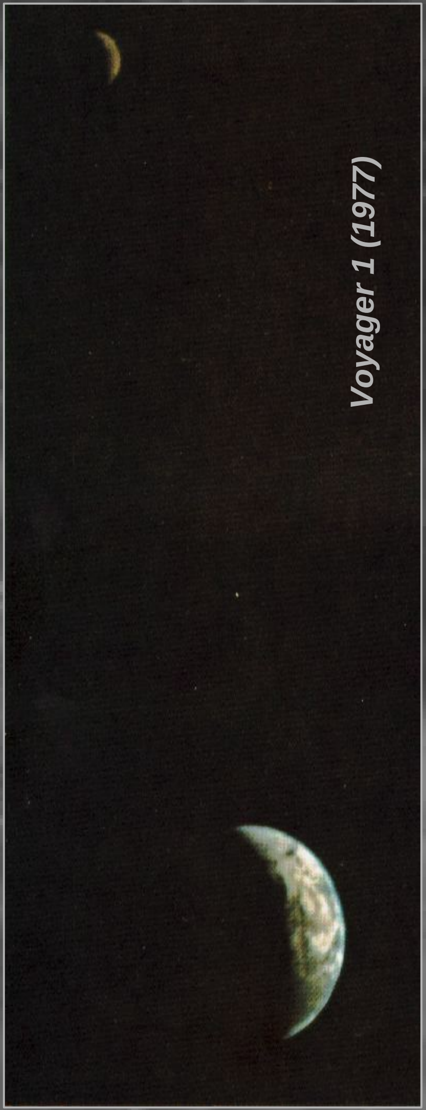

Voyager 1 (1977)

FLIGHT DYNAMICS and OPERATIONS

C. La Rocca, E. Perozzi, G. Di Genova, S. Ponzi

telespazio

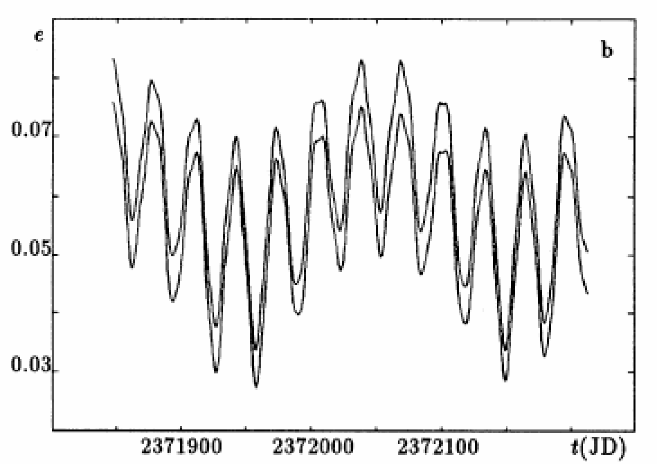
Roma (ITALY)

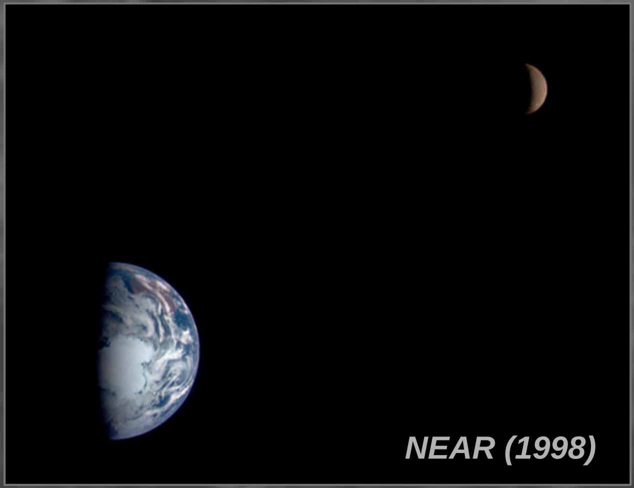
Moon Base International Conference
Venice workshop, May 26-27, 2005

THE PECULIAR ORBIT OF THE MOON

> ***Isaac Newton found the lunar problem so difficult that he complained "it made his head ache and kept him awake so often that he would think of it no more"***
>
> A.E Roy, *Orbital Motion,* Adam Hilger 1988

THE MOON IS SUBJECTED TO CONSISTENT SOLAR PERTURBATIONS




NEAR (1998)

- **Earth/Moon unusual mass ratio = 1/81** **(Neptune/Triton = 1/ 750)**
- **Distance: 380.000 km (>1/4 from L1):**
- **Solar perturbations: 0.044 < *e* < 0.067; 4°58' < *i* < 5°19'; nodes regress (p=18.6 y), apses advance (p=8.85 y)**

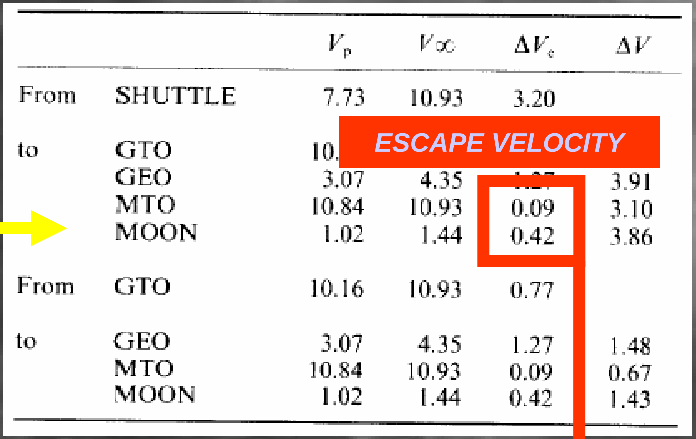
THE SAROS (i.e. 18-year eclipse prediction cycle) IS THE « NATURAL » PERIOD OF THE MOON

from CELESTIAL MECHANICS *to* FLIGHT DYNAMICS

Walter Hohmann's great contribution to astronautical progress was the discovery of a new use for an old object: the ellipse. W.I.McLaughlin: 'Walter Hohmann's Roads in Space', JSMA 2, 2000.

