“Laboratorio di Astrofisica Spaziale”

Analisi dell'ambiente spaziale: studio del Sole, dell'atmosfera terrestre e della loro interazione; astrodinamica con studio particolareggiato delle orbite e delle caratteristiche di una missione spaziale (propulsione, trasmissione dati, …)

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Università di Trieste: FISICA SPAZIALE

- Storia
- Astrofisica & Astronomia
- Fisica della Terra
- Fasi di una Missione Spaziale

AMS

Sommario

- Corso:
  - Programma, orario, materiale, esami, disponibilita’
- Motivazioni & Storia
- Astrofisica
- Astronomia
- Fisica della Terra
- Programmi Commerciali
- Programmi Educativi
- Conclusioni

Programma del Corso 1/2

1. INTRODUZIONE ALLA FISICA SPAZIALE
   - Scopi dell'esplorazione spaziale
   - Storia dell'esplorazione dello spazio
2. IL SOLE E L'AMBIENTE CIRCOSTANTE LA TERRA
   - Il Sole
   - L'atmosfera
   - La ionosfera
   - La magnetosfera
   - Le fasce di radiazione di Van Allen
3. INTRODUZIONE ALL'ASTRODINAMICA
   - Orbite kepleriane
   - Generalità sulle orbite
   - Cambiamenti d'orbita
   - Scelta dell'orbita per un satellite astronomico

Programma del Corso 2/2

4. GEOMETRIA DI UNA MISSIONE SPAZIALE
   - Geometria sulla sfera celeste
5. PROPULSIONE E POTENZA NELLO SPAZIO
   - Caratteristiche dei motori per razzi
   - Sistemi di propulsione
   - Sistemi di potenza
6. SISTEMI D'ASSETTO
   - Guida e controllo d'assetto
   - Sensori d'assetto
7. ULTERIORI SISTEMI DI UN SATELLITE
   - Sistema termico di un satellite
   - Struttura di un satellite
   - Telecomunicazioni di un satellite
8. LABORATORIO CON ARDUINI

Orario & materiale

- Orario:
  - Lunedì 14-17 Aula E T17
  - Martedì 13-16 Aula E T17
  - Venerdi' 11-13 Aula E T17

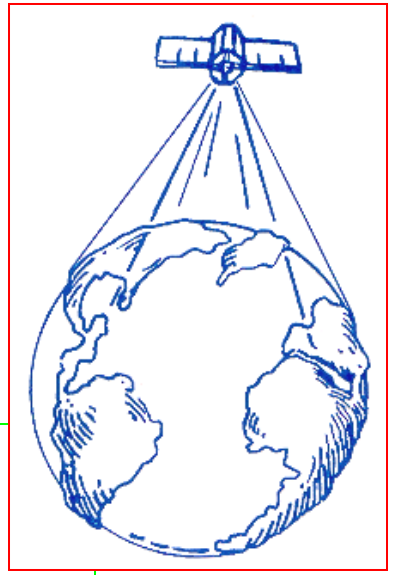
- Materiale
  - Dispense (Italiano)
  - Tutto su "Moodle" https://moodle2.units.it/
  - Libro di riferimento: "Space Mission Analysis and Design" (SMAD), J.R. Wertz and W.J. Larson, 3rd edition, Space Technology Library (in biblioteca)

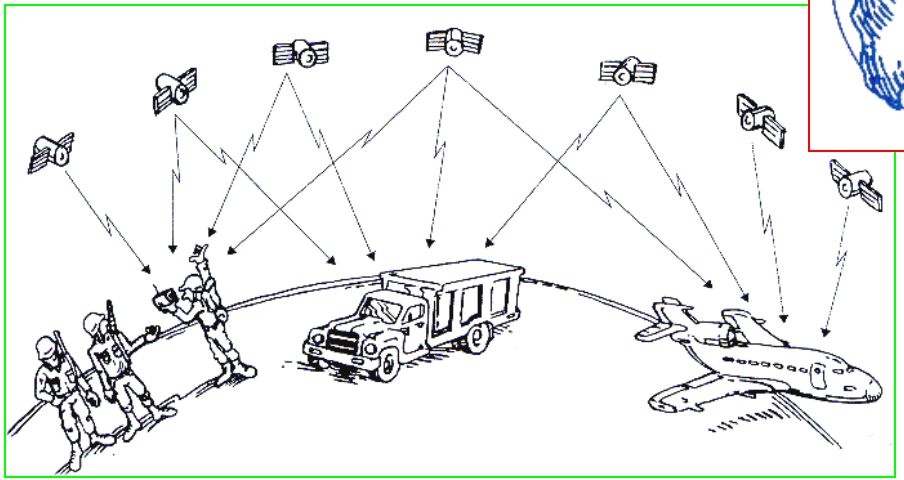
Esame & disponibilità

- Esame:
  - Seminario di 20 minuti con un approfondimento di un argomento a piacere (consiglio: venite a parlarne prima)
  - Due o tre domande sul programma
  - Avvisare almeno una settimana prima
- Disponibilità:
  - E.mail o telefono, ricevimento all'Università (lun. 9-10)
  - Richiesta: lista e-mail e un cellulare di (almeno) una persona di riferimento
- Altro:
  - PC a disposizione? E.mail & mac-address

Motivazioni 1/2

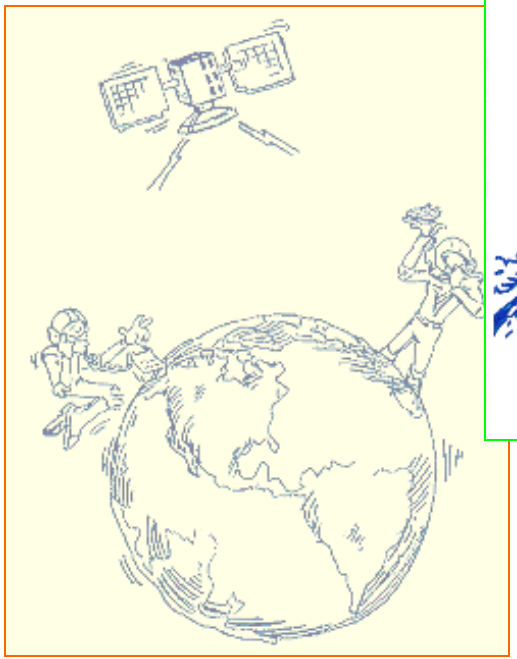
- Osservazioni della Terra
- Comunicazioni
- Navigazione





Motivazioni 2/2

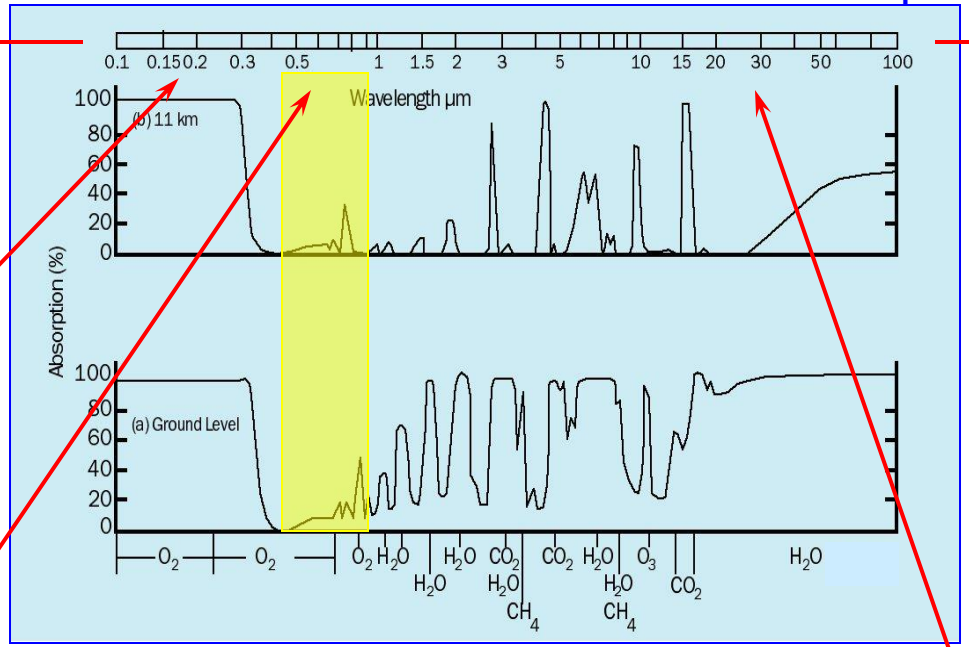
- Scienza
- Esplorazione



Atmosfera

Raggi X / γ: gas intergalattico, dischi accrescimento

Microonde / Onde Corte: fondo radiazione cosmica, elettroni in campi magnetici

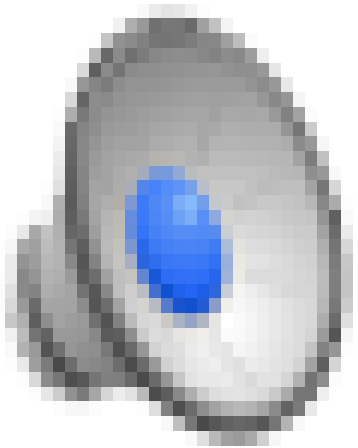


UV: stelle calde

Visibile: stelle fredde

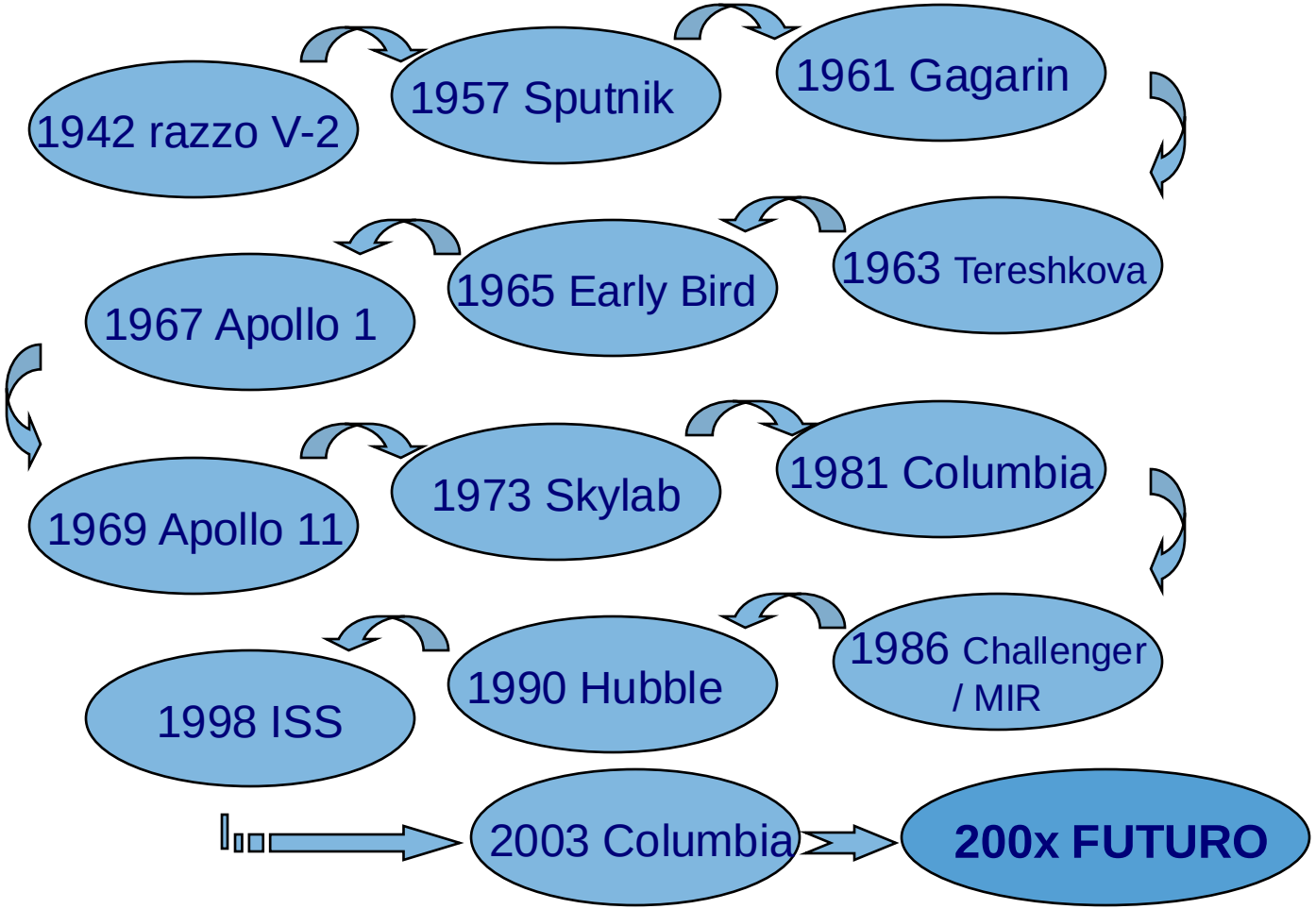
IR: polveri cosmiche, comete

Storia 1



YouTube “Escape Velocity - A Quick History of Space Exploration”

