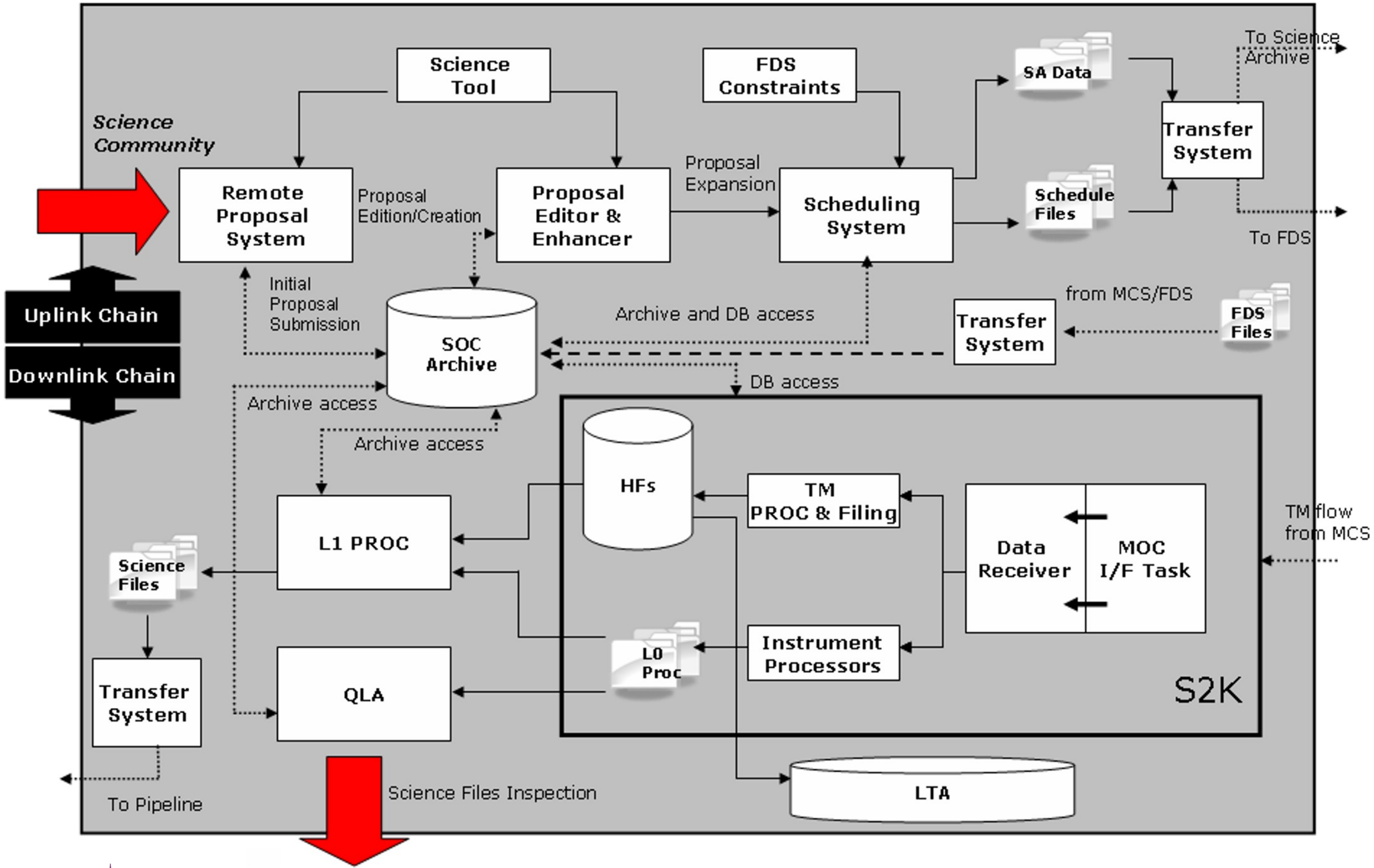
Src: Wikipedia

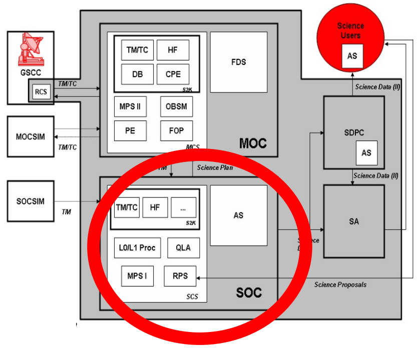
- Software is Critical to Mission Success:
- On-board SW Patching (and Dumping) allows to solve contingencies (example: 1991 Galileo probe high gain antenna deployment failure, after hammering the s/c patched for low gain antenna rate increase x100).
- Better validate before (see A501 flight slide).

Science Control Center (SOC)



SOC Data flow

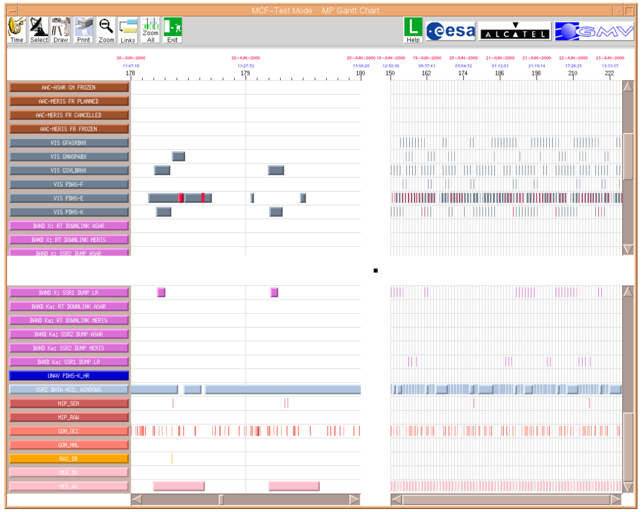


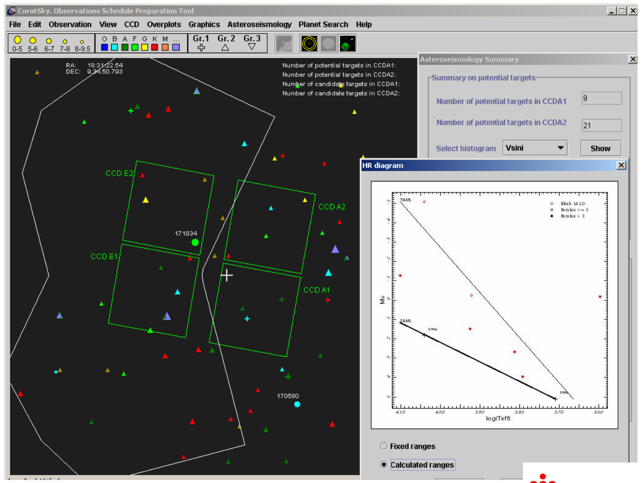


SOC Data Processing

- Science Operations System (SCS).
- Payload Monitoring System,
  - Parameter Derivation.
- Payload Pipeline Processing,
  - Level L1(/L2).
- Analysis System (AS).
- Quick Look Analysis (QLA).
- Quality Control.

- Event and Anomalies Logs for science observations (r/t, s/w, …).

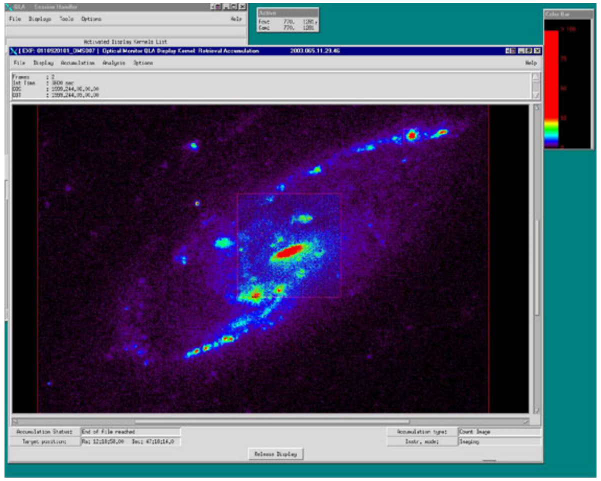


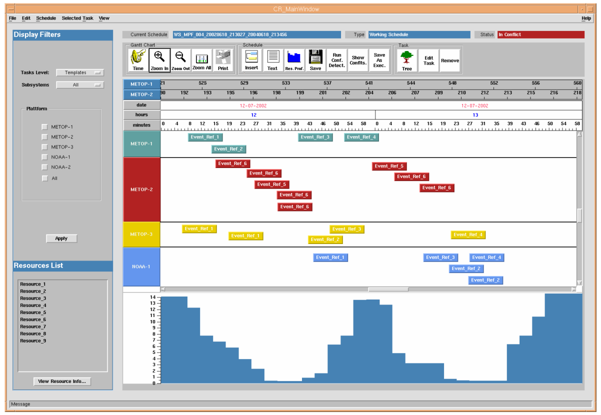


SOC Data Processing (II)

- Science Reprocessing for,
  - Fix s/w or r/t anomalies.
  - Improvements of calibration or s/w.
- Trend Analyses.