HOHMANN TRANSFERS

- **Short tranfer times: < 1 week**



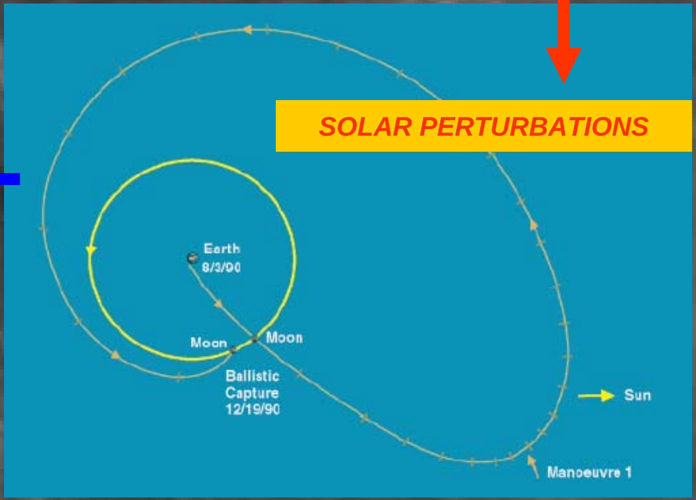
		V_p	$V\infty$	ΔV_e	ΔV
From	SHUTTLE	7.73	10.93	3.20	
to	GTO	10.	[illegible]	[illegible]	[illegible]
	GEO	3.07	4.35	[illegible]	3.91
	MTO	10.84	10.93	0.09	3.10
	MOON	1.02	1.44	0.42	3.86
From	GTO	10.16	10.93	0.77	
to	GEO	3.07	4.35	1.27	1.48
	MTO	10.84	10.93	0.09	0.67
	MOON	1.02	1.44	0.42	1.43

ESCAPE VELOCITY

THE MOON AS A GATEWAY TO INTERPLANETARY SPACE

WEAK STABILITY BOUNDARY (WSB) TRAJECTORIES

- **long transfer times: months**
- **significant delta-V savings**
- **feasibility demonstrated by the success of ESA SMART-1**



SOLAR PERTURBATIONS

IMPROVED ACCESSIBILITY

FLIGHT DYNAMICS REQUIREMENTS

Hohmann transfer is an optimal strategy only if the ratio between the radius of the final orbit to that of the departure orbit is less than 15.58

Larson & Wertz, Space Missions analysis and Design, Kluwer, 1996.

APOLLO

Description	delta-V *(km/sec)*	mission type	delta-V *(cumulative)*
Transfer to the Moon	3.2	flyby	3.2
Lunar Orbit Insertion	0.8	orbiter	4.0
Landing	2.1	lander/rover	6.1
Ascent	2.0		8.1
Transfer to Earth	0.8	sample return	8.9
Earth Orbit Insertion	3.2	round-trip	12.1

LUNAR BASE

TRANSFER TRAJECTORIES

Fast *(manned)*
Long-duration *(unmanned, cargo)*

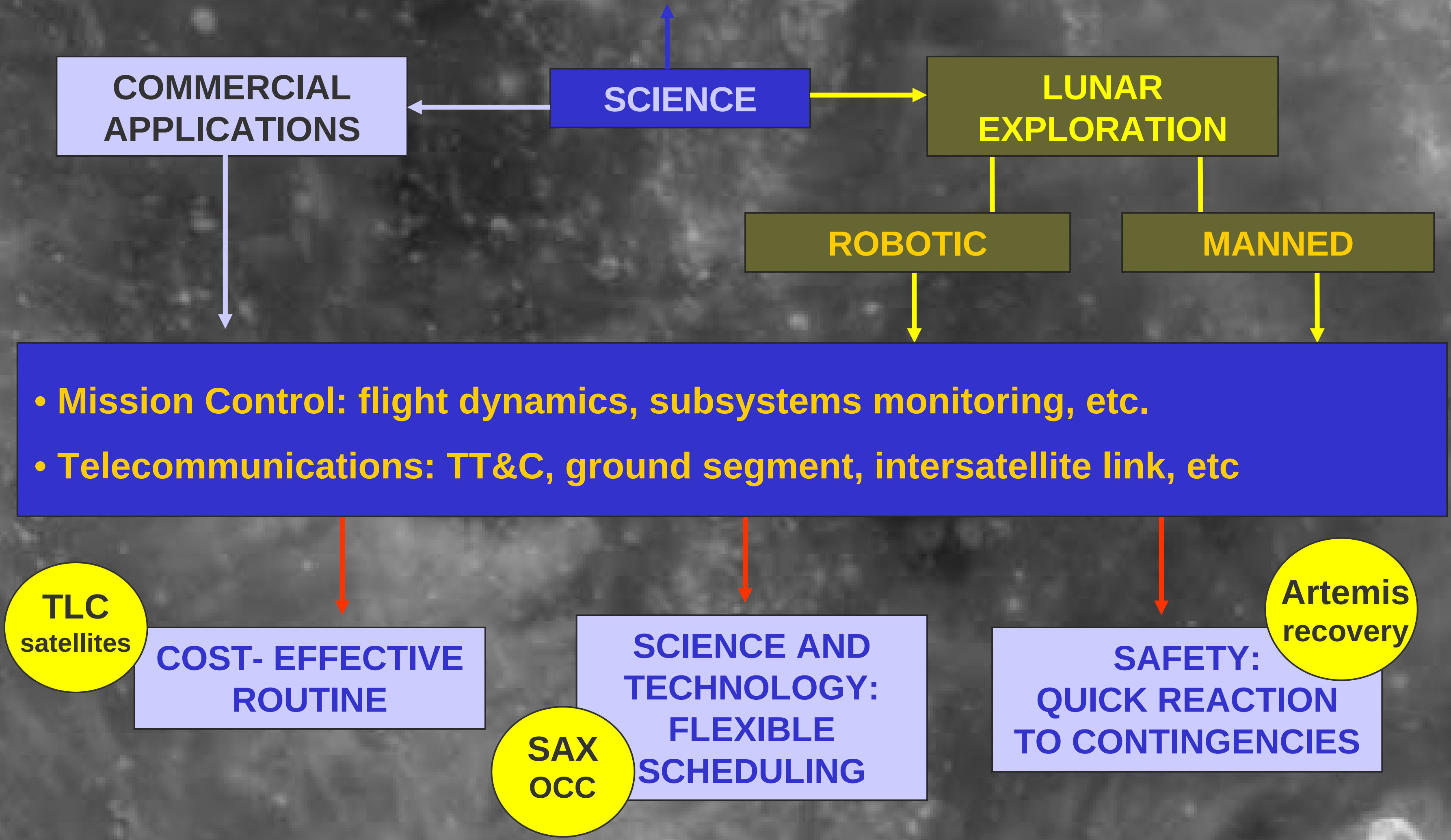
PROPULSION:

High-thrust, low spcific impulse *(e.g. chemical)*
Low-thrust, high specific impulse *(e.g. electric)*
High-thrust, high specific impulse *(e.g nuclear)*

IN SITU FUEL PRODUCTION

OPERATIONS

Maximise the scientific return from investment in spacecraft and other data collection sources by efficiently and reliably operating the data- collecting hardware which produces scientific discoveries NASA “The Vision for Space Exploration” web site, 2004



COMMERCIAL APPLICATIONS

SCIENCE

LUNAR EXPLORATION

ROBOTIC

MANNED

- Mission Control: flight dynamics, subsystems monitoring, etc.
- Telecommunications: TT&C, ground segment, intersatellite link, etc

TLC satellites

COST- EFFECTIVE ROUTINE

SAX OCC

SCIENCE AND TECHNOLOGY: FLEXIBLE SCHEDULING

Artemis recovery

SAFETY: QUICK REACTION TO CONTINGENCIES

A LUNAR OUTPOST

Permanent human presence on the Moon requires a novel integrated approach to routine and single-event remote operations.

ENVIRONMENT	INFRASTRUCTURE	OPERATIONS
Earth-Moon-L1 space	SPACECRAFT / CREW STS	Flight Dynamics System
Lunar Base	SURVIVAL FACILITIES	Monitoring human health and life support systems
Moon Surface / Orbit	MANNED / UNMANNED ROBOTIC EXPLORERS	Global TLC coverage and remote control

THESE FUNCTIONS SHALL BE REMOTELY IMPLEMENTED AND MAINTAINED BY MEANS OF 24h BROADBAND TELECOMMUNICATION LINK EITHER DIRECT-TO-EARTH OR VIA DATA-RELAY SATELLITES

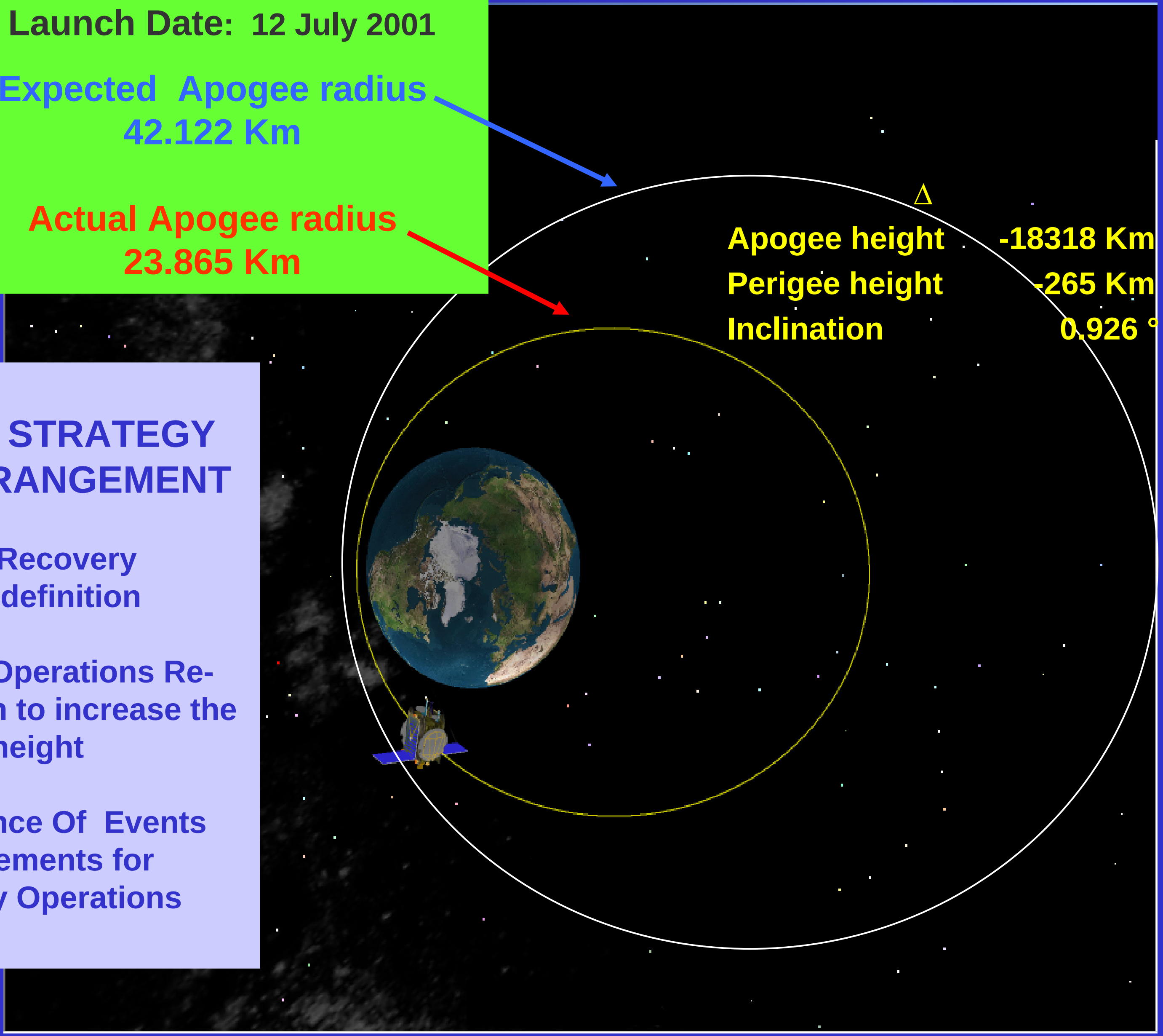
Telespazio experience in state-of-the art integrated space systems involving highly demanding operational environments relies on routine and contingency operations of advanced telecommunication satellites (e.g. ESA Artemis) as well as on the in-flight management of a scientific mission (e.g. ASI BeppoSAX).