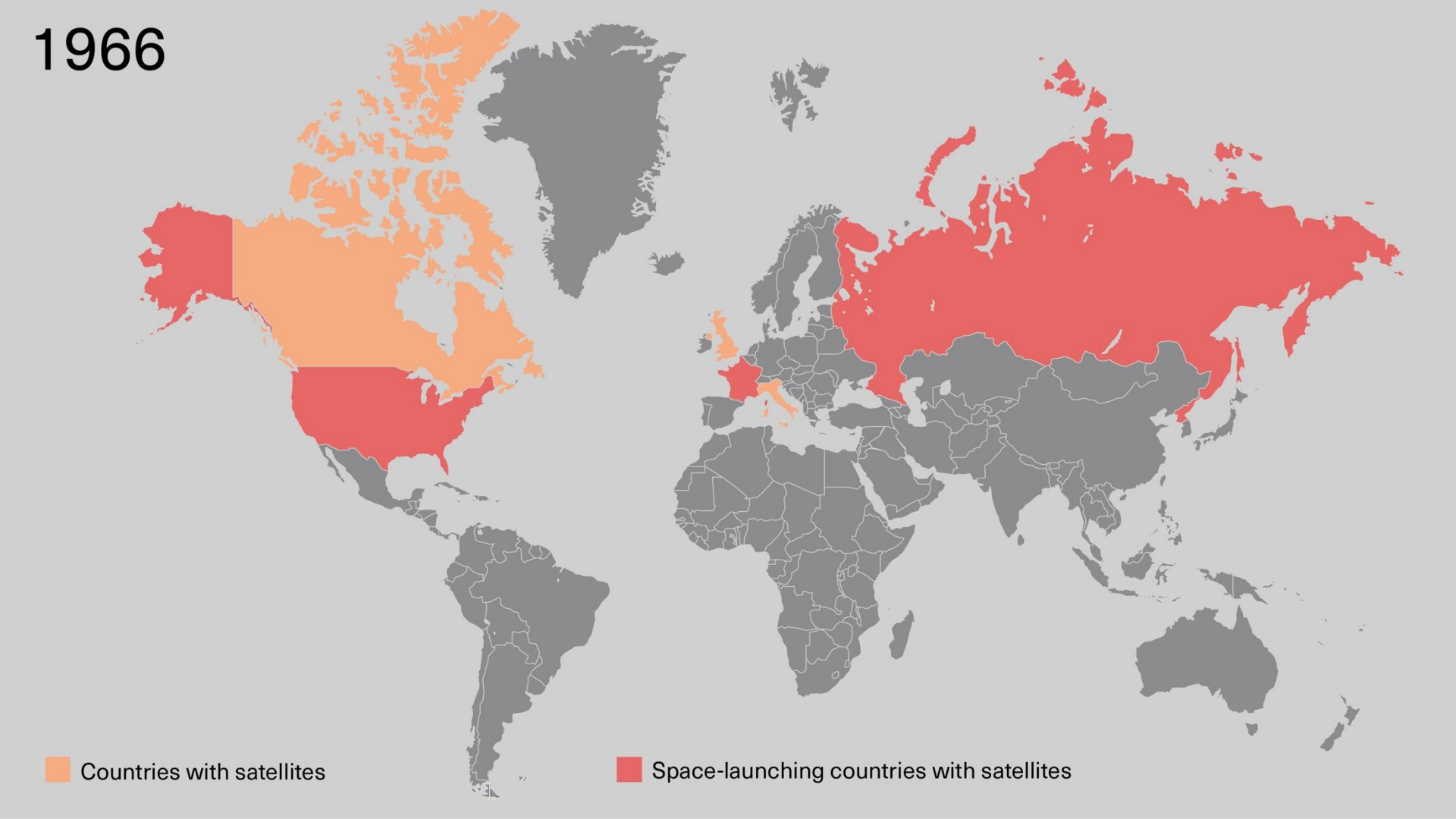
Storia 2

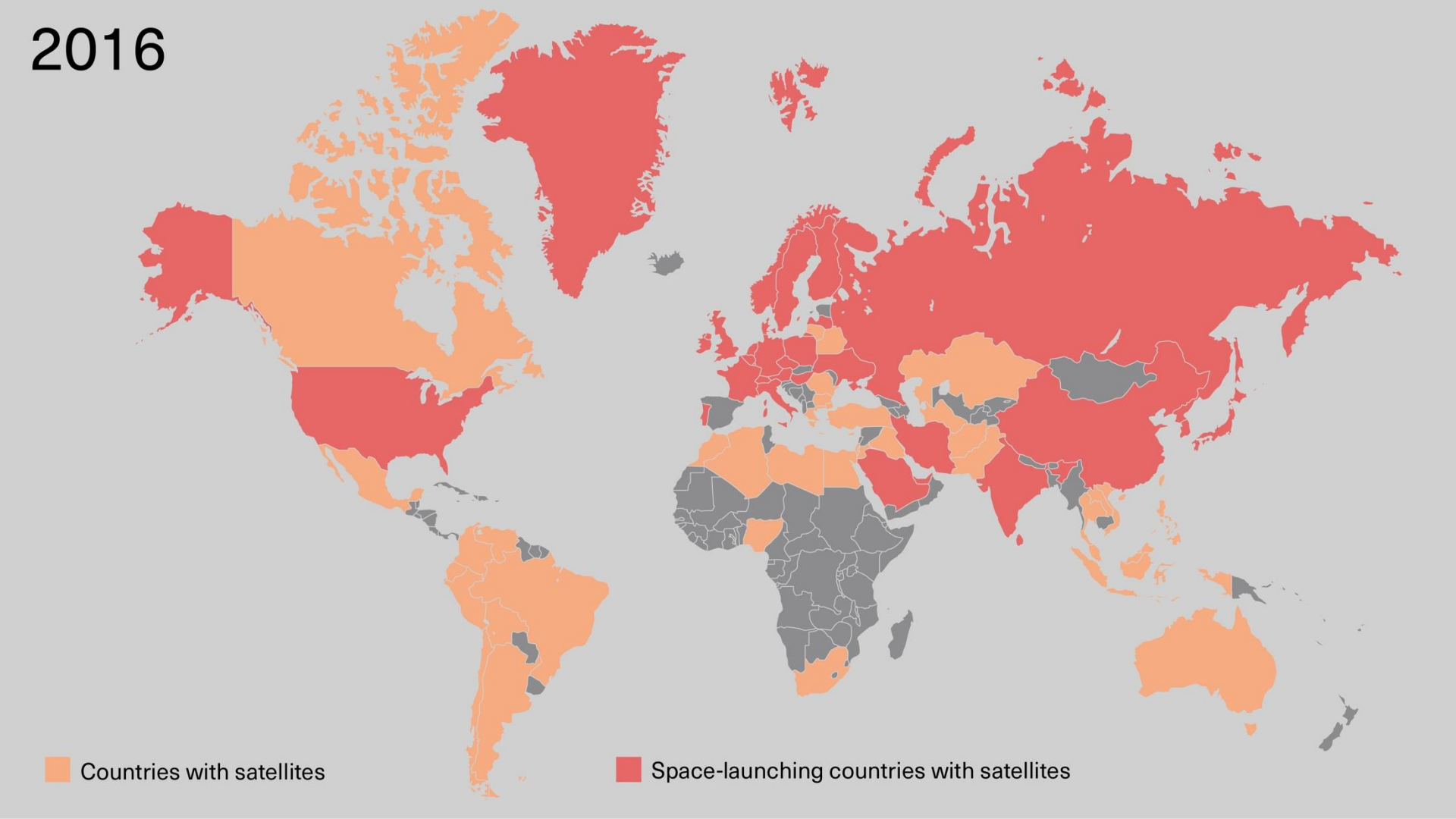

1942 razzo V-2
1957 Sputnik
1961 Gagarin
1963 Tereshkova
1965 Early Bird
1967 Apollo 1
1969 Apollo 11
1973 Skylab
1981 Columbia
1986 Challenger / MIR
1990 Hubble
1998 ISS
2003 Columbia
200x FUTURO

Storia 3

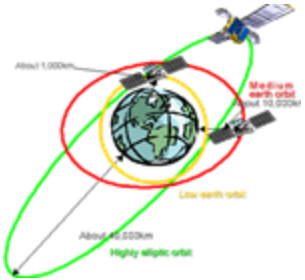
- Fino al 2010 < 100 satelliti
- Fino al 2019 2062 satelliti
  - US 900
  - Europa 600
  - Russia 150
  - Cina 300

- 2020 1300 lanci
- 2021 ~8000 lanci

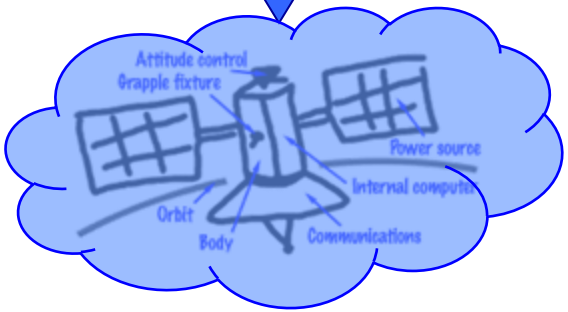

1966
Countries with satellites
Space-launching countries with satellites


2016
Countries with satellites
Space-launching countries with satellites

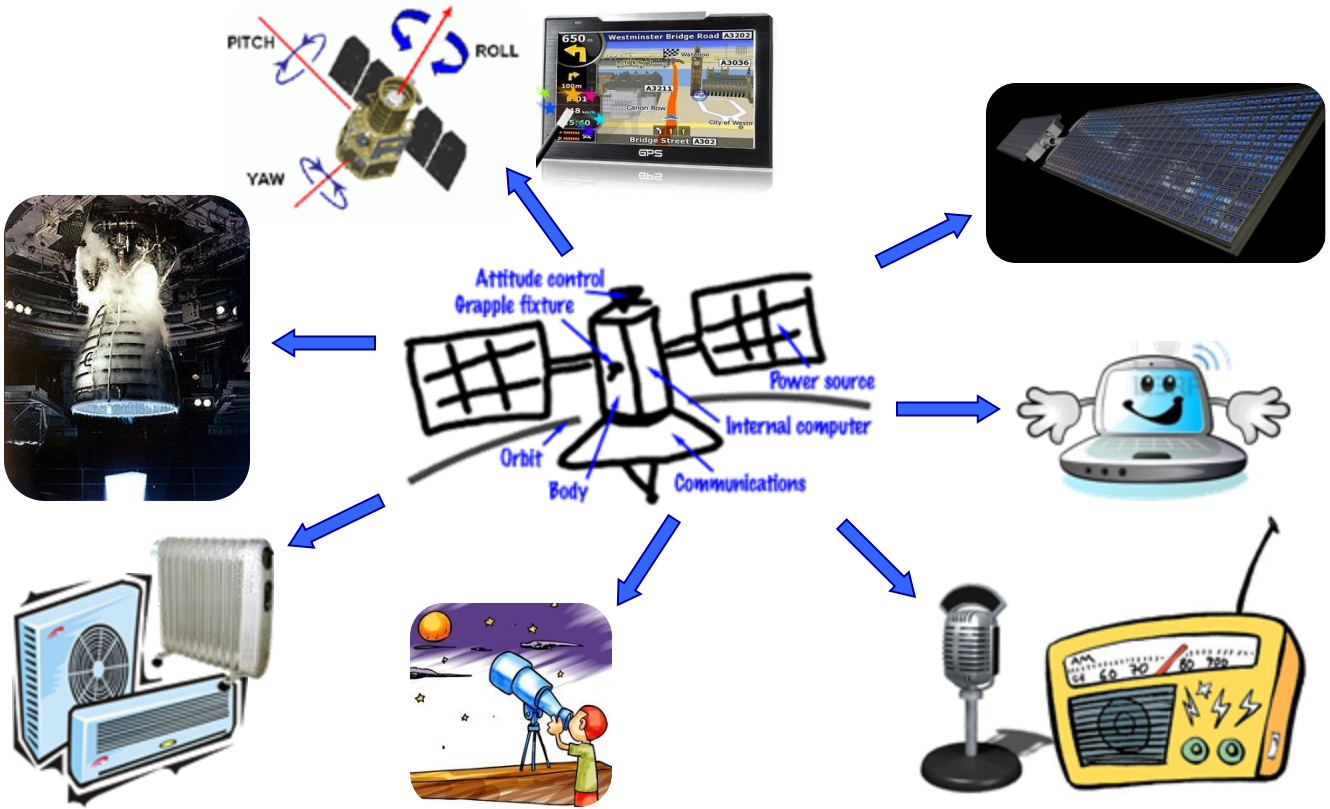
Una Missione Satellitare



Missione Satellitare

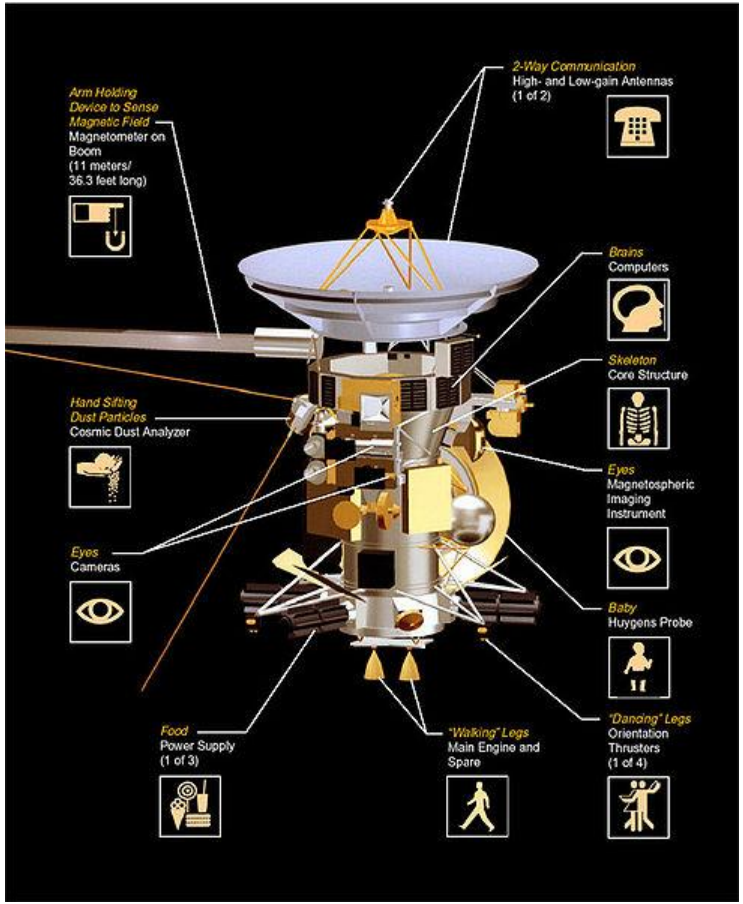


I Sistemi di un Satellite 1/2



I Sistemi di un Satellite 2/2

Cassini – Huygens



Difficoltà Tecniche

- Condizioni ostili ambiente spaziale:
  - escursioni termiche
  - vuoto
  - dosi di radiazione cosmica
  - particelle e frammenti
- Problematiche al lancio (vibrazioni)
- Strumentazione di dimensioni, massa e consumi ridotti