- Archive and Dissemination.
  - Multi-mission, multi-messenger archives.
  - See dedicated slide later on.





Mission Planning (SCS)

- It is not Mission Analysis.
- MP is different if astronomical or surveyor or planetary (incl. EO) or r/t mission.

- …**aims to produce (science) TC sequences** to be sent to MOC, where timelines are produced.

- Note aside: IUE was controlled with joystick! Like a ground telescope at that time.

Mission Planning (II)

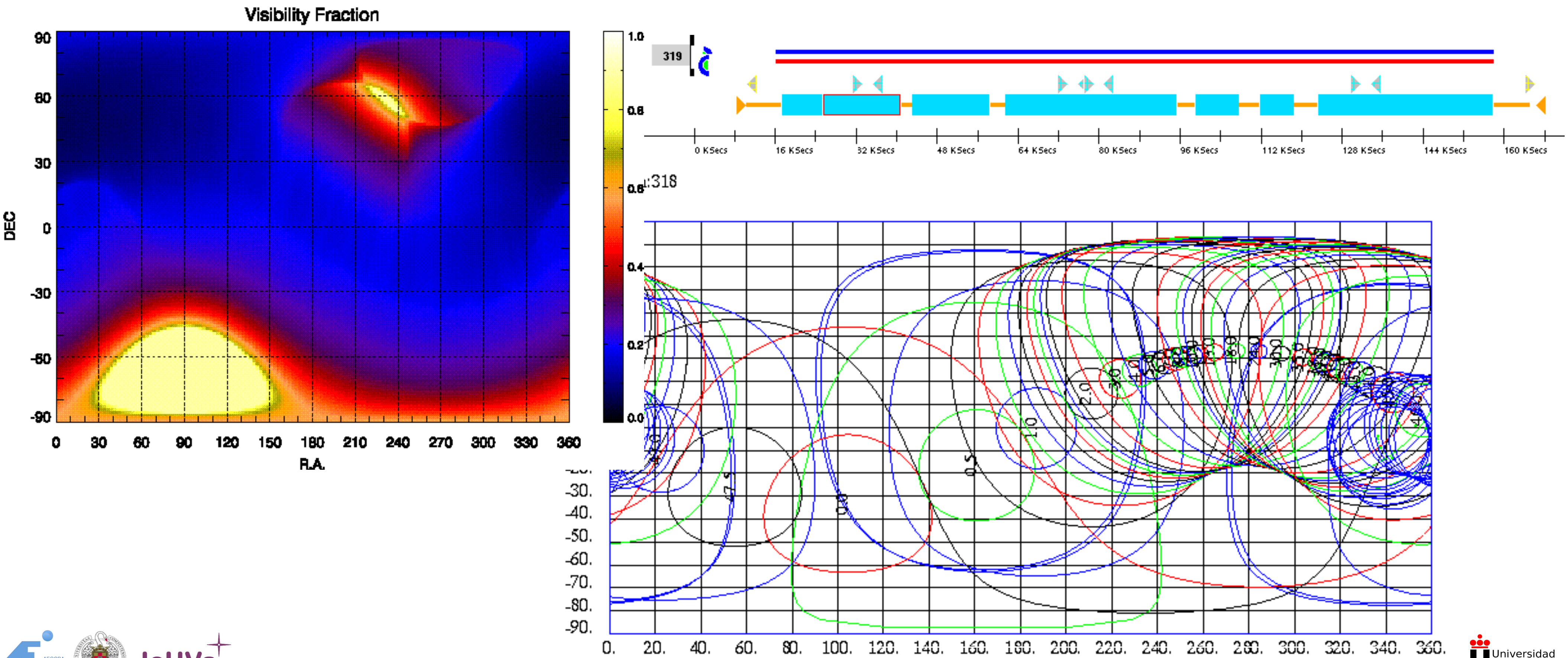
- Hence, observation planning must take into account many factors,
  - Downlink passes? Bandwidth limitations?
  - Visibility G/S constrains? Memory constraints? Other resources limitations?
  - Astronomical constraints? Sun aspect? Position angle? (OM-> burnt!)

-Too Handling is another issue. Reaction time is key.

-Anticipated ToO are also tricky!

-Coordinated observations with other observatories increase the challenge!

Mission Planning (III)



Src: A guided tour to the scheduling of an XMM-Newton orbit/ESA

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EGSE

- Aims for integration of subsystems, payload, spacecraft.
- Measures and records spacecraft performance parameters for,
  - Solar Array Power Simulator (SAPS) & Battery Power Simulator(s).
  - RF / Telemetry, Telecommand & Ranging front end equipment.
  - Data handling.
  - Attitude / Orbit Control Equipment.
  - Experiment / Instrument / Payload Checkout & Processing Equipment.
  - Overall processor / coordinating computer.
- Allows **functional checkout and performance test** on the spacecraft, **both in development and when in-flight.** Allows testing of new procedures.
  - h/w simulators supported by s/w simulators.
  - (See Apollo 13 film).

Data Operations

Data Processing Levels

- **Level 0,** Raw TM.

- **Level 1,** Level 0 data cleaned, consolidated, chronologically ordered and packetised.
  - Level 1a, per instrument classified.
  - Level 1b, per instrument mode and in scientific format.

- **Level 2,** Calibrated and corrected, in proper scientific units.

- **Level 3 ,** final products, ready for scientific research.

TFG-TFM, not difficult but handle with care!

Data Processing and Archives

- The data processing facilities provide final user the mission products, accompanied of ancillary data and any data required for science research (L2/L3).
- SCS produces Quality Reports / Data Screening reports.
- SOC typically provides (Interactive) Analysis Systems for final user, strongly based on Automated Processing Facilities (Pipeline).

- The (Final) Archive is responsible for storing, maintaining and distributing all that mission data.
- It is not a bare repository, it provides additional services.
- It is the legacy of the mission, and allows downloads years after decommissioning…

Data Operations

Photo credit: Procolotor / Wikimedia Commons

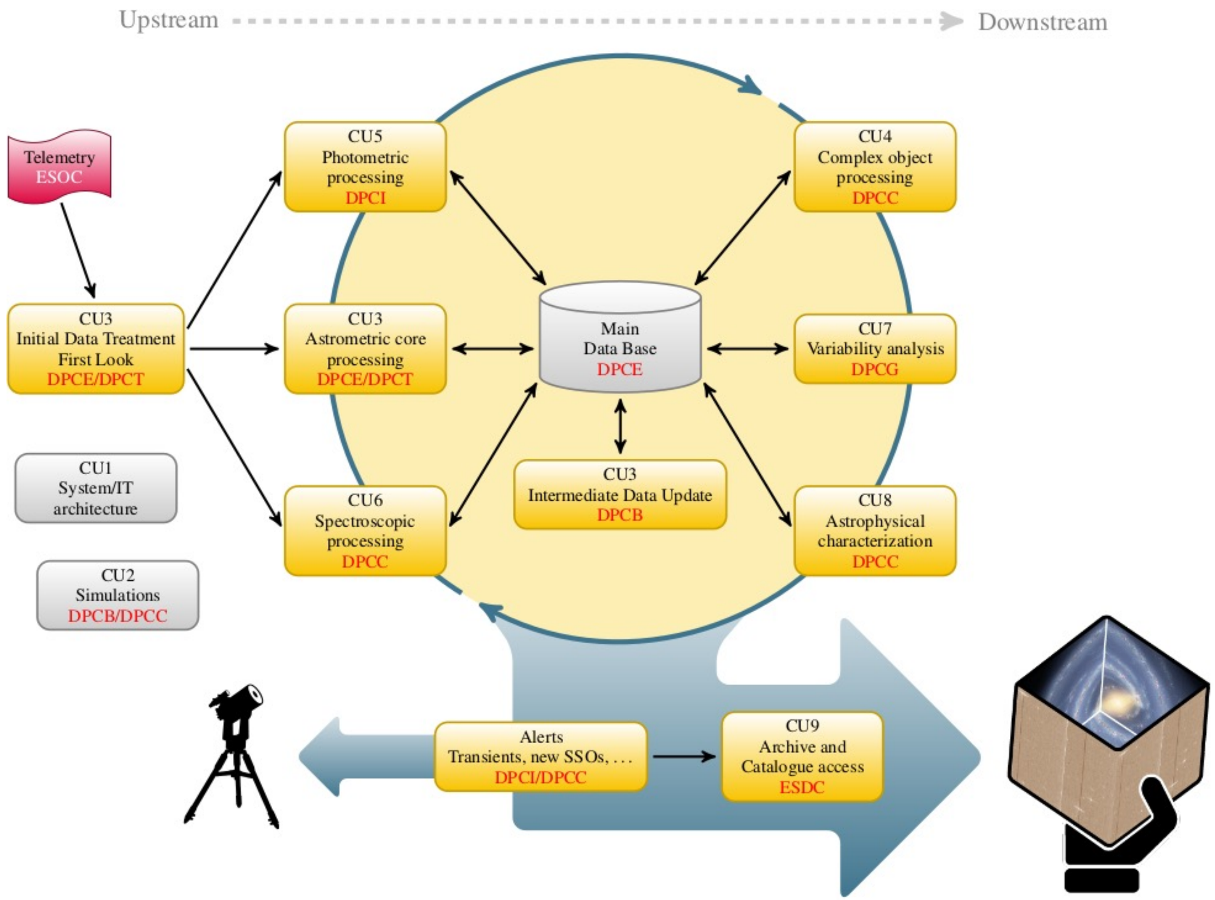
Src: NY Times/Connie park

Src: Wikipedia

Huge Data Operations

- Sometimes really complex because of size.
- GAIA requires distributed RDBMS, filesystems, …