ESA ARTEMIS GEO satellite RECOVERY

Launch Date: 12 July 2001

Expected Apogee radius
42.122 Km

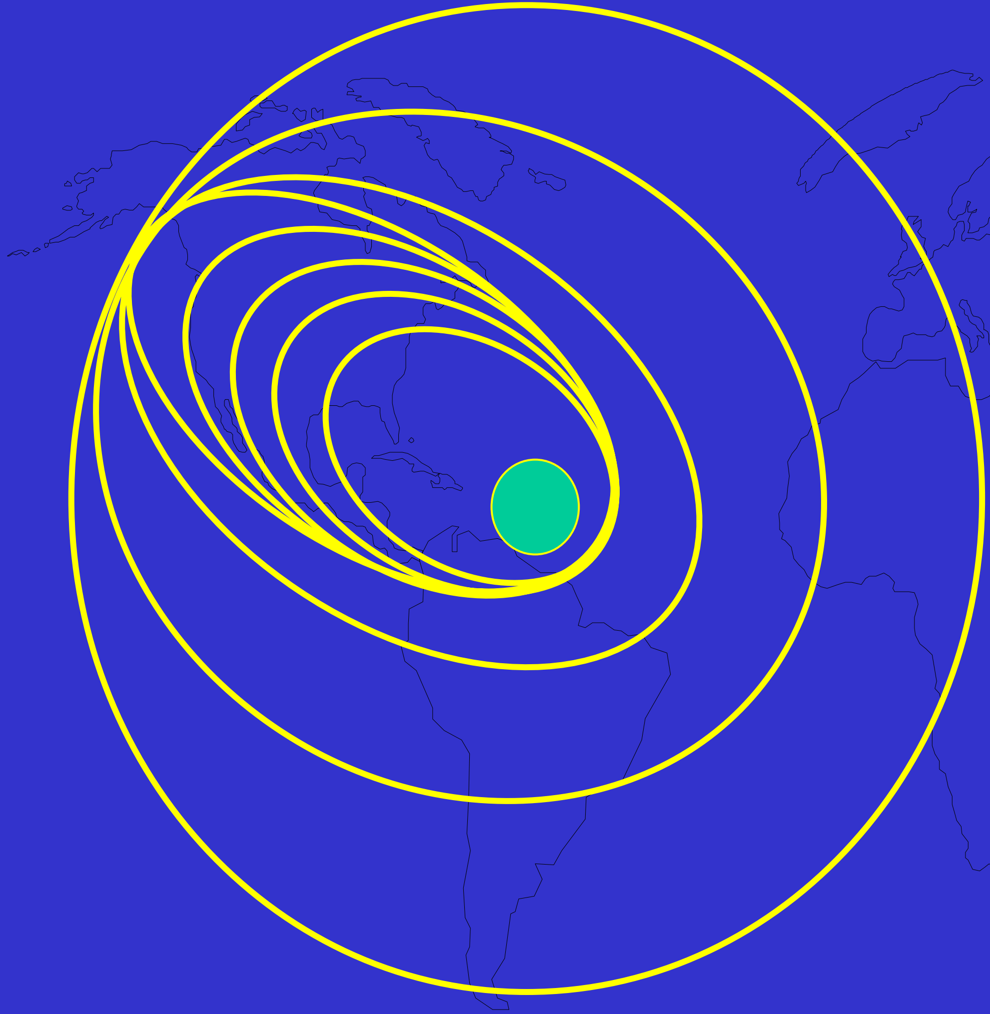
Actual Apogee radius
23.865 Km



LEOP STRATEGY REARRANGEMENT

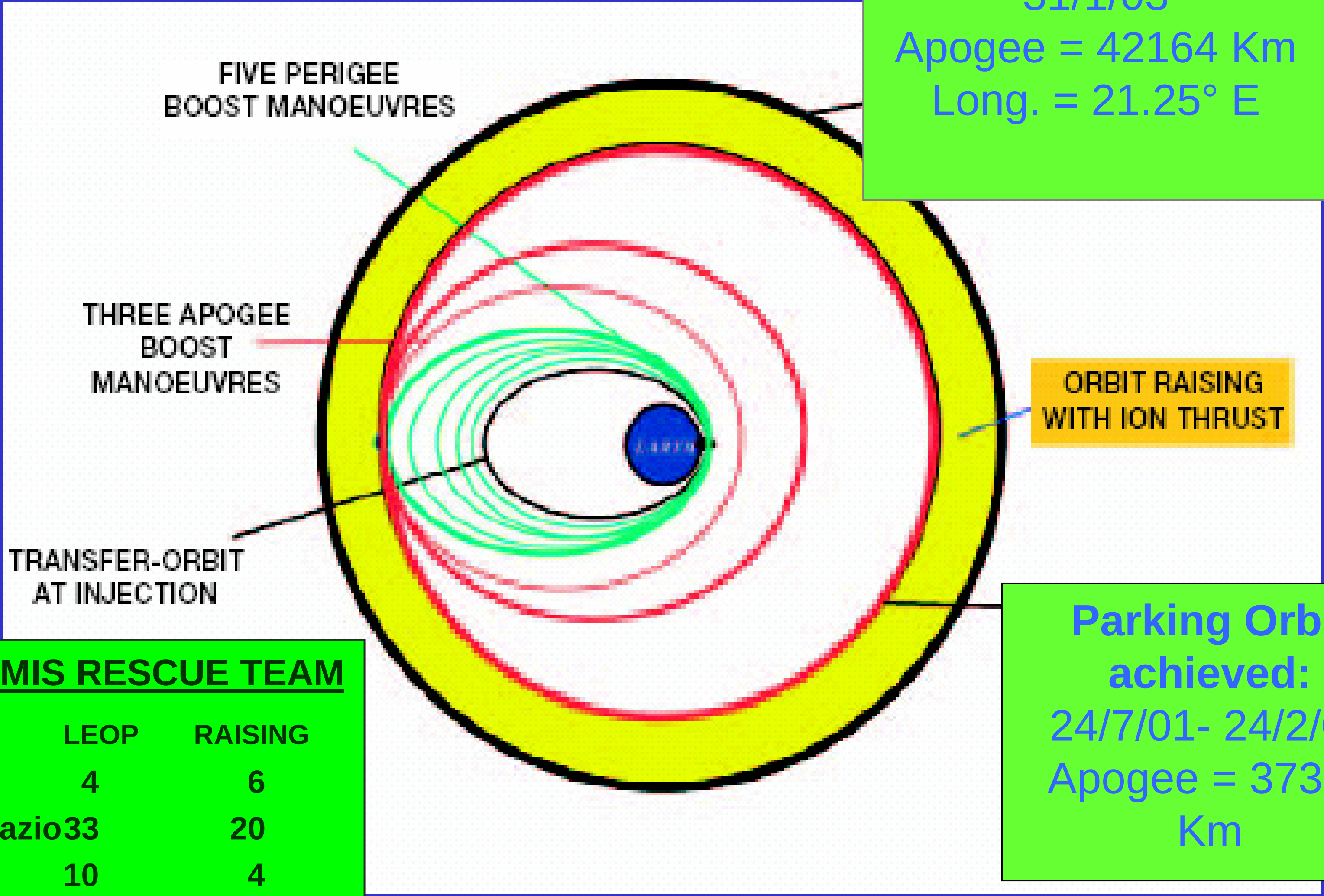
- Orbital Recovery Strategy definition
- LEOP Operations Re-definition to increase the Apogee height
- Sequence Of Events rearrangements for Recovery Operations

RESCUE IMPLEMENTATION AS A LONG DURATION LEOP



- **Apogee rising** *(perigee burns)* **then Perigee rising burns**
- **All burns but first out of visibility**
- **A TT&C network is needed for 24h coverage in parking orbit**