Difficoltà Tecniche 2/2

Radiazione nello Spazio (esempio)

Componenti Primarie

- Raggi Cosmici – particelle provenienti dallo spazio profondo
- Particelle Solari – particelle provenienti dal Sole
- Cinture di Radiazione – cinture di particelle energetiche che circondano la Terra

Componenti Secondarie

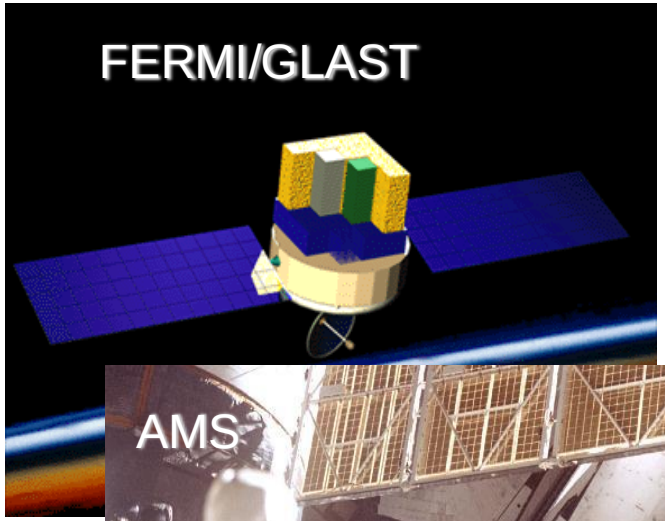
- Sciami Elettromagnetici – raggi cosmici nell'atmosfera
- Bremsstrahlung – elettroni attraverso un materiale/atmosfera
- Scintillazione (fluorescenza) particelle attraverso l'azoto atmosferico o componenti ottiche
- Radiazione Cherenkov – flash prodotti da particelle ad alta velocità attraverso materiali

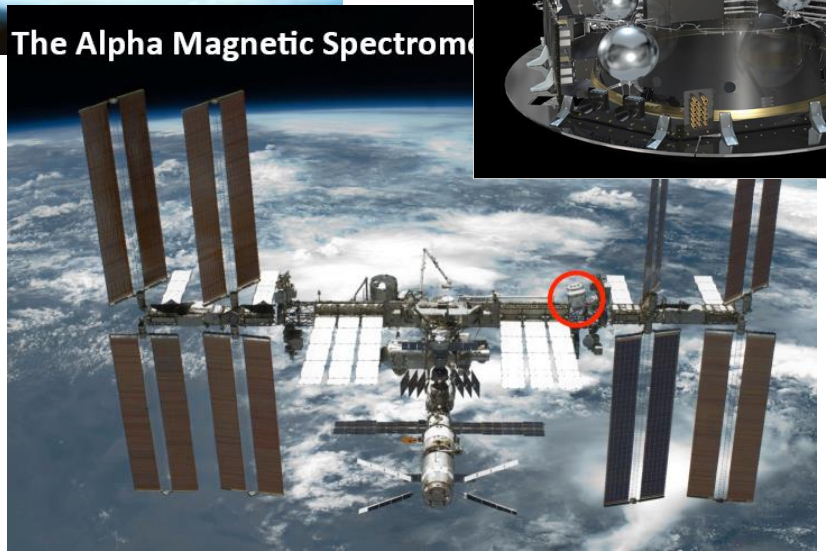
Strategia

Stazione Spaziale Internazionale (ISS)

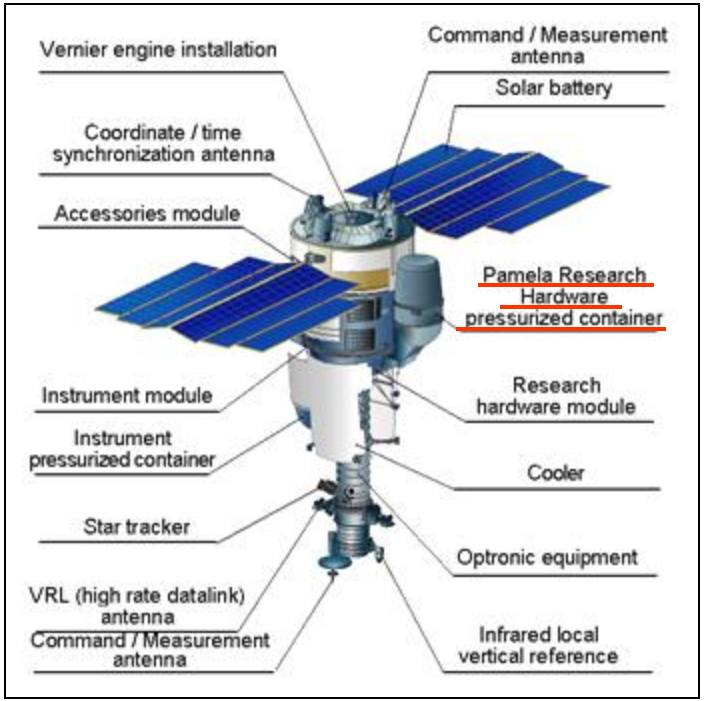
- tempo in orbita lungo
- recupero della strumentazione

Astrofisica: XMM - GLAST – AMS – Planck – Euclid …



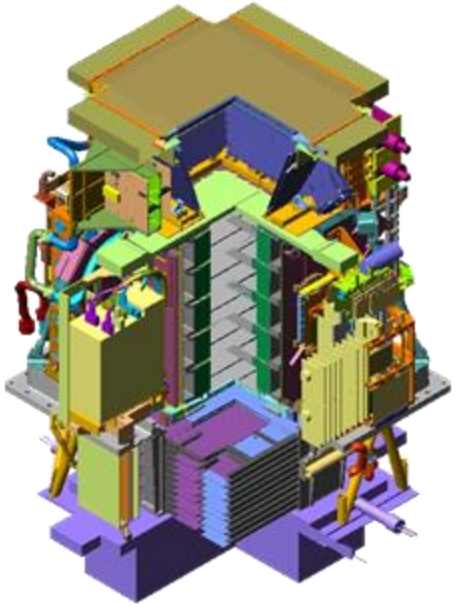


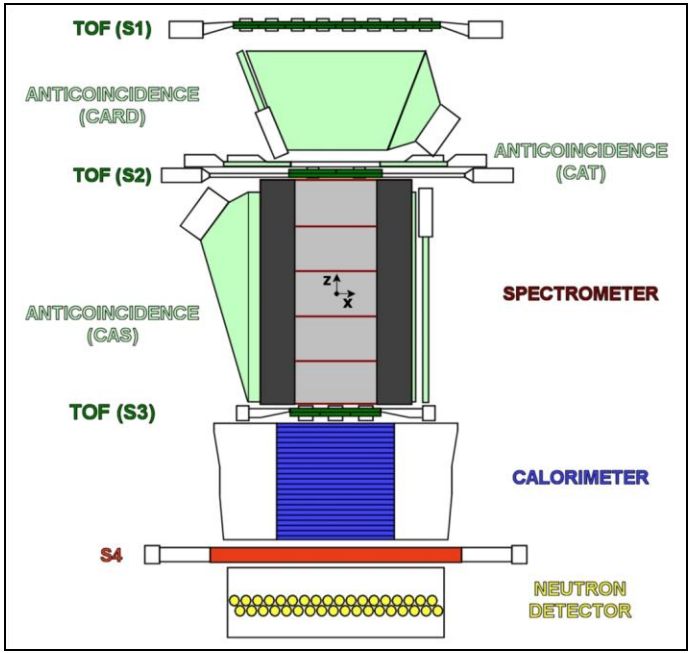
PAMELA 1/6



- Multi-spectral remote sensing of earth's surface
  - → near-real-time high-quality images
- Built by the Space factory TsSKB Progress in Samara (Russia)
- Operational orbit parameters:
  - inclination ~70°
  - altitude ~ 360-600 km (elliptical)
- Mass: 6.7 tons
- Active life >3 years
- Launch: 15/06/2006
- Data transmitted via Very high-speed Radio Link (VRL)