- Sometimes much simplier…

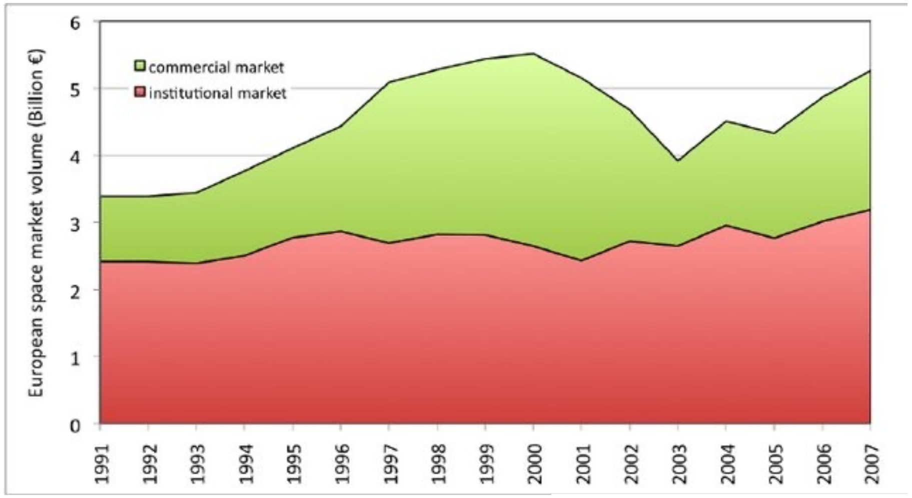


Src: https://www.cosmos.esa.int/web/gaia/dpac /ESA

The New Space

The New Space

- We can divide the evolution of the space sector, with emphasis on space business, in three phases:
- **Phase 1:** Government driven space economy (1950 – 1970)
- **Phase 2:** Commercial space (1970 –now)
- **Phase 3:** New Space (2000 – present).



Src: Suymmerer (2011)

- It is a broader scenario involving dozens of national space agencies, space commissions, **industry, academia and private companies**, distributed throughout the globe.

Small G/S

- G/S get smaller and smaller,
- Even affordable for the individuals.

Src: The AMSAT Journal, November/December 2019

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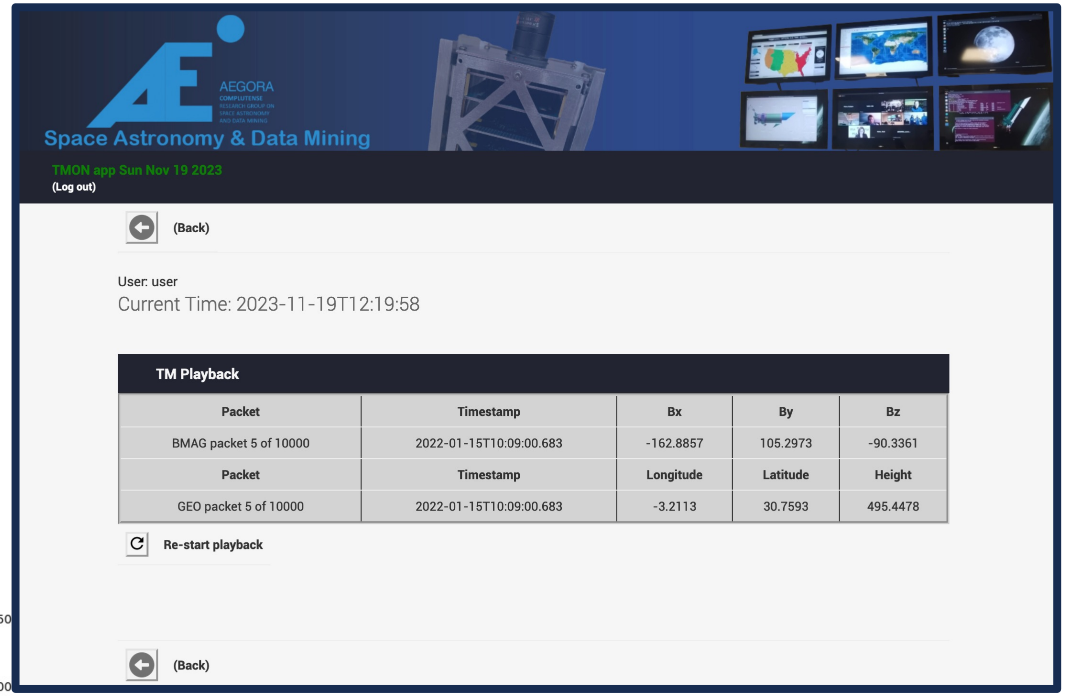
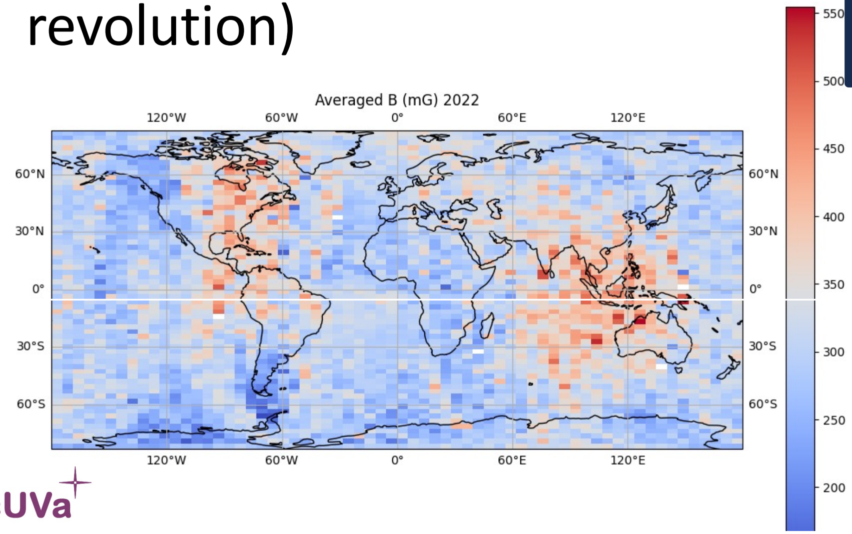
Efficient G/S

- Available open sw for cubesat data processing allows final processing,
  - Mission Analysis (GMAT).
  - Orbit prediction libraries.
  - Image Processing.
  - (see Lesson #4, the cubesat revolution)