- **Transfer to Geo with mixed propulsion (chemical + electric)**
- **Two different ion propulsion technologies:** *Electron-bombardment Ion Thruster Assembly (EITA) and Radio frequency Ion Thruster Assembly (RITA)*
- **330 days of continuous Ipp activation**
- **residual propellent in Geo = 92 Kg**

SUCCESSFUL RESCUE



Geo Orbit achieved:
31/1/03
Apogee = 42164 Km
Long. = 21.25° E

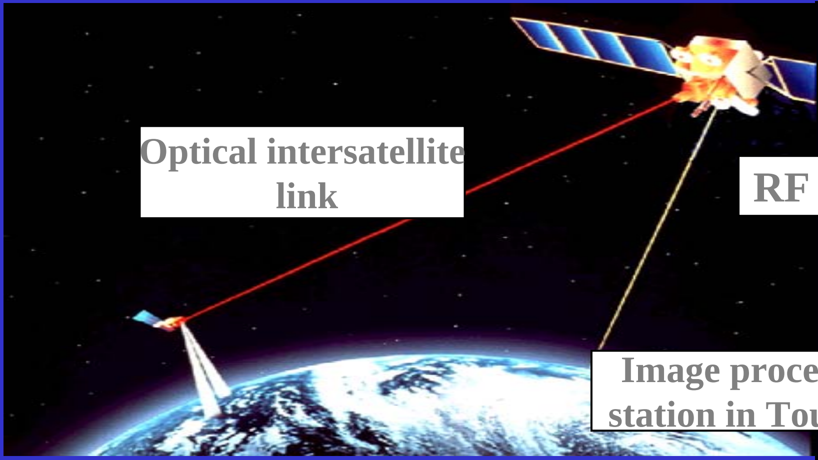
Parking Orbit achieved:
24/7/01- 24/2/02
Apogee = 37341 Km

ARTEMIS RESCUE TEAM

	LEOP	RAISING
ESA	**4**	**6**
Telespazio	**33**	**20**
Alenia	**10**	**4**
Astrium	**6**	**4**
Vega	**4**	**2**