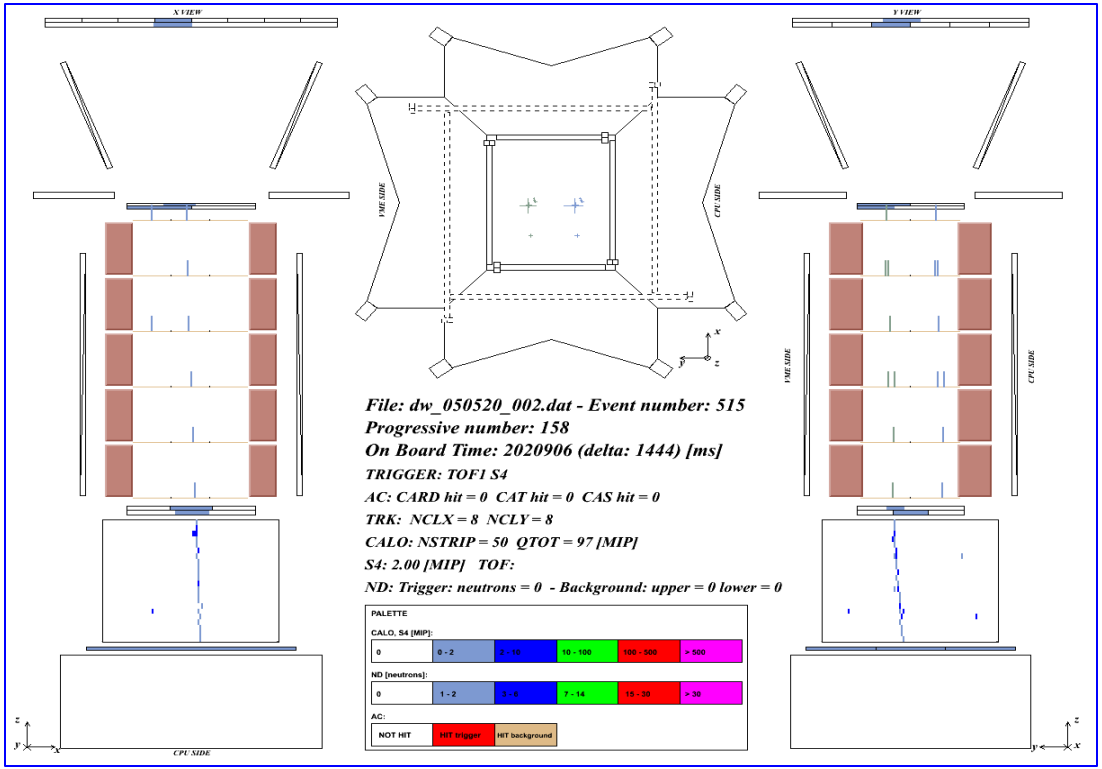
PAMELA 2/6





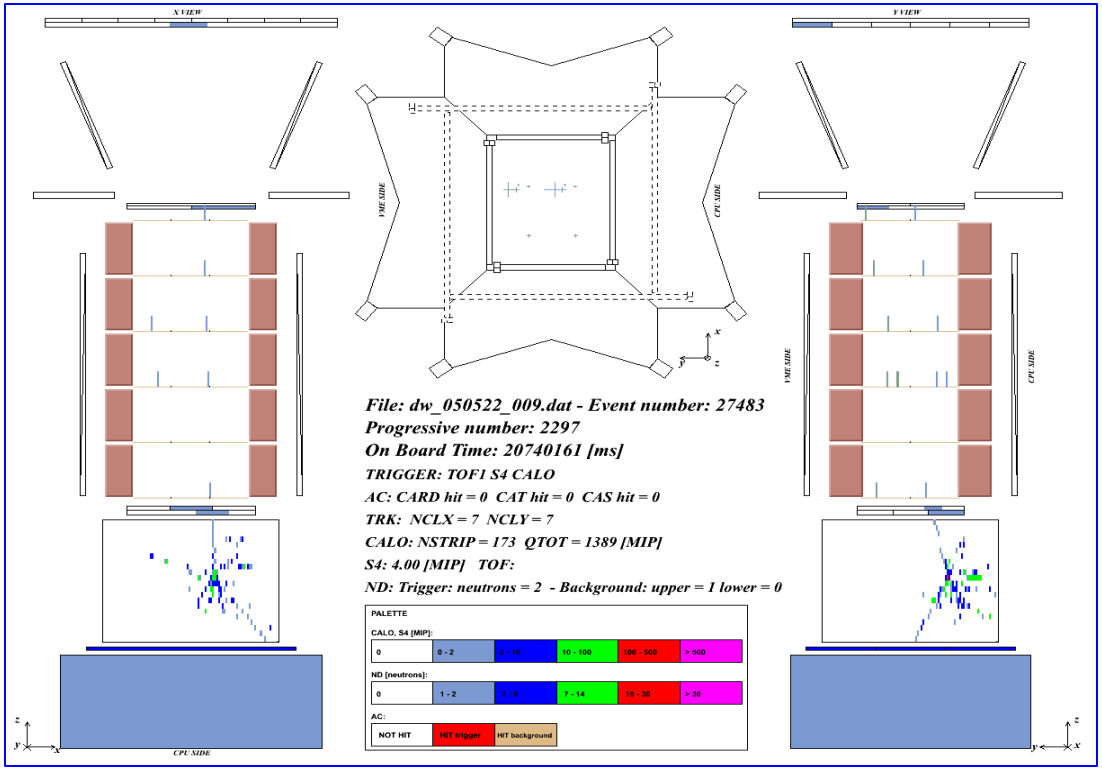
GF: 21.5 cm² sr
Mass: 470 kg
Size: 130x70x70 cm³
Power Budget: 360W

PAMELA 3/6



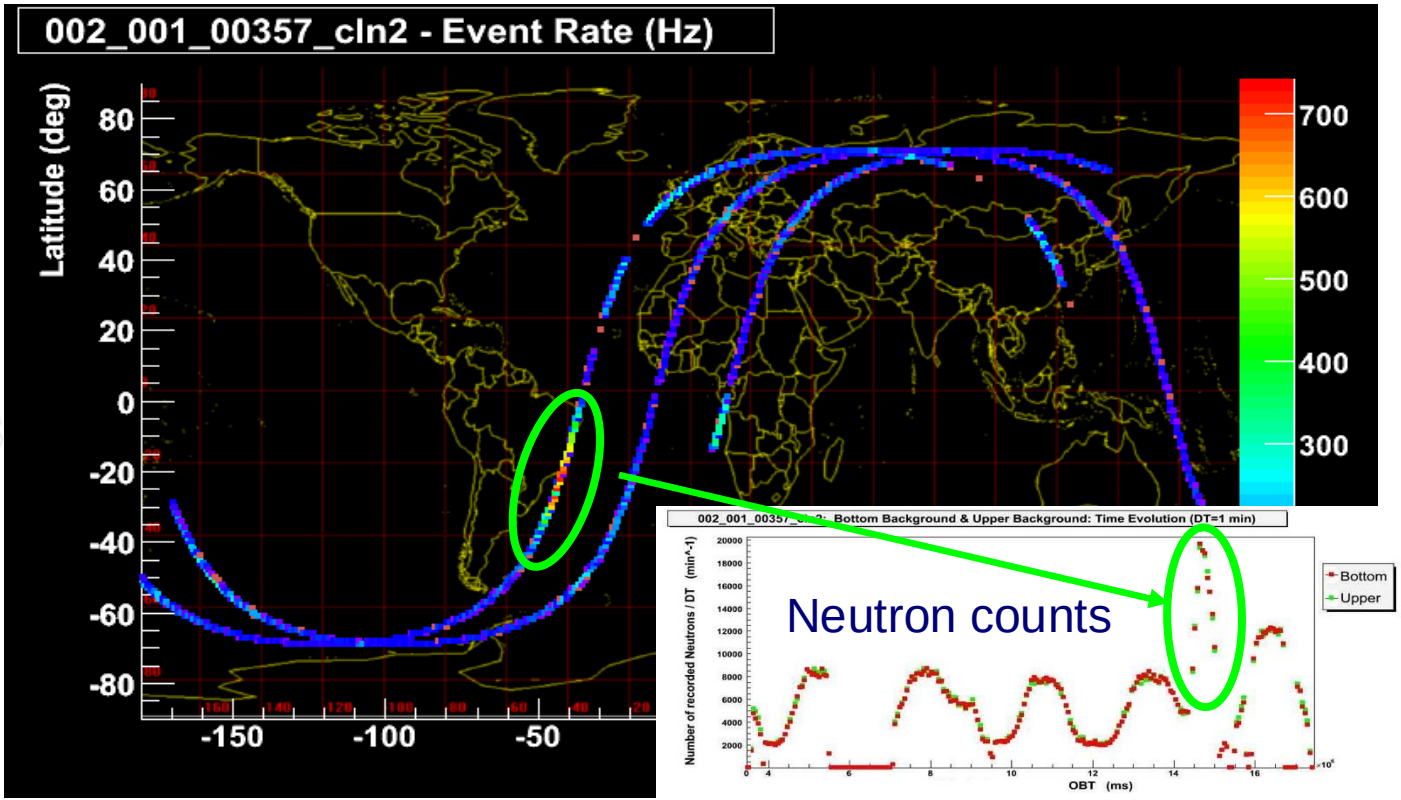
Non-interacting event

PAMELA 4/6



Interacting event

PAMELA 5/6


002_001_00357_cln2 - Event Rate (Hz)
Latitude (deg)
80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
700
600
500
400
300
Neutron counts
Number of recorded Neutrons / DT (min^-1)
OBT (ms)
Bottom
Upper

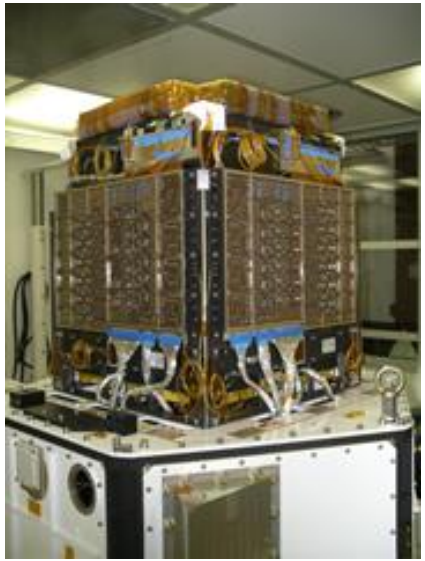
PAMELA 6/6

	energy range	particles/3 years
Antiproton flux	80 MeV - 190 GeV	~3×10^{4}
Positron flux	50 MeV – 270 GeV	~3×10^{5}
Electron flux	up to 400 GeV	~6×10^{6}
Proton flux	up to 700 GeV	~3×10^{8}
Electron/positron flux	up to 2 TeV (from calorimeter)	
Light Nuclei (up to Z=6)	up to 200 GeV/n	He/Be/C: ~$10^{7/4/5}$
AntiNuclei search	(sensitivity of the order of 10^{-7} in He/He)	

AGILE 1/2

Astrorivelatore Gamma Immagini LEggero

- Missione dedicata all'astrofisica gamma
- Optimal imaging capabilities in both the gamma-ray energy range (30 MeV-30 GeV) and hard X-ray range (15-60 keV)
- Scientific Team: researchers and engineers of INAF-IASF, INFN, and several Italian Universities. The project is headed by M. Tavani (Principal Investigator) and G. Barbiellini (Co-Principal Investigator)
- Participation of several leading companies from the Italian space industry, including CARLO GAVAZZI SPACE, ALCATEL-ALENIA Space LABEN, OERLIKON-CONTRAVES Space, TELESPAZIO, and MIPOT



AGILE 2/2

Major topics are:

- Active Galactic Nuclei
- Gamma Ray Bursts
- Pulsars
- Gamma-Ray Unidentified Sources
- Supernova Remnants
- Compact Objects and Binary Systems
- Gamma-ray Diffuse Emission
- TeV Sources
- Fundamental Physics

Gamma-ray Imaging Detector (GRID)		
Energy Range	30 MeV – 50 GeV	
Field of view	~ 3 sr	
Sensitivity at 100 MeV (ph cm^{-2} s^{-1} MeV^{-1})	6×10^{-9}	(5σ in 10^6 s)
Sensitivity at 1 GeV (ph cm^{-2} s^{-1} MeV^{-1})	4×10^{-11}	(5σ in 10^6 s)
Angular Resolution at 1 GeV	36 arcmin	(68% cont. radius)
Source Location Accuracy	~5–20 arcmin	S/N~10
Energy Resolution	$\Delta E/E\sim1$	at 300 MeV
Absolute Time Resolution	$\sim 1\,\mu$s	
Deadtime	$\sim 200\,\mu$s	
Hard X–ray Imaging Detector (Super-AGILE)		
Energy Range	10 – 40 keV	
Field of view	107°×68°	FW at Zero Sens.
Sensitivity (at 15 keV)	~5 mCrab	(5σ in 1 day)
Angular Resolution (pixel size)	~ 6 arcmin	
Source Location Accuracy	~2-3 arcmin	S/N~10
Energy Resolution	$\Delta E<4$ keV	
Absolute Time Resolution	$\sim 4\,\mu$s	
Deadtime (for each of the 16 readout units)	$\sim 4\,\mu$s	
Mini-Calorimeter		
Energy Range	0.3 – 200 MeV	
Energy Resolution	~ 1 MeV	above 1 MeV
Absolute Time Resolution	$\sim 3\,\mu$s	
Deadtime (for each of the 30 CsI bars)	$\sim 20\,\mu$s	

AGILE was successfully launched on April 23, 2007 by the Indian PSLV-C8 rocket from the Sriharikota base (Chennai-Madras).

The AGILE satellite was injected in the nominal equatorial orbit in agreement with the Scientific Requirements of the Mission. The satellite was tracked during its first pass over the ASI Malindi ground station in Kenya on Apr. 23rd. During its first orbit, its radio signal was also independently detected from the Sriharikota and Bangalore ground stations. The satellite is now in the initial Commissioning Phase. All test results are nominal.

AGILE 2/2

Major topics are:

- Active Galactic Nucle
- Gamma Ray Bursts
- Pulsars
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- Compact Objects and
- Gamma-ray Diffuse E
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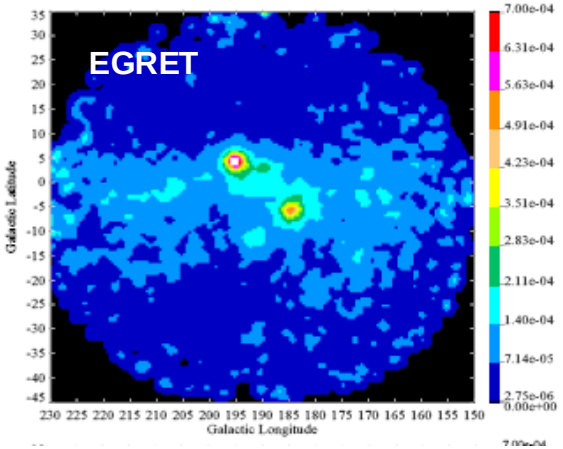