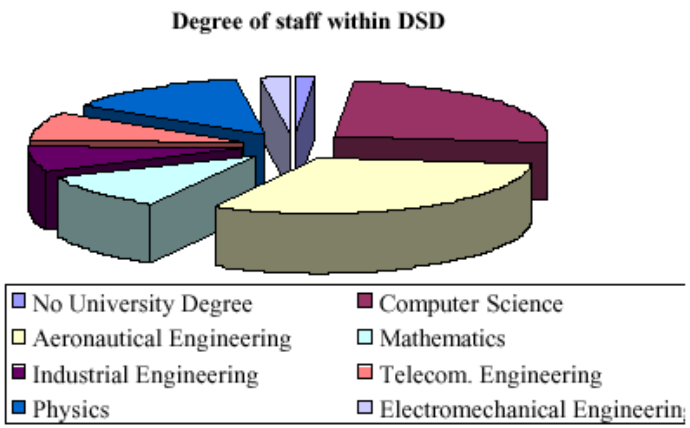




Staffing – the human factor

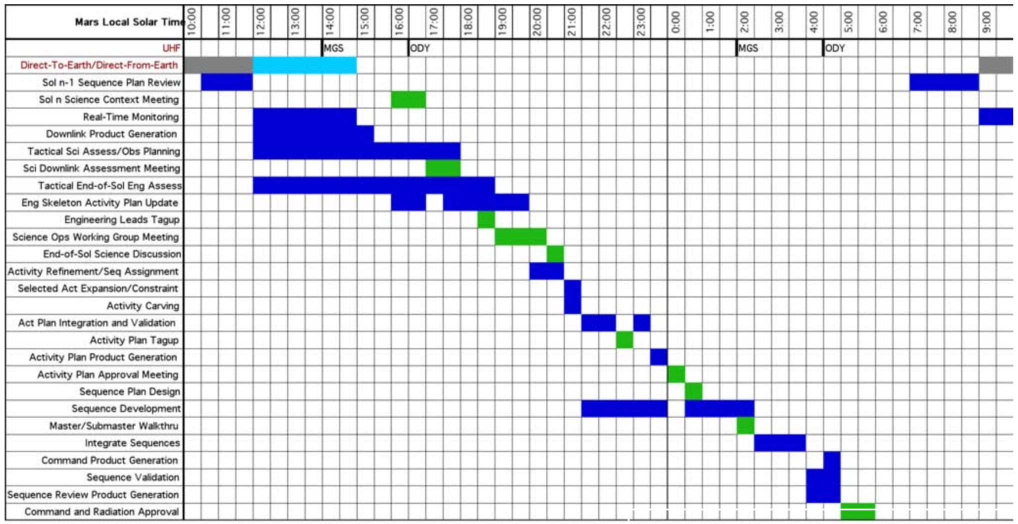
Interdisciplinary teams

- Different profiles required in each area,
  - Management, Flight Control.
  - Mission Analysis, Flight Dynamics.
  - Software Support, Computer Support.
  - Science User Support.
  - Operators (SPACON, INSCON, Computer).
  - Platform/Payload engineers.
  - Data Processing Operators.
  - Science Archive Engineers and Scientist.
  - …
- Public relations, Outreach, site management/support…



Mars Exploration Rover

- Early in the development, MER management launched a study to help determine whether to use Mars Time staffing.
- They were looking for an optimal operations schedule for coordinating the work of two hundred and fifty mission personnel on Earth who would be operating dual rovers on Mars.



Src: Bass D., Choosing Mars Time

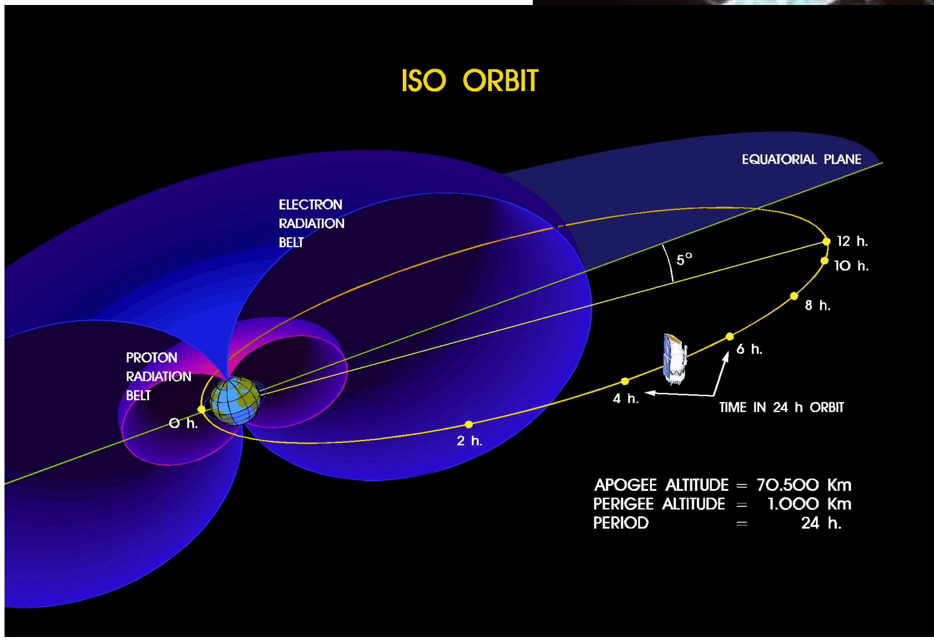
Mars Exploration Rover (II)

- Mars Time staffing plans consistently scored better than Earth time for:
  - Ability to command every sol.
  - Optimal time utilization, conservation of margin.
  - Response to off-nominal situations.
  - Maximized potential mission return.
  - Little or no cross training required.
- However, Mars Time staffing plans scored lower in sustainability, resulting in the following conclusions,
  - Mars Time staffing requires more crews to sustain extended duration operations.
  - Straight Mars Time can be sustained for short duration (<30 sols).

IUE, ISO, XMM

Src: Science Exploration / ESA

- IUE shifts followed IUE orbit.
- ISO shifts were fixed in time.
- XMM (r/t mission) does g/s maintenance at perigee.



Src: ESA multimedia

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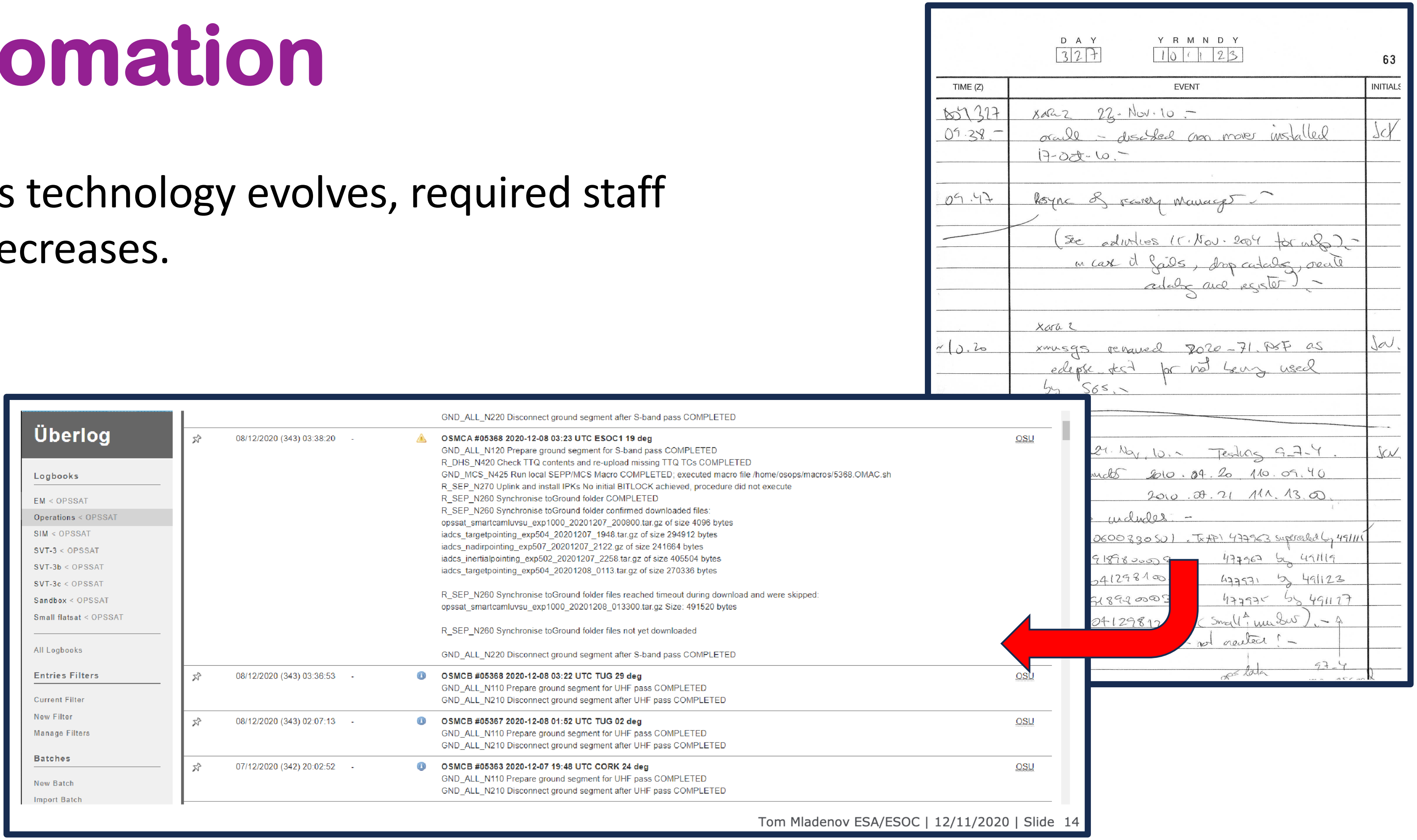
Automation

- As technology evolves, required staff decreases.