ADVANCED TELECOMMUNICATION SYSTEMS

SPOT4 - ARTEMIS



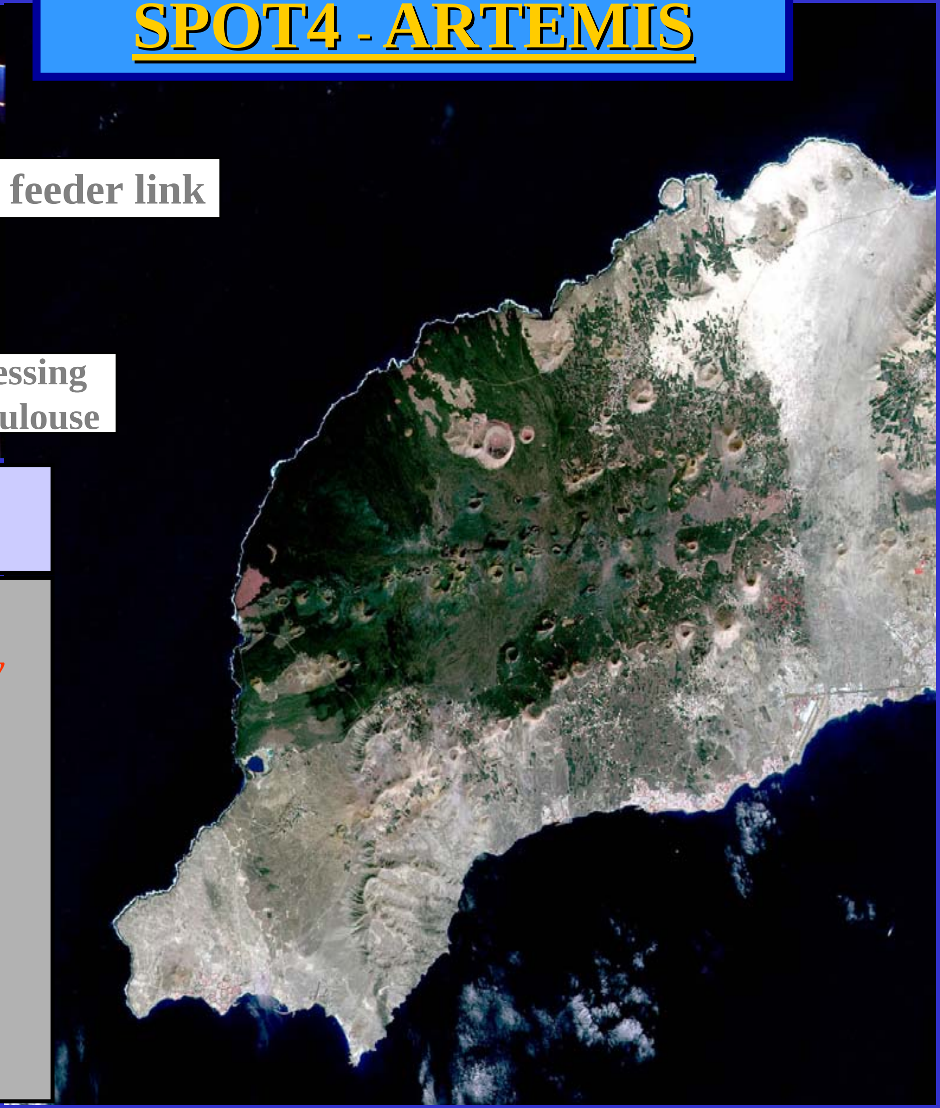
Artemis SILEX optical link

A worldwide Première:

30 November 2001, 17:45 Lanzarote, Canary

A picture taken by an earth Observation satellite, transmitted by Optical laser light via a data relay Satellite directly to the image Processing center.

(the picture shows the west part of Lanzarote)