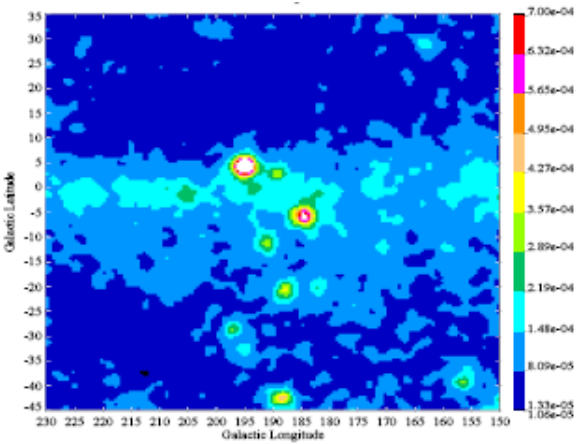

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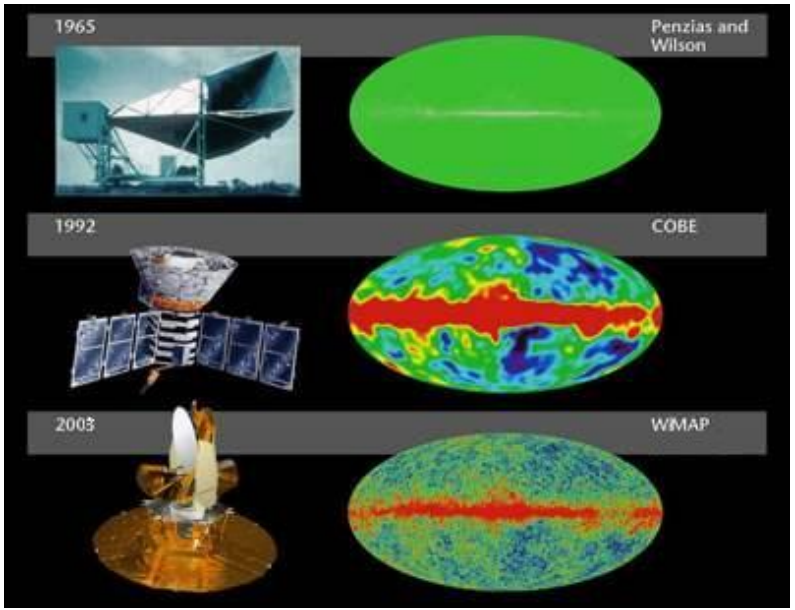
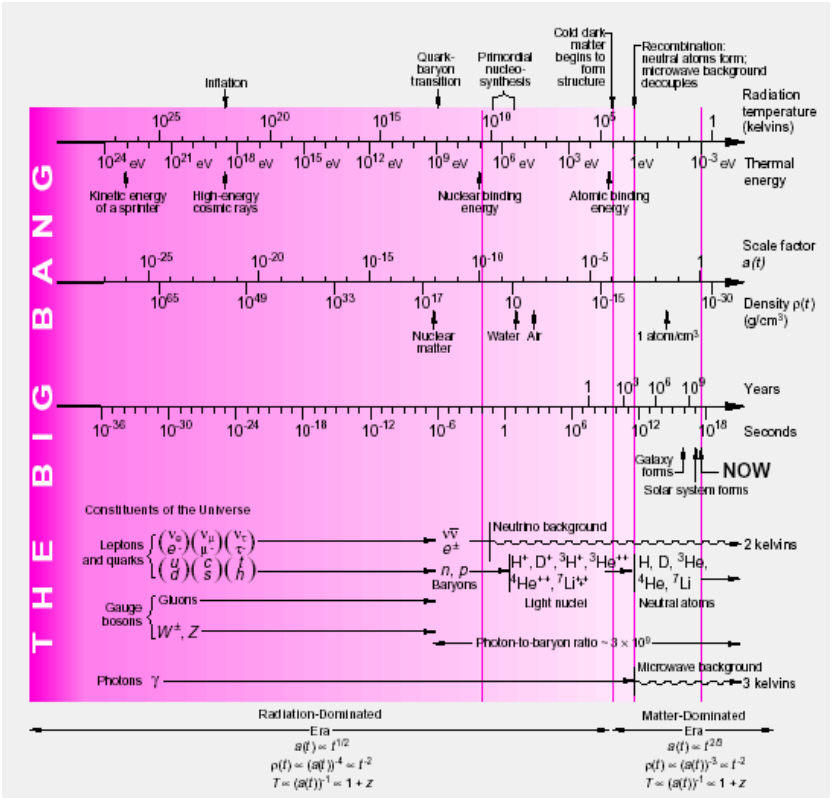
Planck 1/3

Cosmic Microwave Background





Planck 2/3

Planck was the third mission on CMB (first european)

- Better sensitivity ($\Delta T/T \sim 2 \times 10^{-6}$) and angular resolution (up to 5')
- Wider frequency range

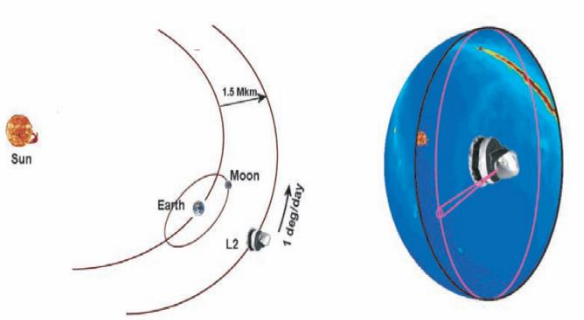
Main scientific Objectives:

- Determination of geometry of the Universe
- Determination of the correct theory about the Universe origin and evolution
- Complete map of CMB anisotrophies

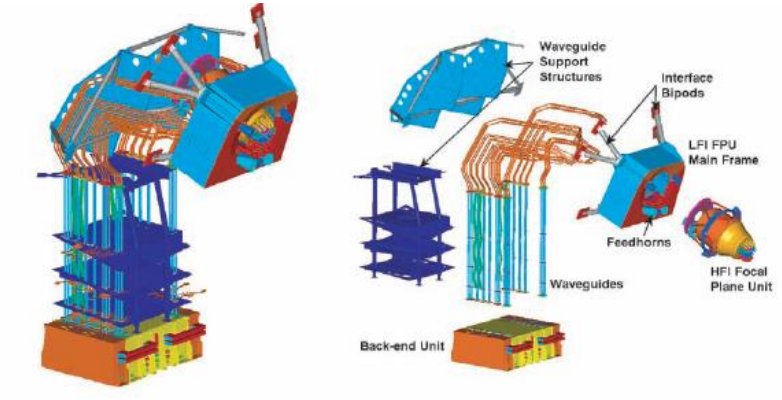
Orbit: Lissajous around Lagrangian point L2 of Earth-Sun-Moon system

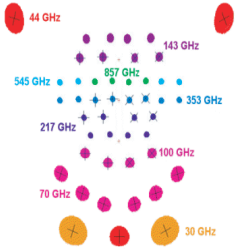
Distance from the Earth: 1.5 x 10^6 km

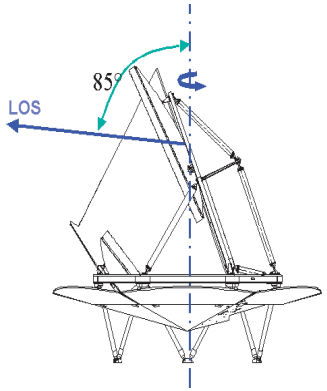
Spin axis: opposite direction respect to the Sun

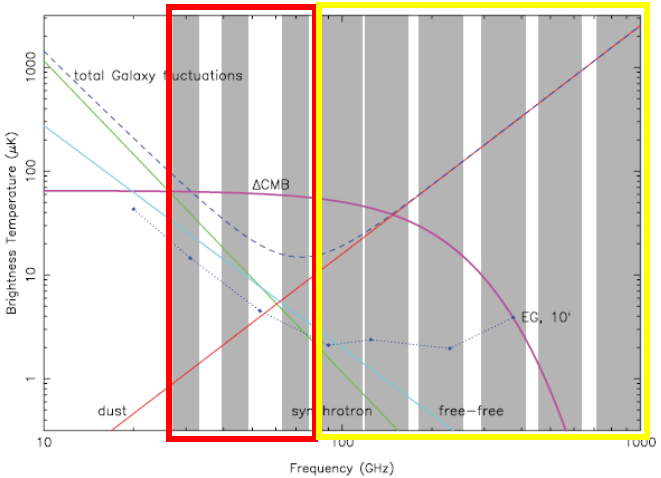


Planck 3/3









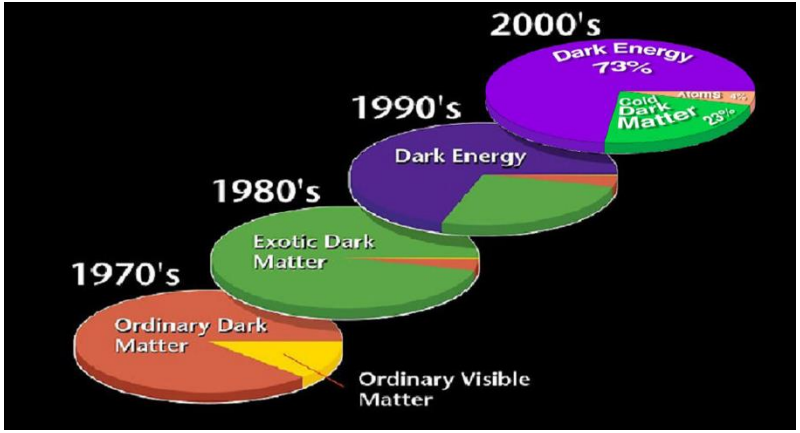
Centre frequency (GHz)	30	44	70
Bandwidth (GHz)	6	8.8	14
Angular resolution (arcminutes, FWHM)	33	24	14
Detector temperature (K)	20 K		
ΔT/T Intensity [10^{-6} μK/K]	2.0	2.7	4.7
ΔT/T polarization [μK/K]	2.8	3.9	6.7

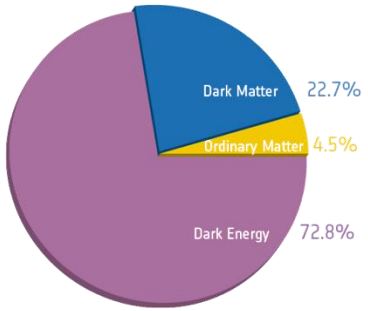
ASTROPHYSICS: Euclid

Age of the Universe:
13.8 billion years

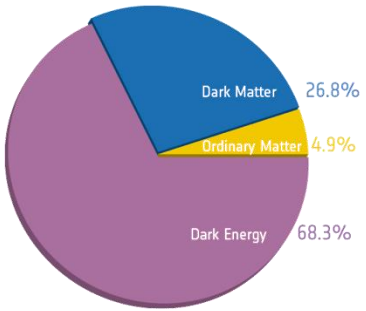
Composition:

5%	ordinary matter
27%	dark matter
68%	dark energy





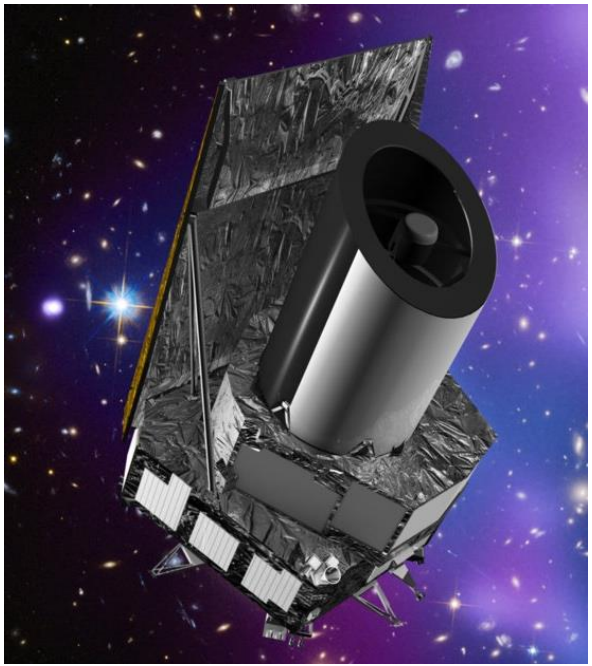
Before Planck



After Planck

ASTROPHYSICS: Euclid

- A telescope in space to explore the DARK Universe
- ESA mission, in collaboration with the European scientific community, USA, Canada 13 countries, 1000 researchers
- Launch: July 2023, 7 years

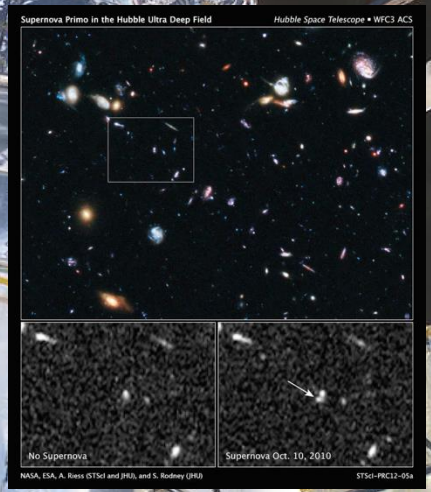


Scientific objectives:
Map the Universe across 10 billion light years, to reveal the history of its expansion and structure.
Imaging in the visible and near-infrared provides the morphology and colours of billions of galaxies down to z~2 (11 billion years ago).