Automation (II)

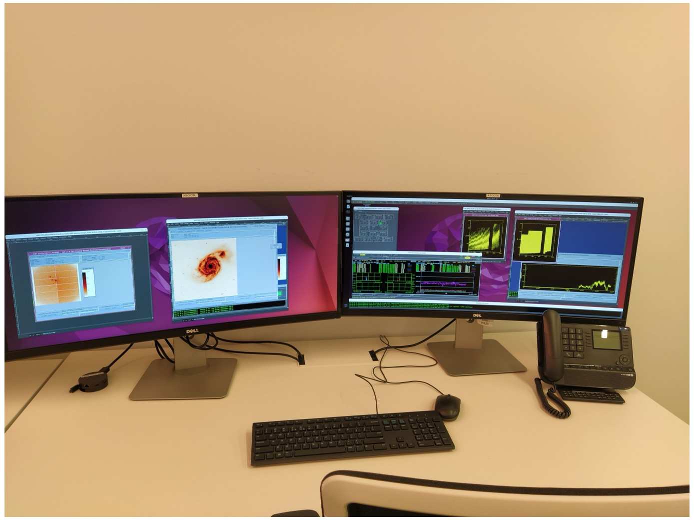
- Costs are reduced. There are even dedicated workshops, the RCSGSO-> automation vs closures.
- It is a natural evolution,
  - ESOC, SPACON for XMM, for INT+XMM, for GAIA+INT+XMM
  - ESAC, INSCON+SPACON->INSCON-> Data Aid-> Automated.
- SPACON for Eutelsat.

Src: Blen Gleze / http://www.conniesurvivors.co

Src: https://aircraft.airbus.com

Automation (III)

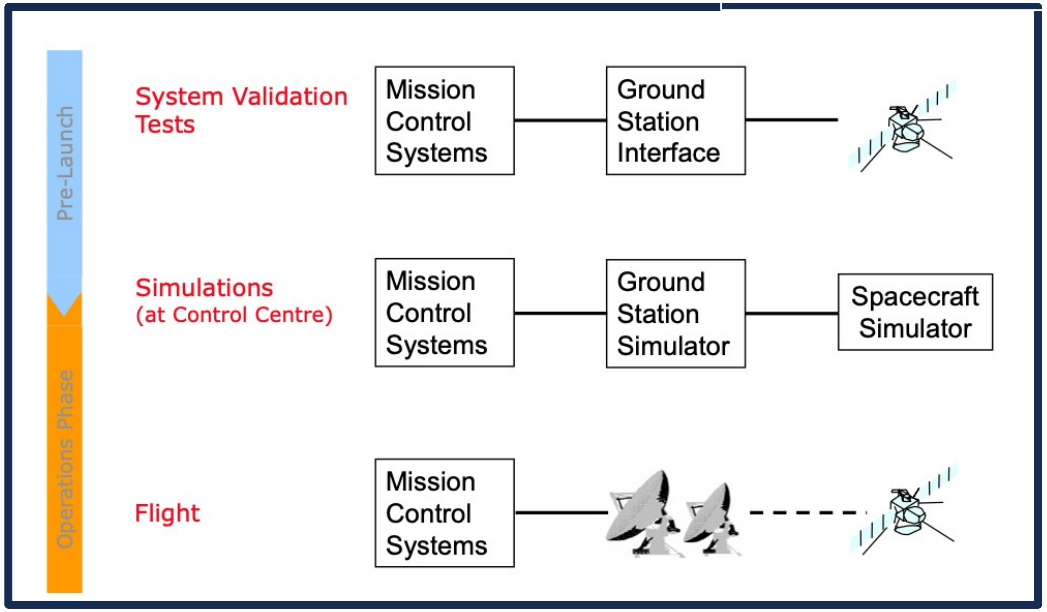
- IA can be (and is being) applied to all procedures, see lesson #5
  - Routine checks, Mission planning, Helpdesk, On board handling (including ISAM emergencies!)
- IA is easier to apply in some missions/areas than others! But it is evolving…

Validation and training

- **Validation** is required on the procedural/automated tools side.
- **Training** is required on the human side (and IA too!).

Src: P.Ferri/U.Southampton/ESA 2014



- Validation and Simulations were key issues at Lunar landing and Apollo XIII!

Training

- Simulations.
- Cross-training.

esa european space agency

esoc (european space operations centre)

Memorandum ref.: TOS-OFC/ISO/385/JF/vi Villafranca: 12 March 1998

From :

To :

cc :

Subject-1: IDCS Restart Procedures.

The recently experienced Uplinker Task abortion in REV-837 (980302) created some confusion about the proper recovery of the IDCS (ISORT) under these circumstances. The following is a brief description and guideline indicating the agreed steps to be undertaken and by whom, in order to return the IDCS (ISORT) back into operation.

1. In case of an anomalous behaviour of the IDCS (ISORT), SCC-SPACON is requested to report the anomaly and any evidence (symptoms of failure) to the VCS Computer Operator (CO). During normal working hours the CO will advise Software Support (S/S). Jointly, they will attempt to recover the system, else during non-working hours CO will proceed on its own with the recovery, attempting to restart the IDCS as per available procedures provided in the Computer's Guide, informing SCC-SPACON about the sequence of activities, as follows:

1.1 Restart Individual Task(s) of the IDCS (ISORT).

If the above method returns the IDCS (ISORT) into operations, no further action is required beside reporting the problem with all possible evidences to S/S.

Note: 1 minute is required by CO to restart an individual task.

If re-starting of individual task(s) does not cure the anomalous behaviour of the IDCS (ISORT), CO will proceed with the next step.

1.2 Perform a Warm Restart of the IDCS (ISORT). SWS_08 (Proc. 6)

If the warm restart returns the IDCS (ISORT) into operations, no further action is required beside reporting the problem with all possible evidences to S/S.

Training working note

- 4 -

Problem Solving #2

Revision 1.00, 21 Feb 1996

SPACONs inform that they don't receive any TM. They get a message such as "LINKCONF: MBXE Mailbox IZZL_DRECEIVER_MB not available" when they try to reestablish or disconnect the TM link.

EXEC shows that the tasks "RECEIVER" and "TLM PROC" are not running. Place the cursor on the receiver task and press "R" to restart it. The TM processing task is not individual, one must run the "TLM_PROC_RESTART" procedure. The SPACON must be informed as detailed in the procedures. TM and TC links have to be restablished. For that the LINKSET task that was previously actived must be restarted to allow the creation of the mailboxes.

PROBLEM SOLVED

SPACONs inform that nothing works.

Well, in fact the whole system is down. HALT finishes everything; we get some errors at the end about files till open such as "[ISOOPS.DDB]DDBM_TABLES.GSC" (a global section). BOOT WARM fails to restart the buffer manager.

The thins is that there is a user (Matty) logged in. He is running this buffer monitor utility which maps the buffer manager global section. Upon boot, the buffermanager fails to remap its GS as it is mapped by another process. WHO givs wh is on as well as the PID of the session. STOP PROC/ID=PID kills it. After another BOOT WARM everything works fine again.

PROBLEM SOLVED

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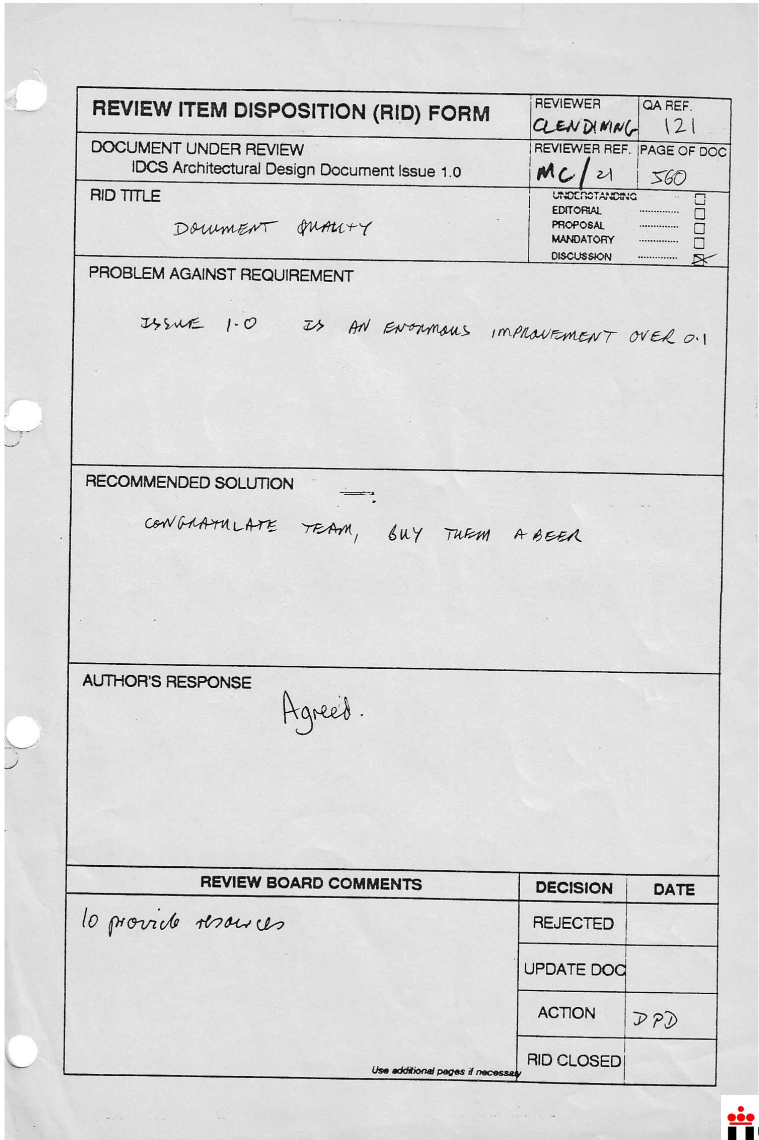
Validation

- See other talks for engineering procedures and standards.
- SVVT/ST, CoCo, CCBs, RIDs, meetings,…
- Not always is boring ….