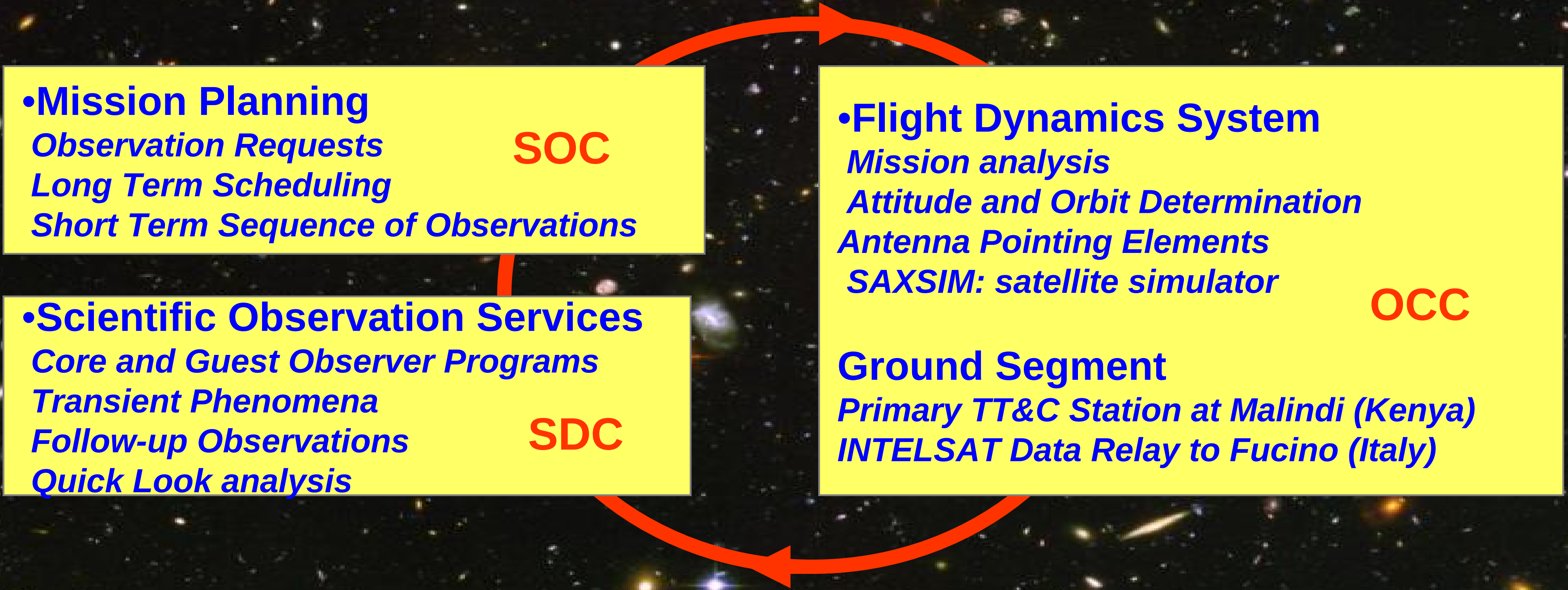
BeppoSAX

The Italian X-ray Astronomy Satellite

FLIGHT DYNAMICS & OPERATIONS

Launched on April 30, 1996
500 km circular equatorial orbit
Wide field camera (WFC) + narrow field instrument (NFI)
Mission ended on April 30, 2002

Science and Mission Operations Under Telespazio Responsibility



- **Mission Planning**
  - *Observation Requests*
  - *Long Term Scheduling*
  - *Short Term Sequence of Observations*

SOC

- **Scientific Observation Services**
  - *Core and Guest Observer Programs*
  - *Transient Phenomena*
  - *Follow-up Observations*
  - *Quick Look analysis*

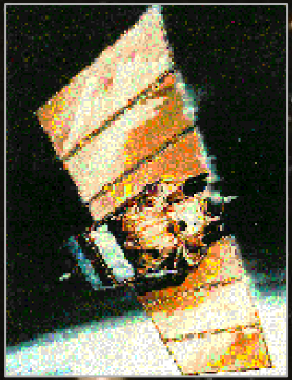
SDC

- **Flight Dynamics System**
  - *Mission analysis*
  - *Attitude and Orbit Determination*
  - *Antenna Pointing Elements*
  - *SAXSIM: satellite simulator*

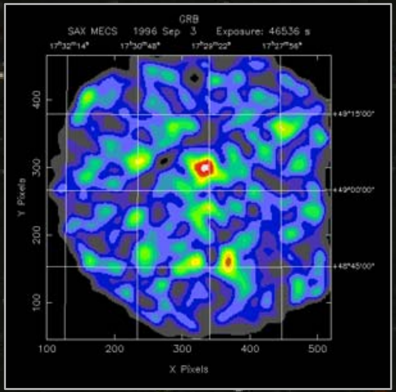
OCC

Ground Segment

Primary TT&C Station at Malindi (Kenya)
INTELSAT Data Relay to Fucino (Italy)



BeppoSAX and GRB’s



Gamma Ray Bursts (GRB’s)are transients observed as intense pulses in the low-energy gamma-ray regime.

GRB's are short-duration events and their positions are poorly constrained if no follow-up observations in other wavelengths are available.

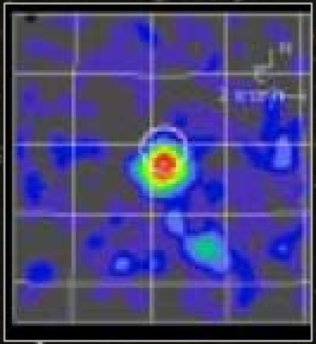
UNTIL THE FIRST X-RAY AND OPTICAL COUNTERPARTS WERE DISCOVERED THANKS TO THE BeppoSAX SATELLITE, THE NATURE OF GRB’s WAS UNKNOWN.

It now appears that many if not all GRB's are the results of processes in distant galaxies, presumably collisions of highly condensed objects.