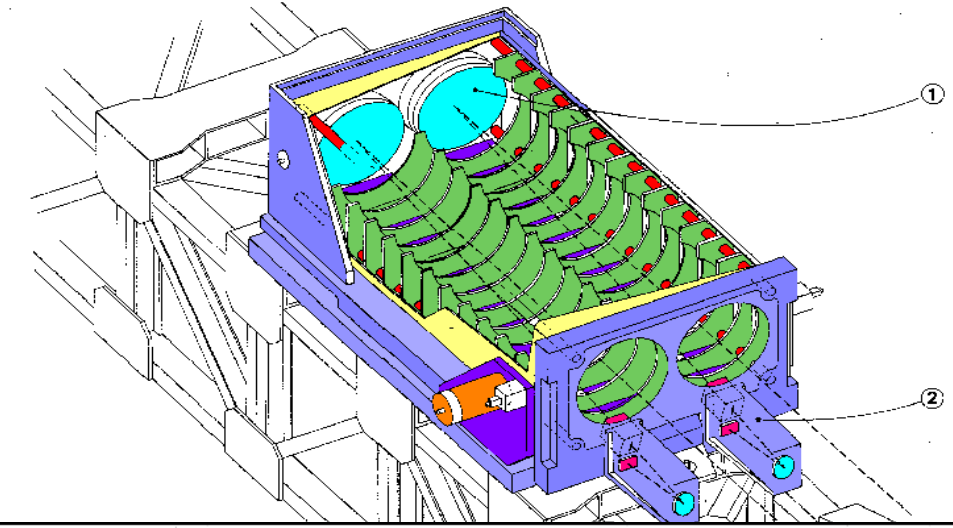
Mass	2˙100 kg
Payload Mass	855 kg
Size	4.5 × 3.1 m
Telemetry	855 Gbit/day
2 instruments	VIS, NISP

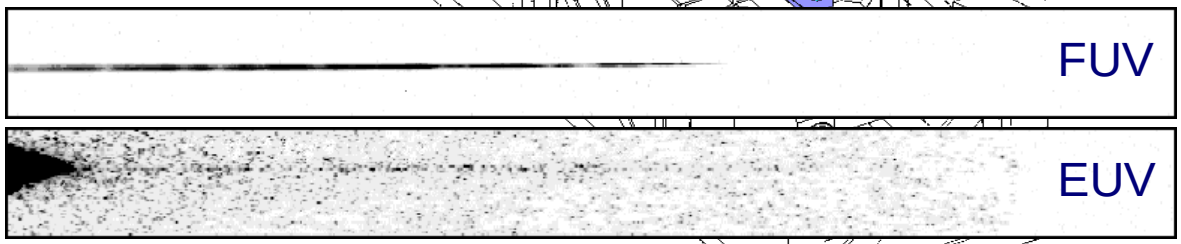
36 × 16 million of CCD pixels – Visible
16 × 4 million of detector pixels – Infra-Red

Astronomia: Hubble



Astronomia: UVSTAR 1/4



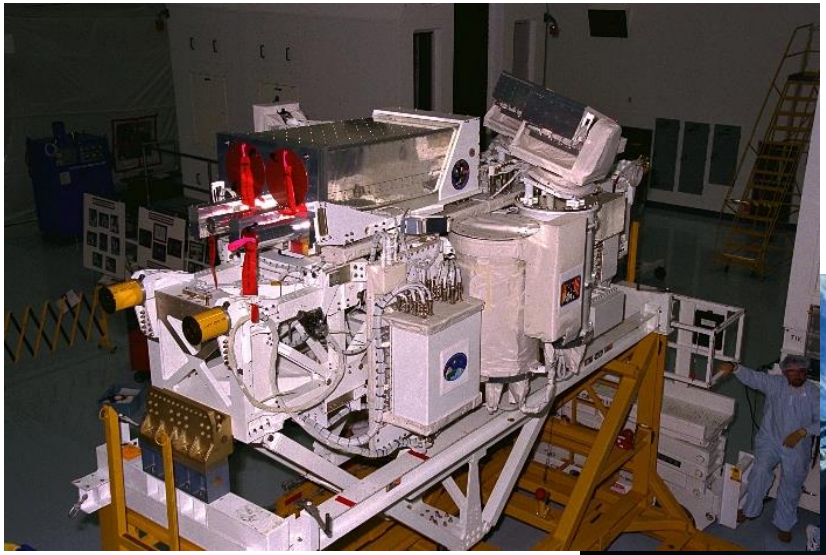


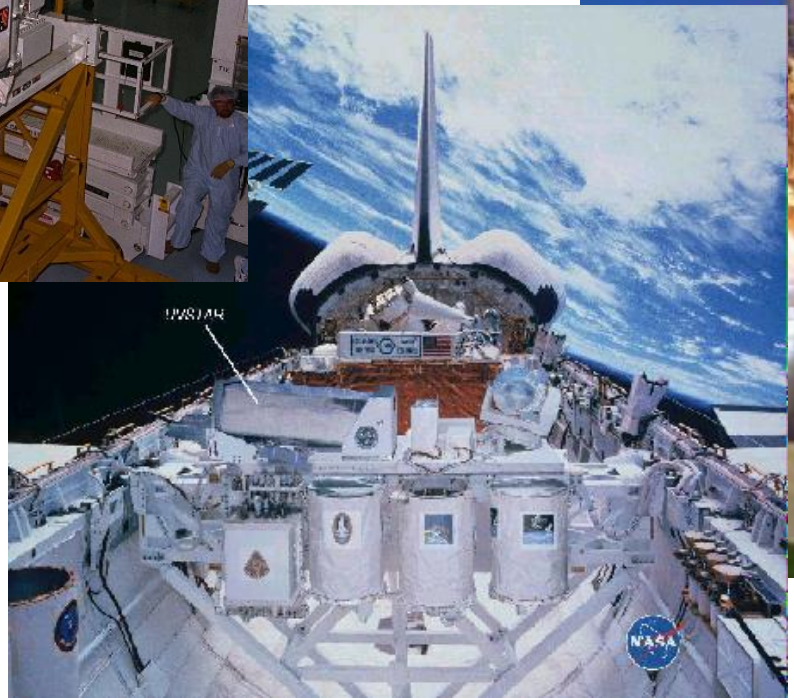
spazio

Lunghezza d'onda

1. Mirrors
2. Spectrographs / Detectors
3. Hitchhiker – M Bridge

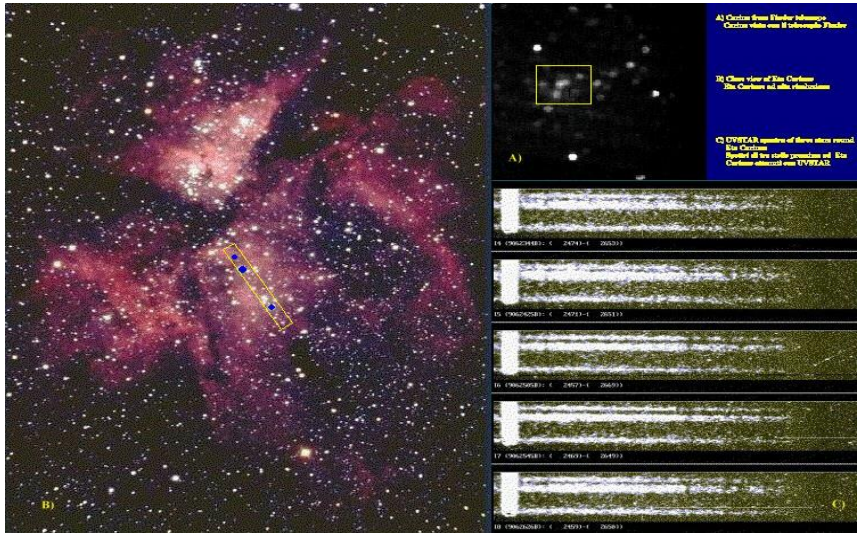
Astronomia: UVSTAR 2/4

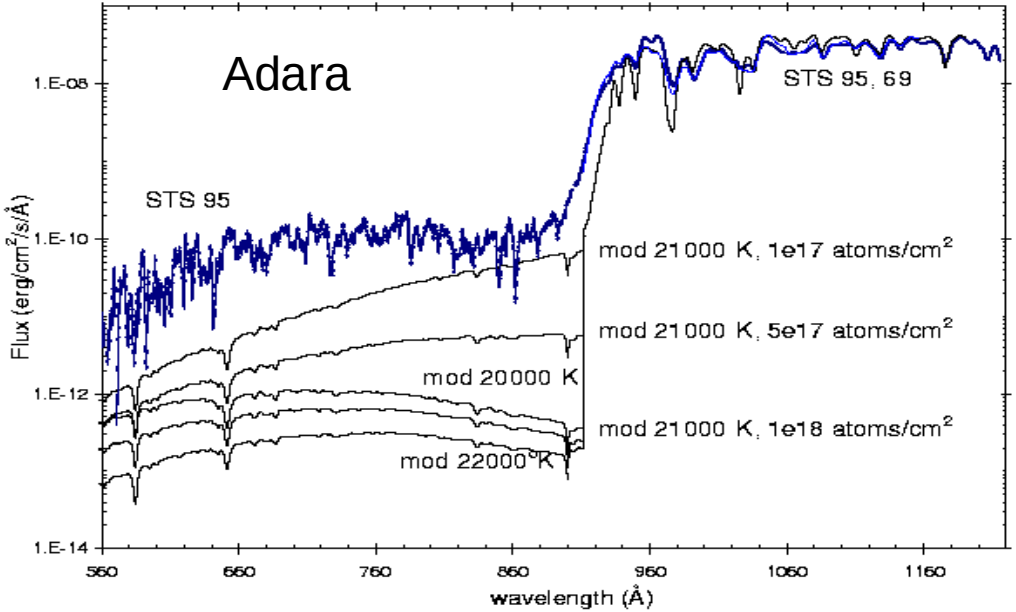




Astronomia: UVSTAR 3/4

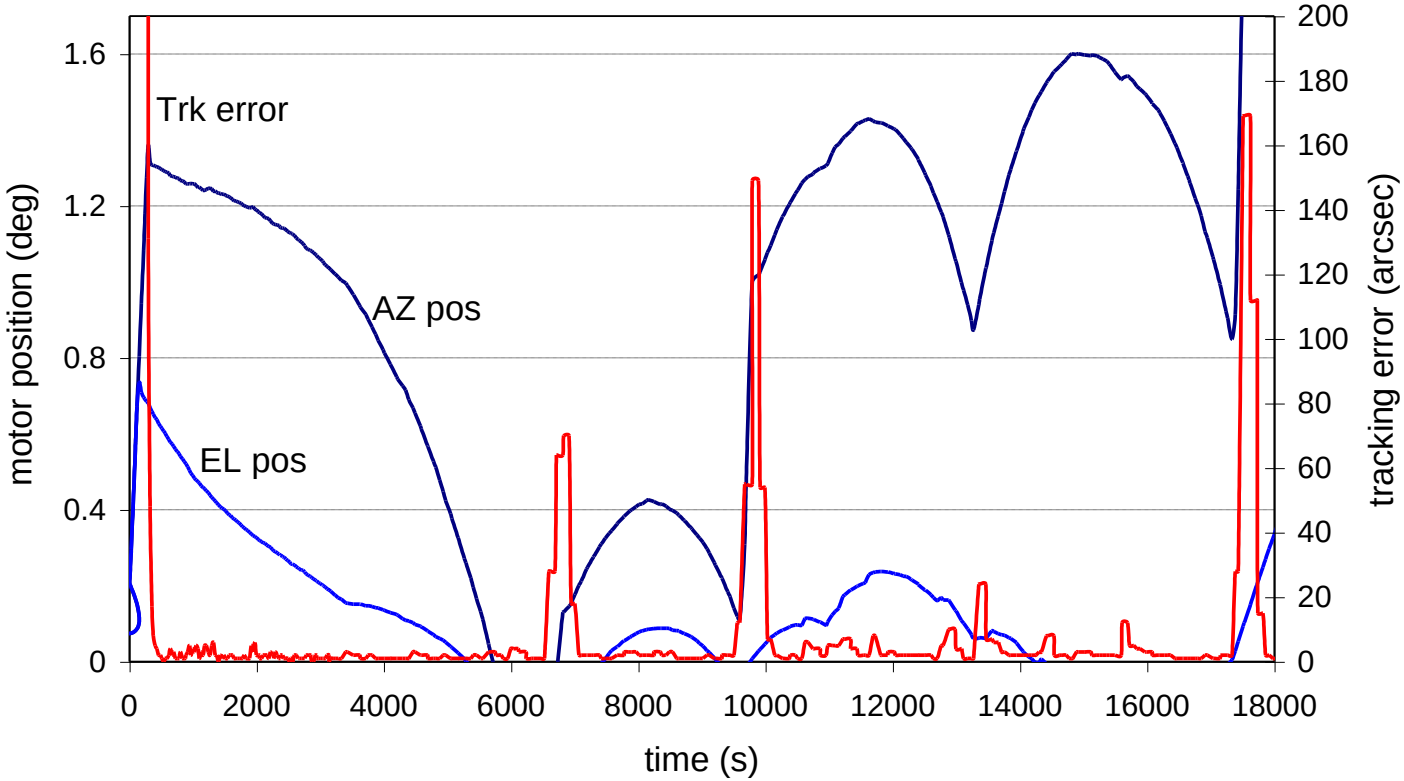
- sistema di movimentazione autonomo munito di 2 telescopi ausiliari per la direzione di puntamento
- osserva atmosfere stellari, regioni HII, anelli di IO, comete
- analisi spettrale del flusso nelle varie componenti UV (FUV/EUV)