REVIEW ITEM DISPOSITION (RID) FORM

REVIEW ITEM DISPOSITION (RID) FORM	REVIEWER: CLENDINING	QA REF.: 121
DOCUMENT UNDER REVIEW: IDCS Architectural Design Document Issue 1.0	REVIEWER REF.: MC/21	PAGE OF DOC: 560

RID TITLE: DOCUMENT QUALITY

UNDERSTANDING ☐ EDITORIAL ☐ PROPOSAL ☐ MANDATORY ☐ DISCUSSION ☒

PROBLEM AGAINST REQUIREMENT

ISSUE 1.0 IS AN ENORMOUS IMPROVEMENT OVER 0.1

RECOMMENDED SOLUTION

CONGRATULATE TEAM, BUY THEM A BEER

AUTHOR'S RESPONSE

Agreed.

REVIEW BOARD COMMENTS	DECISION	DATE
To provide resources	REJECTED	
	UPDATE DOC	
	ACTION	DPD
Use additional pages if necessary	RID CLOSED	

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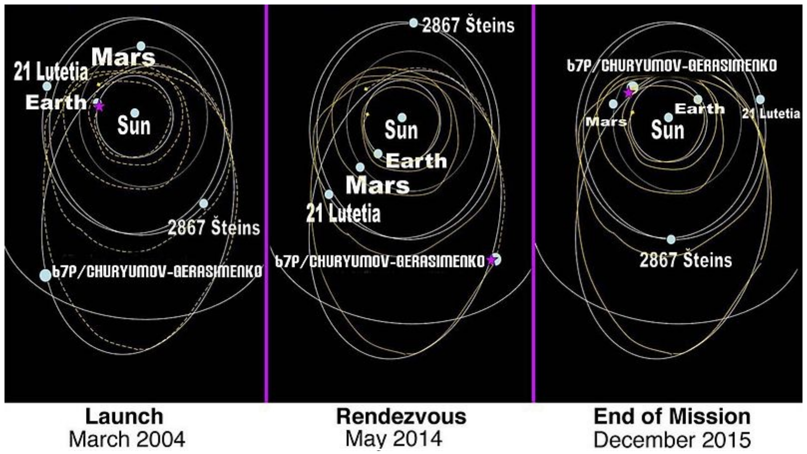
As the time goes…

Every action has consequences

- And so, operations have consequences.
- Ariane 5 ECA failed in 2002. It was grounded until the cause of the failure could be determined.
- Rosetta, to be launched in 2003 to rendezvous with comet 46P/Wirtanen in 2011 with smart mission analysis…
- …delayed and targeted to comet 67P/Churyumov–Gerasimenko, revised launch in 2004.
- **New target, same lander!**



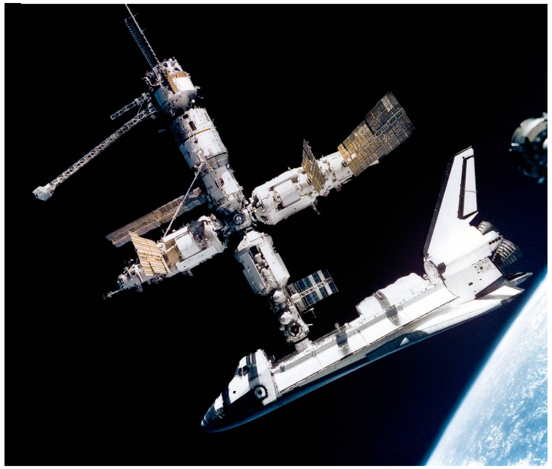
Src: wikipedia

Long life operations

- Missions are born, live and (are) dead.
- Reasons for closing them,
  - Technical end (ISO) Btw, How to measure ISO remaining Helium?
  - Decision to stop (safety rules applied to COMPTON)
  - Cut funding (IUE, MIR).

- Scientific missions, will live while,
  - In good condition (!).
  - High oversubscription factors in AO.
  - High rate published papers.
- **Reducing costs is a goal for survival (!)**

Src: nasa.gov



Src: nasa.gov

JcUVa

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Long life operations (II)

- Two major strategies possible,
  - Keep every frozen. Apply resources to maintain the baseline in operational condition.
  - Routinely upgrade the s/w and h/w, keeping in line with latest developments, better platforms.
- The nature of astronomical observatory in continuous usage by external community, keeping/increasing as much as possible the returned data, points to the second strategy (linked to costs reduction)

Adapting to the future

- IUE Gyros were failing as satellite aged, but new procedures allowed to operate till the end.

- XMM inertial wheels going to be used further than expected-> new strategies needed.
- XMM OM filter wheel going to be used further than expected -> limitation to be turned in just one direction.

SCIENCE OBSERVATIONS WITH THE IUE USING THE ONE GYRO MODE

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Abstract. The International Ultraviolet Explorer (IUE) is a geosynchronous orbiting telescope launched by the National Aeronautics and Space Administration (NASA) on January 26, 1978, and operated jointly by NASA and the European Space Agency. The science instrument consists of two spectrographs which span the wavelength range of 1150 to 3200 Å and offer two dispersions with resolutions of 6 Å and 0.2 Å. The spacecraft's attitude control system originally included an inertial reference package containing 6 gyroscopes for 3-axis stabilization. The science instrument includes a prime and redundant Field Error Sensor (FES) camera for target aquisition and offset guiding. Since launch, 4 of the 6 gyroscopes have failed. The current attitude control system utilizes the remaining 2 gyros and a Fine Sun Sensor (FSS) for 3-axis stabilization. When the next gyro fails, a new attitude control system will be uplinked which will rely on the remaining gyro and the FSS for general 3-axis stabilzation. In addition to the FSS, the FES cameras will be required to assist in maintaining fine attitude control during target aquisition. This has required thoroughly determining the characteristics of the FES cameras and the spectrograph aperture plate as well as devising new target acquisition procedures. The results of this work are presented.

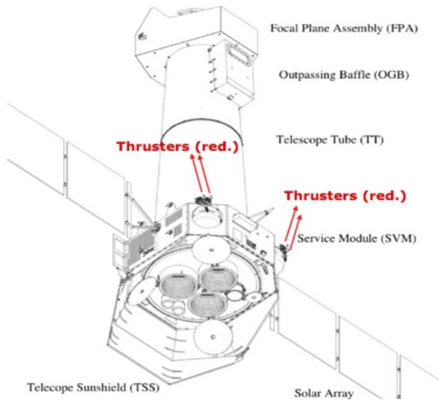
Operational procedures, incl. mission planning, need to adapt to new scenario.

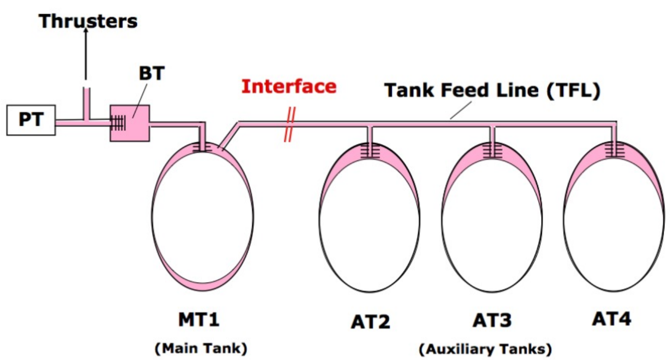
In-flight tank replenishment

- Primary actuators for attitude control of XMM-Newton are the **Reaction Wheels**.

- Thrusters of the RCS only used to unload the accumulated momentum from external torques in the reaction wheels and to adjust biaswheel speeds in preparation of the planned scientific pointing sequences.

- (As alternative, planning will make the unload process!)