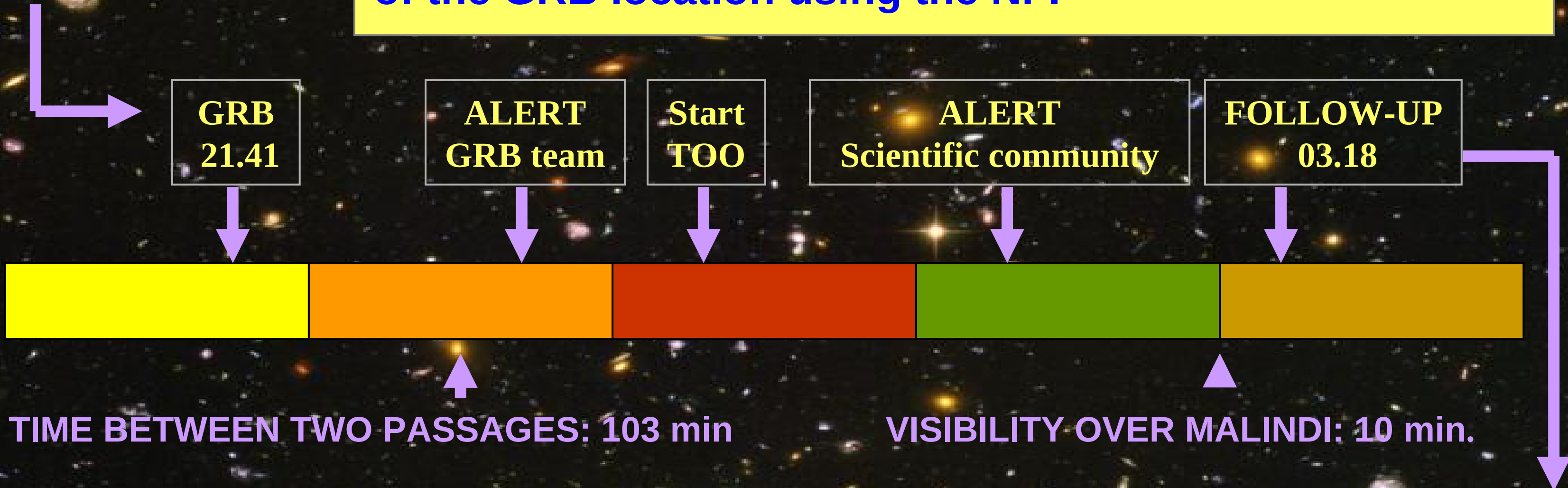
GRB970508 in CAMELOPARDIS

BeppoSAX DISCOVERY and FOLLOW-UP

When a GRB is detected by the WFC a quick repointing of the satellite is needed to allow precise determination of the GRB location using the NFI



DISCOVERY: 8/5/1997



GRB
21.41

ALERT
GRB team

Start
TOO

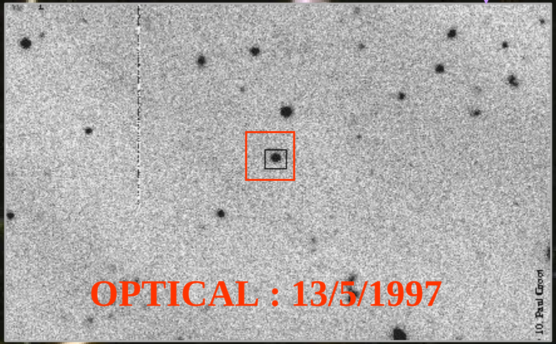
ALERT
Scientific community

FOLLOW-UP
03.18

TIME BETWEEN TWO PASSAGES: 103 min

VISIBILITY OVER MALINDI: 10 min.

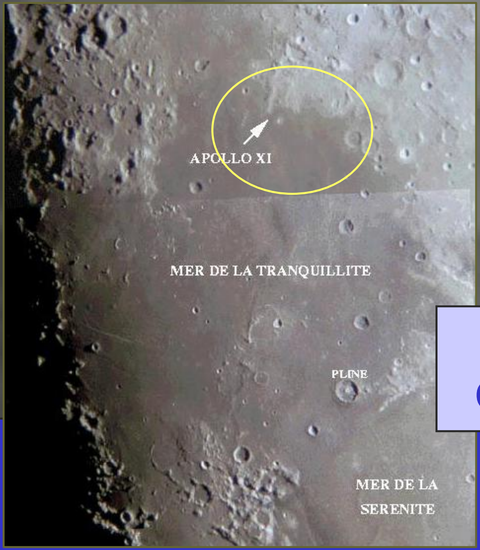
The satellite was repointed in only 5.7 hours thanks to the quick interaction between the Scientific Data Center (SDC), the Scientific Operation Center (SOC) and the Operations Control Centre (OCC)



OPTICAL : 13/5/1997

TELESPAZIO EXPERTISE FOR LUNAR EXPLORATION

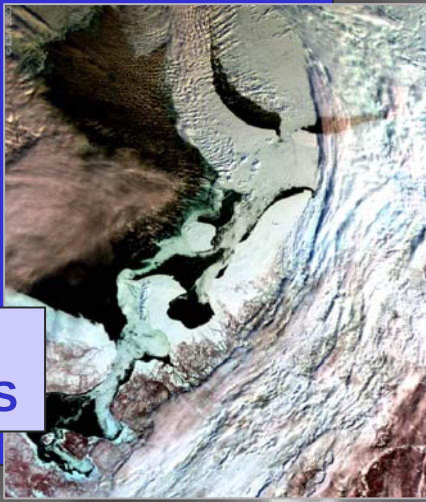
GROUND SEGMENT INFRASTRUCTURES



SPACE GEODESY

- **Ka band TLC (Italsat, Olympus, Artemis)**
- **C-band large diameter antennas (e.g. LARIO 32m): upgrading to Ka and optical links**
- **Inter-Orbit data relay (Artemis)**
- **Flight Dynamics and LEOP services**
- **Lunar Laser Ranging facility and geodetic data processing**
  (on behalf of the Italian Space Agency)
- **Remote Sensing Data Analysis**

FLIGHT DYNAMICS SYSTEMS



OPERATIONS CONTROL CENTERS

CONCLUSIONS

Permanent Lunar infrastructures and the related servicing missions can be considered as a global space system needing continuous remote control

- **Lunar Base Maintainance *(e.g. control centre, fault detection open loop)***
- **Wide Band Communications *(e.g. Direct-To-Earth and intersatellite link)***
- **Manned and Unmanned missions *(e.g. advanced mission profiles and propulsion)***
- **Surface elements remote control *(e.g. lunar expeditions, TLC global coverage via L1 Halo Orbiter)***

GROUND SEGMENT CONTINUOUS COVERAGE

LONG DURATION LEOP

MISSION CONTROL CENTRE

MIXED PROPULSION SYSTEMS

DATA PROCESSING DISSEMINATION AND ARCHIVING

The BeppoSAX and Artemis experience has provided Telespazio with the ability to handle flight dynamics and operations **of complex space systems in peculiar context, resulting in scientific excellence, advanced telecommunication and successful recovery from contingencies.**

telespazio

a Finmeccanica Company

operates in the field of space support systems and services since its establishment, in 1968

Telespazio is a private operator offering an entire range of satellite applications: satellite in orbit control, ground segment design, navigation, fixed and mobile telecommunications, television services, two-way broadband multimedia, Earth observation data and applications, R&D.