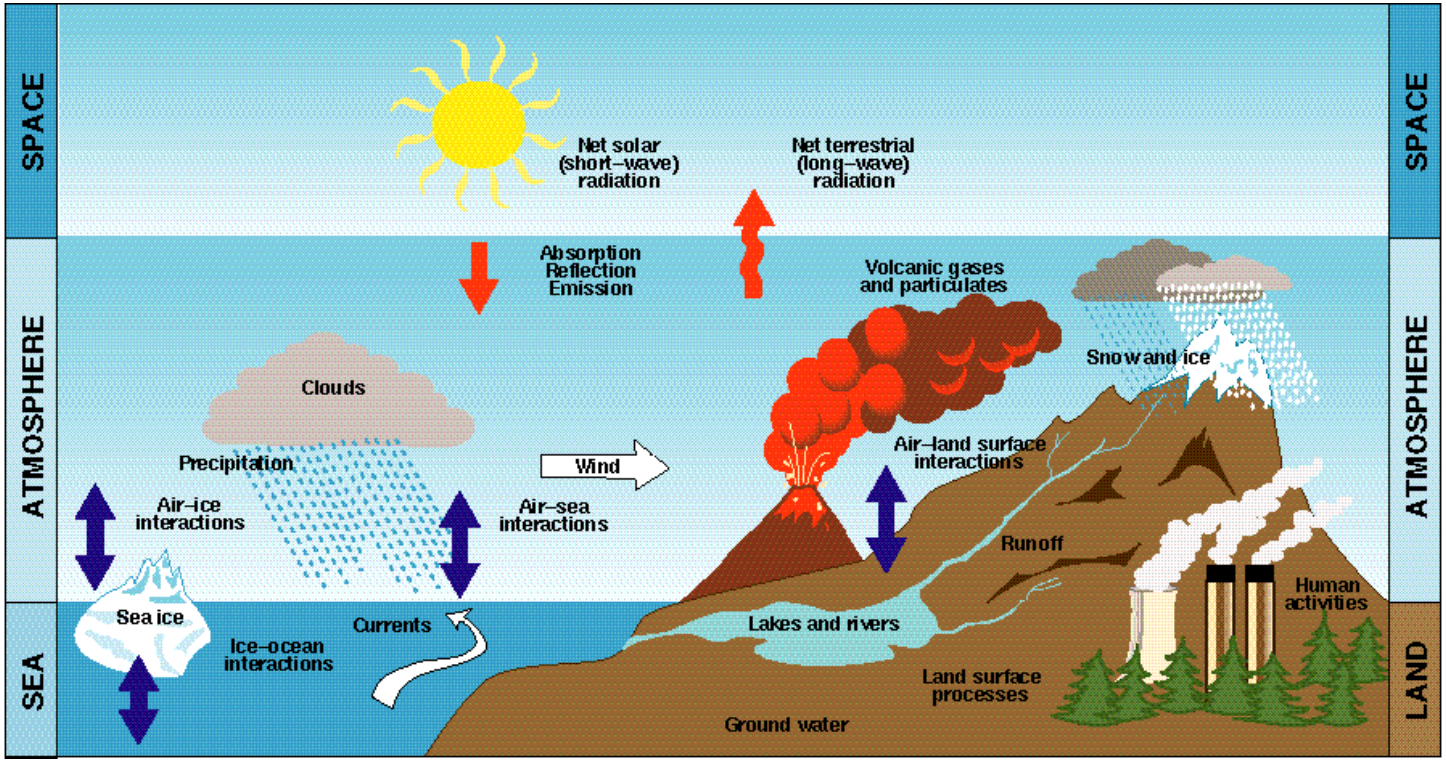


Astronomia: UVSTAR 4/4

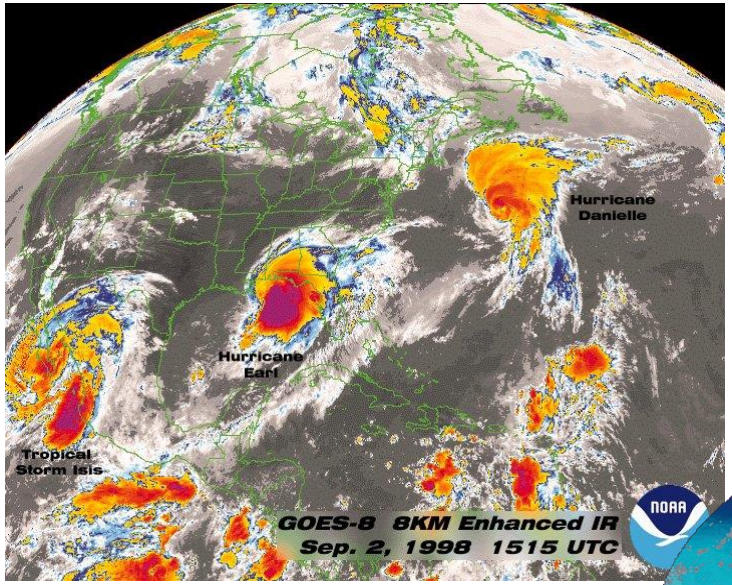
Risultati tecnologici: sistema di puntamento