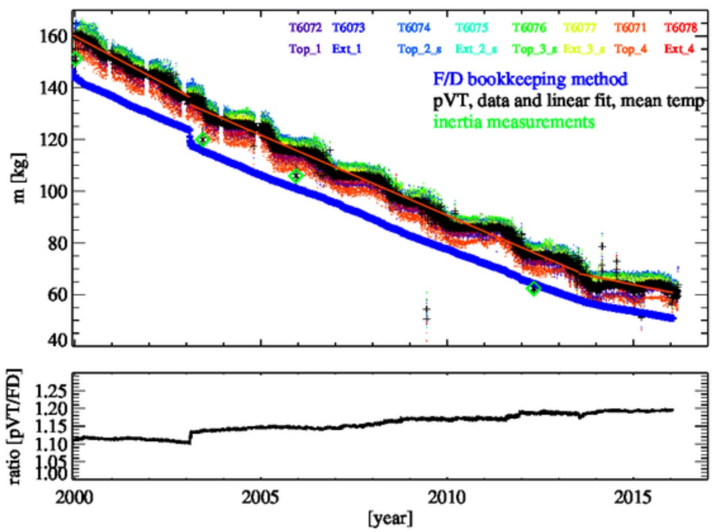




Src: Weissman et al, SpaceOps 2016

In-flight tank replenishment (II)

- To estimate the remaining fuel,
  - Bookeeping, based on accumulated thruster ON-times.
  - On board telemetry of the tank temperatures and of the tank pressure, in combination with their geometry and uses the ideal gas law.
  - Calibration measurements of the spacecraft's inertia.

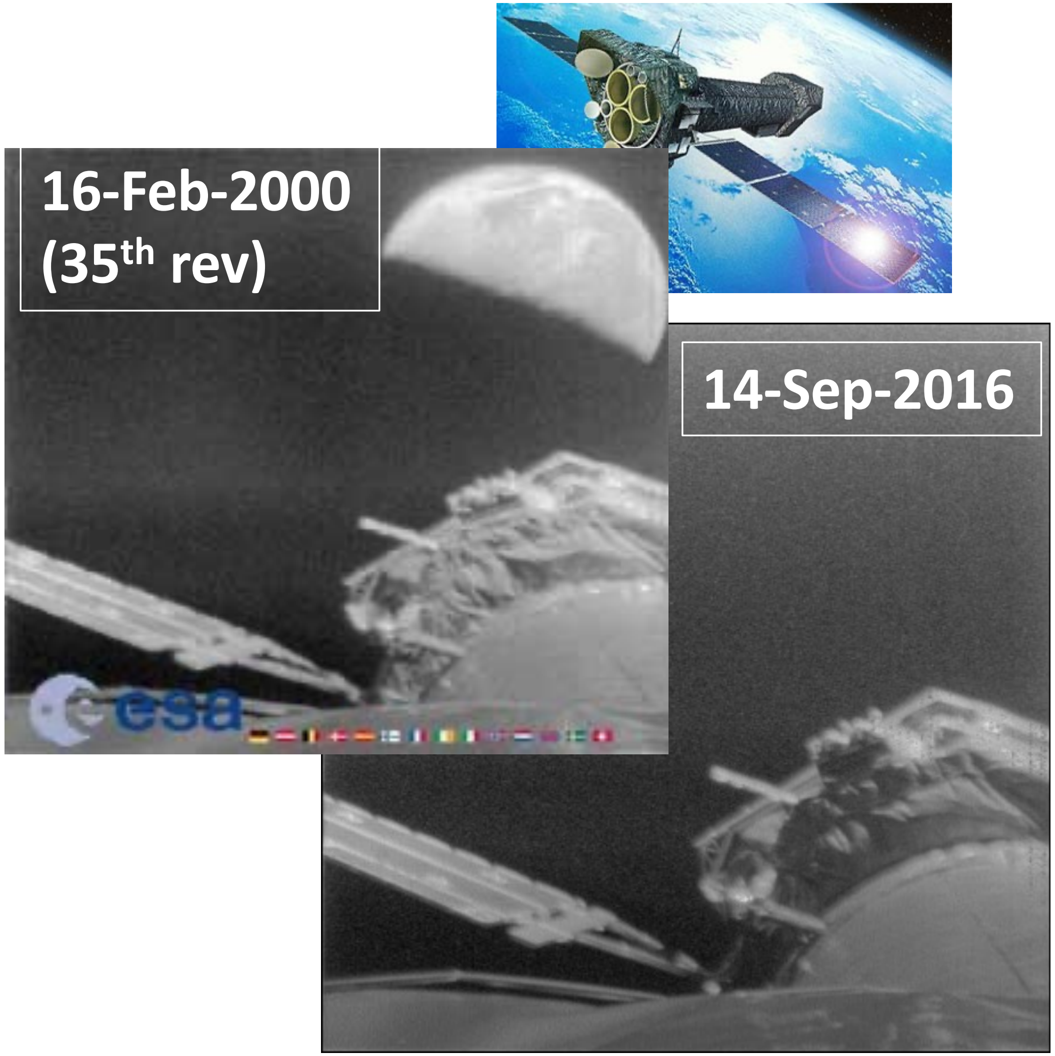


Src: Weissman et al, SpaceOps 2016

Visual Mon. Camera

- XMM FUGA Image, just for checking deployment.
- Then, re-executed several times.

- Behind these scenes:
  - Outreach.
  - Engineering test of 90's technology in hard environment, up 2016!
  - TM bandwidth discussions, Science vs Engineers.

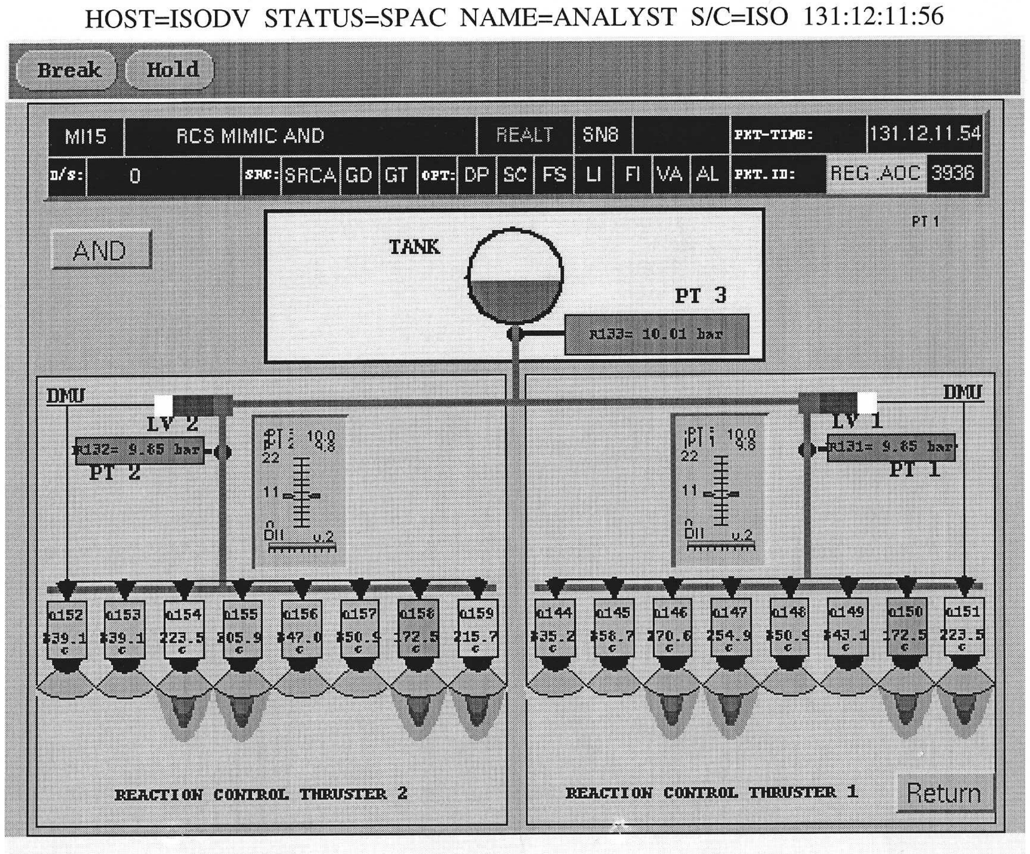


ISO EoL procedures

- Several engineering tests were required, as for star tracker.
- But not all final tests procedures were executed because of press/public images.

- Public Image -> ‘No bucks, no buck Rogers’

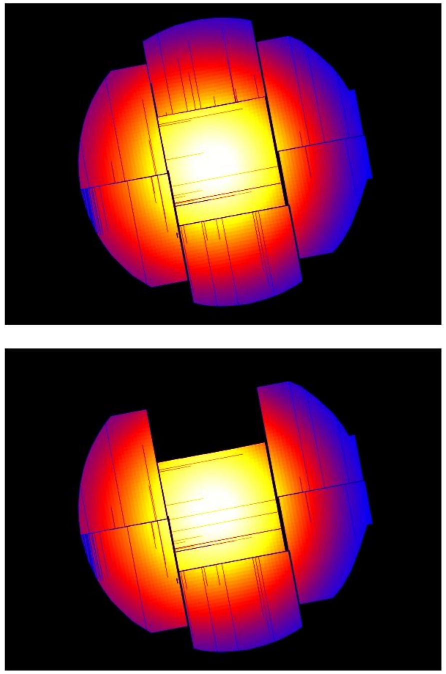
- Btw, the ‘last ISO’ deltaV was not last one (remaining fuel, aka mass, difficult to measure).



Non-planned events

- The impact on MOS1 during orbit 961 proved to be the most damaging to date in the life of XMM-Newton.
- At 01:30 hrs UT on 09 March, 2005 during a routine observation,"FIFO Full" error occurred, and an optical flash image was extracted from the buffers.
- After the flash, CCD6 output was permanently saturated giving no x-ray events any longer.

- The conclusion: a hard short from an electrode to the substrate is injecting large amounts of charge, irrespective of clocking.
- MOS1 now operates with CCD6 switched off.



Src: cosmos.esa.int/web/xmm-newton/mos1-ccd6

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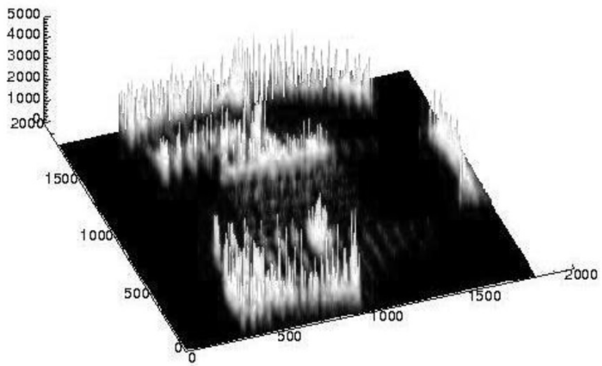
Upset event

- From time to time this CCD is switched on again.
- Just in case, you never knows…
- Mission Planning is taking seriously meteorid showers.



Src: Abbey et al, MICROMETEOROID DAMAGE TO CCDS IN XMM-NEWTON AND SWIFT AND ITS SIGNIFICANCE FOR FUTURE X-RAY MISSIONS, 604,943

Upset Events (II)

- It is important to define order of commands,
  - The Phobos experience.
- It is important to have a big dish at hand.
  - The XMM antenna problem.
    - Single reporting point for press.
    - Physics-dielectric issues.
    - Planning procedures change dramatically
- ARTEMIS FDS modified after orbit injection, because pathfinder ionic propulsion.

- First line solves problem, then procedures makes a final solution (if any, Skyhawk?)
- Sometimes, the launch solves the problem!

Even more upset, the 501 flight

- The Ariane 501 is a good example of operations and its consequences.

- June 1996, inaugural flight.
  - A5 was intended to be Human-qualified (Hermes)!
  - Cluster launch will be cheap.
  - SW reuse is good.

Src: thespacereview.com / ESA

- Inertial reference system reused from Ariane 4.
- Ariane 5 has higher horizontal velocity.
- 64-bit float to 16-bit integer overflow in backup.
- Followed by the same overflow in primary.
- Loss of control, 'Aerodynamic failure', mission lost.

The 501 flight

This document is presently partially in DCDIS

ESA
Director General's Office

ESA/INFO(96)28
Paris, 5 June 1996
(Original: English)

Distribution: All Staff

Message from DG to the staff

Ariane 501

The failure of the first flight of Ariane 5 which all of you were able to watch live on TV, is an enormous disappointment not only for the engineers and technicians who have been working for this programme and for the space scientists involved in the Cluster project, but also for the whole European space community. Although we have had failures before and we are used to living with risks and uncertainty, most of us never imagined that this would happen.

This unfortunate event which is not unique to Europe has shown that even the most rigorous tests and simulations cannot prevent a launch failure and that the launcher business is inherently a risky business. Ariane 5 is a radically new design and much more powerful than its predecessor, Ariane 4. The new launcher is using engines ten times as powerful as those of Ariane 4 and its electronic brain is a hundred times more powerful than that used on previous Ariane launchers.

An enquiry board will be appointed soon to determine the precise causes of the failure. It will report its findings by mid-July so that once the fault is identified and put right, preparations can begin for the second test flight 502. Preliminary analyses, however, show that the new concept is sound.

Once the origin of the malfunction of the 501 flight has been determined and repaired, I will present a plan to the participants in the Ariane 5 programme to provide the means required to bring the programme to a successful conclusion. Several ministers, in particular those from France, Germany and Belgium, have expressed their confidence in the industry's capabilities to master the complex technology and their commitment to the continuation of the programme.

The Ariane programme has been a big success for the Agency and for European space cooperation. You all know that Ariane 5 is central to Europe's ambitions to continue its strong position on the satellite launch market and to its commitments as a partner in the International Space Station.

I would also like to say a few words to the scientific and technical teams of the Cluster Project. The Ariane 5 accident is a definite blow to all those who have invested so much effort for so many years. I am thinking of our engineers in ESTEC and in particular of John Credland, Project Manager, and Rudi Schmidt, Project Scientist, as well as all those who in ESOC were getting ready with such professionalism to put into operation this particularly complex mission. I am also thinking of those who in industry and in the research laboratories have seen disappear their hope for a major success and a source of important discoveries.

Perhaps we can now console ourselves by admiring the magnificent results of SOHO, sister mission of Cluster in our STSP Programme. This failure, hard as it may be, must not let us forget our scientific successes. In fact, not only SOHO, but also ISO, Ulysses, Hubble, Hipparcos provide us with results daily which bring us the due admiration of our partners and scientists.

To you all, researchers, engineers, technicians, who have consecrated an important part of your lives to the Cluster Project and have never spared any effort with the only goal of final success in mind, I wish you the courage and motivation necessary to continue your personal investment in the brilliant missions of our future programme. I would like to congratulate all of you for your excellent work.

In the coming days, our scientific committees will meet to analyse the situation created by the loss of Cluster and the future course of action, in particular if a follow-up to this mission can be envisaged. I will spare no effort and will explore every possibility so as not to miss this opportunity if it exists.

In spite of the failure and of the disappointment, we must not be discouraged. The Ariane Programme and the Scientific Programme will continue. Together with the teams in industry we must do all we can to ensure the Programmes' and the Agency's success.

In the meantime, I want to thank each of you who have contributed to the successes of the Agency, and in particular to that of the Ariane and Scientific Programmes. Your contribution will be essential to help ensure the continued support of our Member States for the Agency and its programmes. I have every confidence in our capacity to overcome this difficult moment.

J.-M. LUTON
Director General

The 501 flight

- Remember the foundations.
- Cluster II was a major success.

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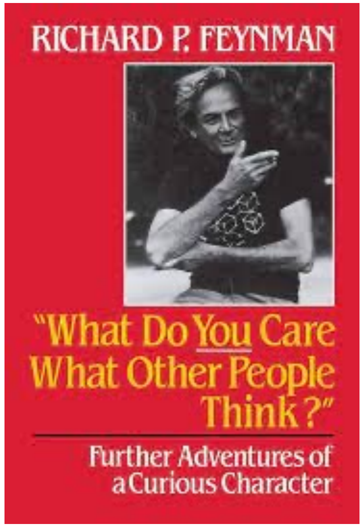
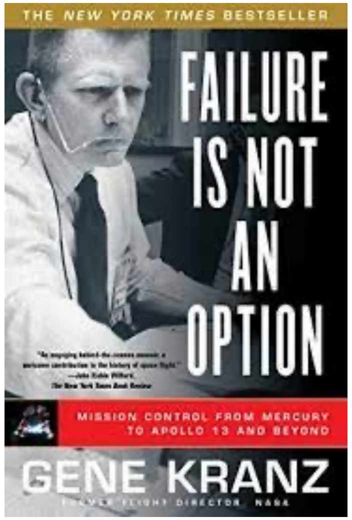
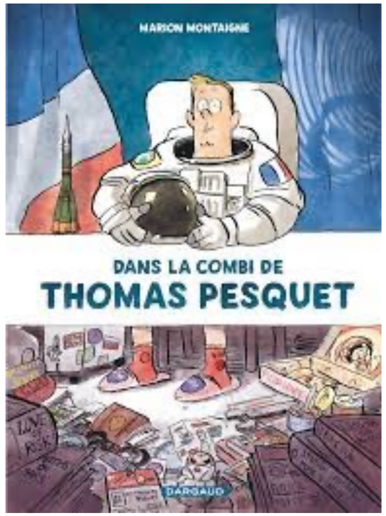
J.-M. LUTON
Director General

Recommended bibliography







...this is not the end...

Credits should follow here…

The human factor

- None of this would have been been possible without the expertise and efficiency of the technicians, engineers and scientists. Working in the space sector has –at least- one peculiarity: when a project begins, it will usually be many years before the teams see the result of their work [...] dreams can true thanks to the effort and dedication of people who believe in the future.

JJ Dordain, ESA 6th DG, 2003-2015

Thank you for your attention...

Thank you for your attention…