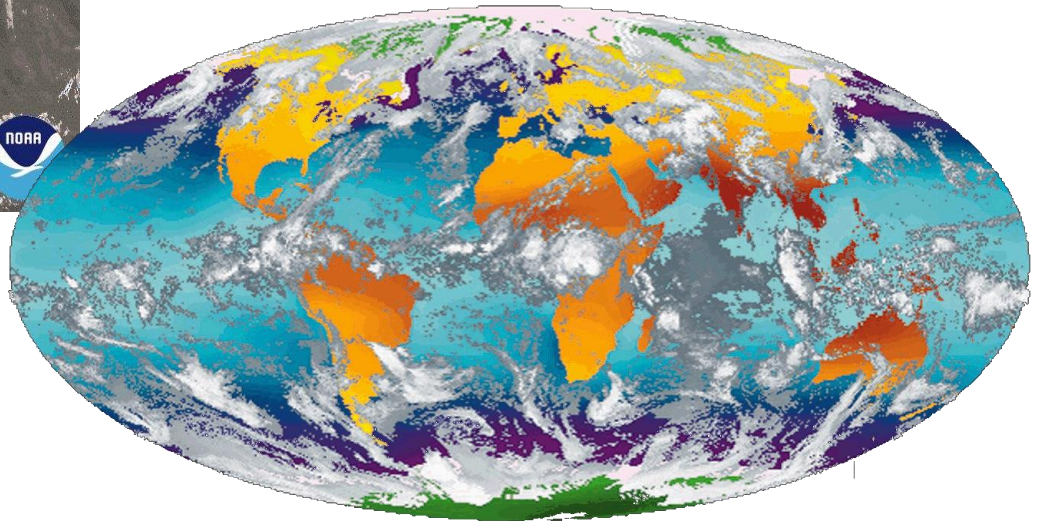


Fisica della Terra

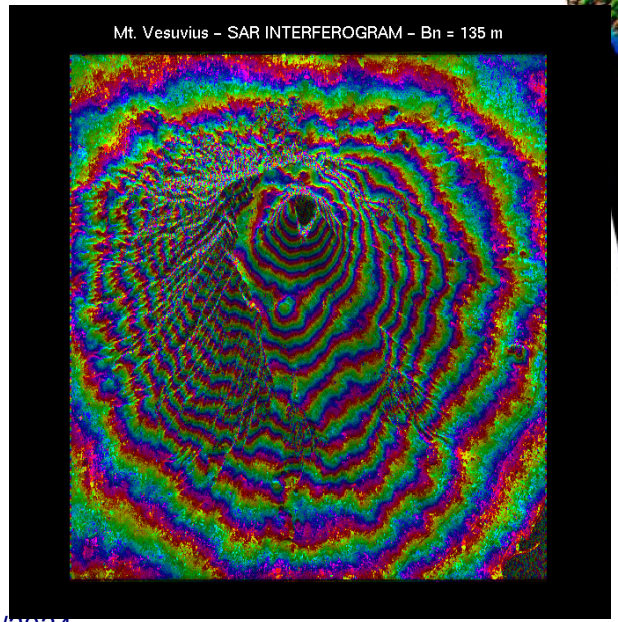


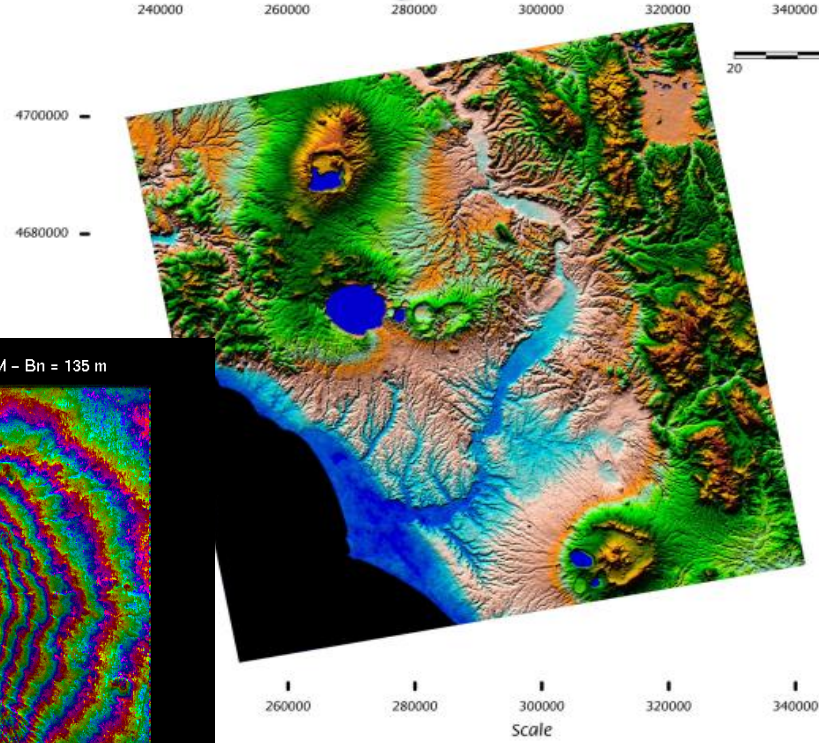
Metereologia

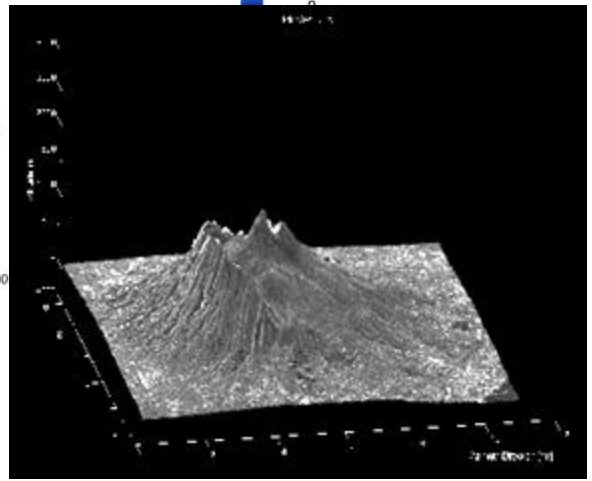




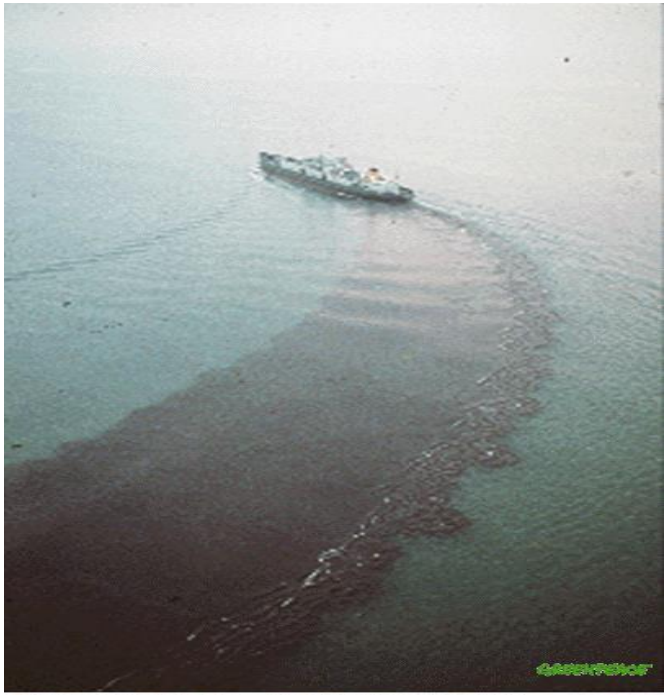
Geologia: Vesuvio



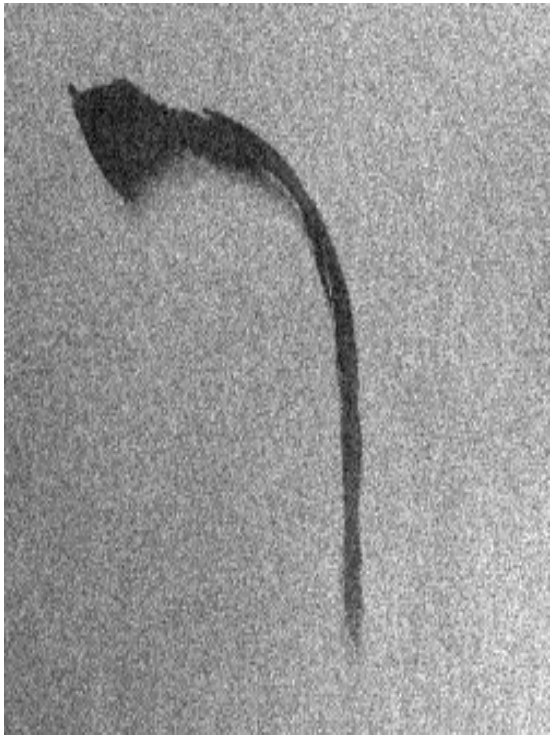




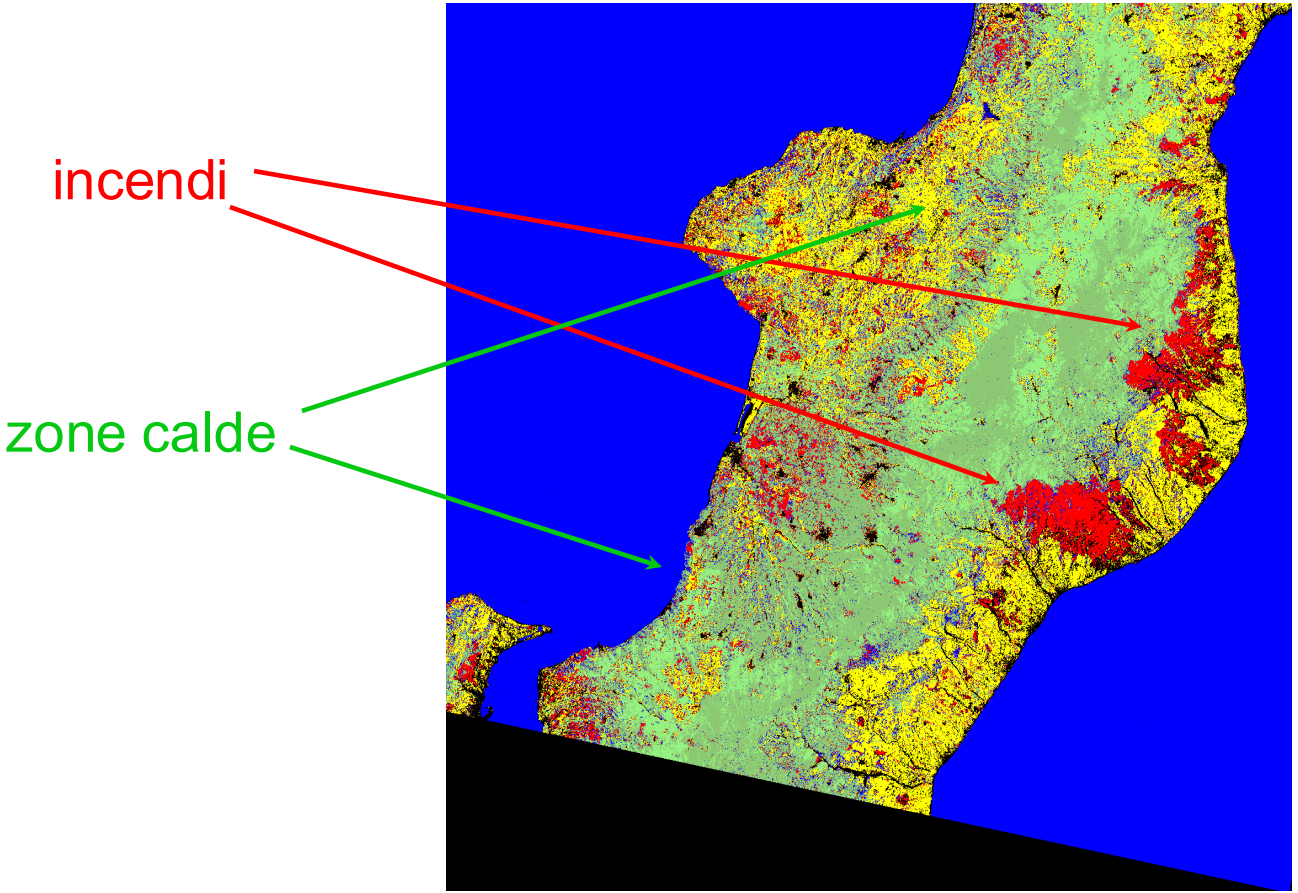
Ambiente: Inquinamento



Thames Water Authority dump ship dumping sewage in the North Sea.
Copyright Greenpeace / Morgan 1989



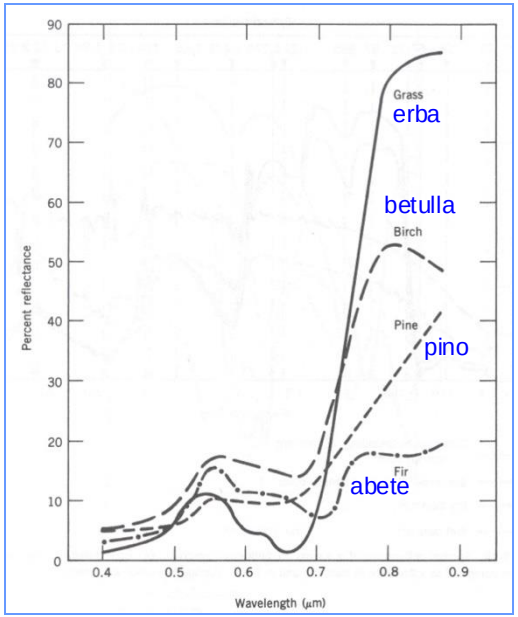
Ambiente: Controllo Incendi

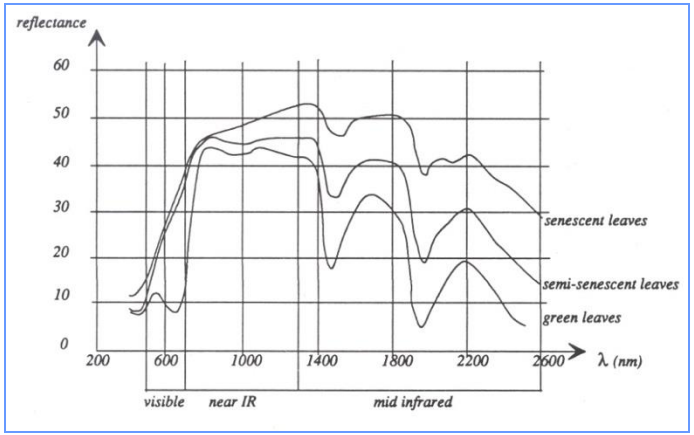


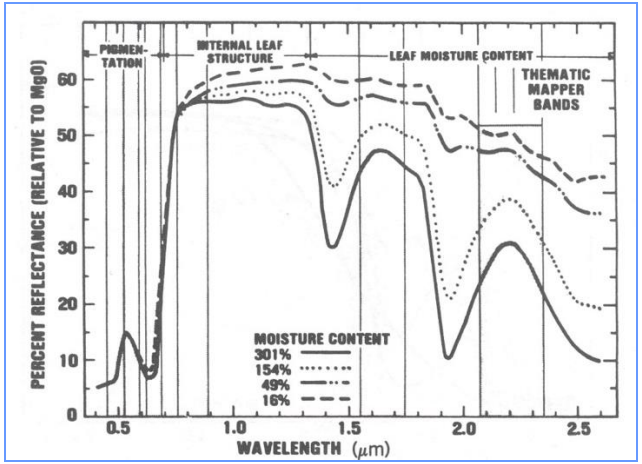
Biologia: vegetazione

Vegetation spectral signatures vary with

- leaf state
- canopy species
- leaf moisture content
- phenological stage



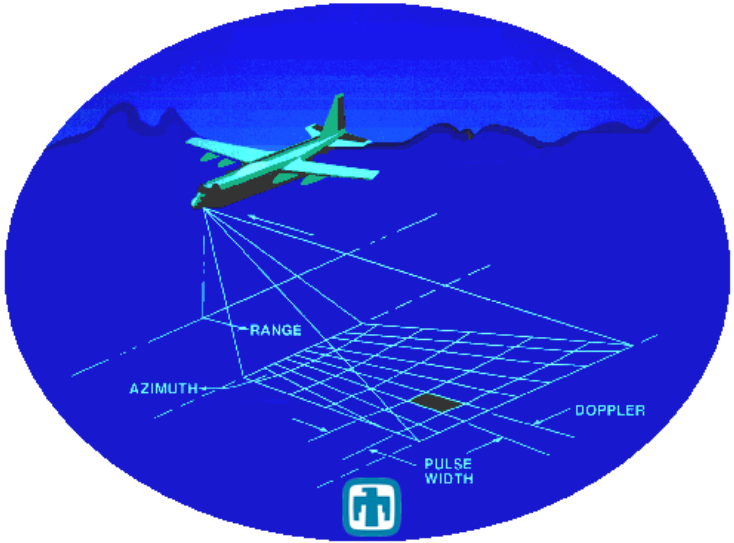


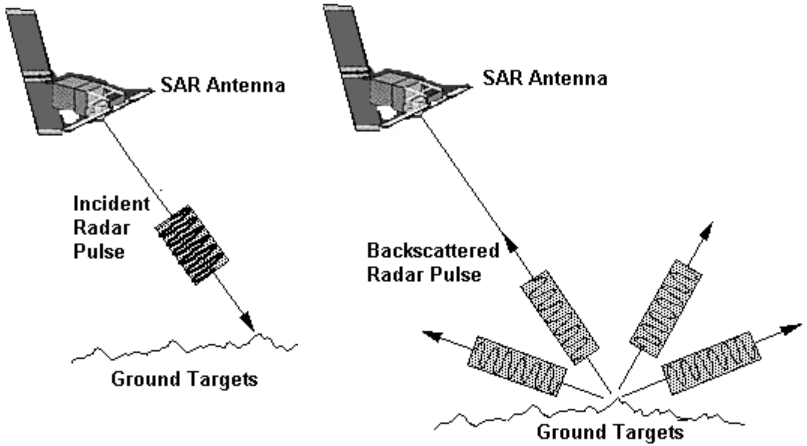


Synthetic Aperture Radar - SAR

Radio Signals

- Long range propagation characteristics
- Reduced effect of weather conditions
- Unique response of terrain





Synthetic Aperture Radar - SAR

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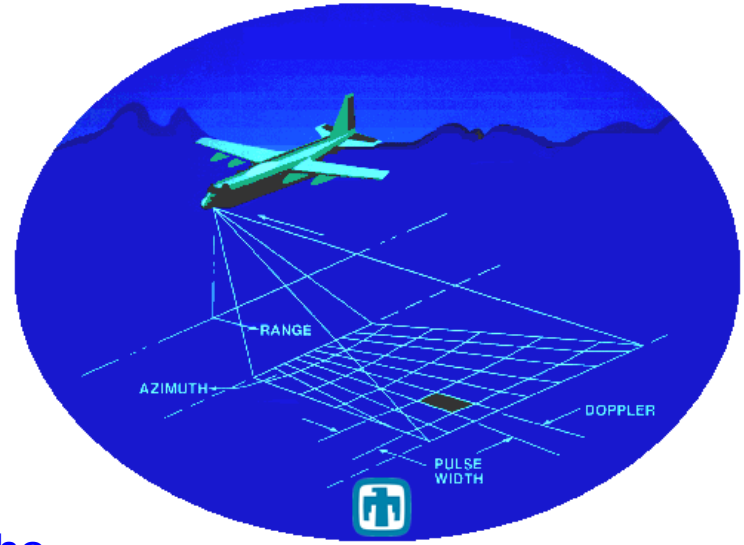
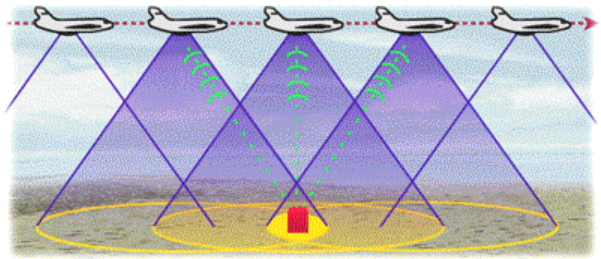


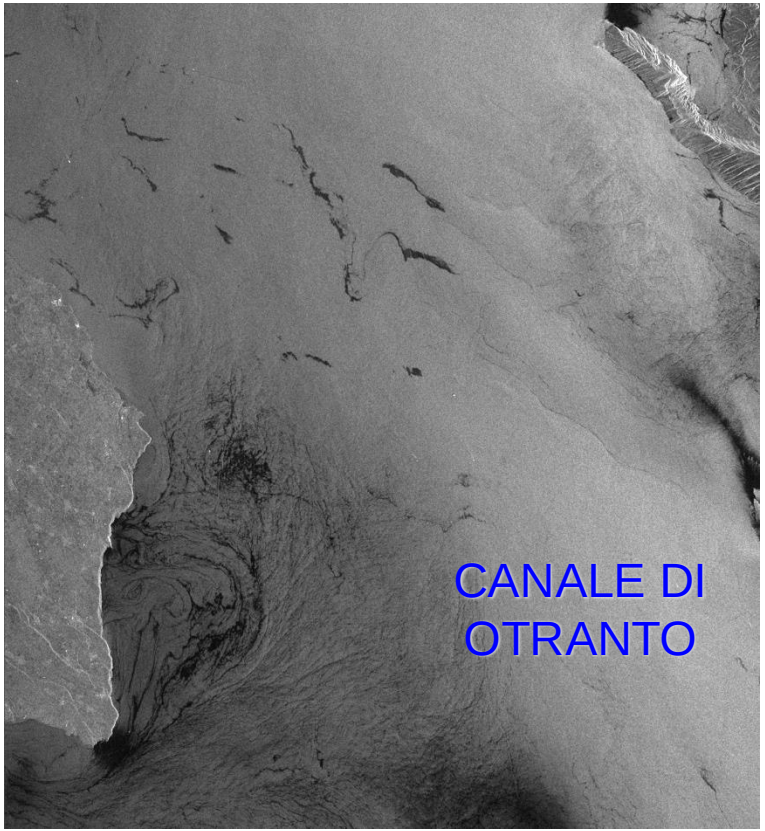
2-dim image

- Range: time between signal transmission and echo (resolution $\propto$ signal width)
- Azimuth: doppler shift processing (resolution $\propto$ beam dimension $\propto$ 1/antenna length)
  - Resolution ~ λ R/d
  - R~50 km, λ~0.03 m, resolution~1 m $\Rightarrow$ d~1.5 km!

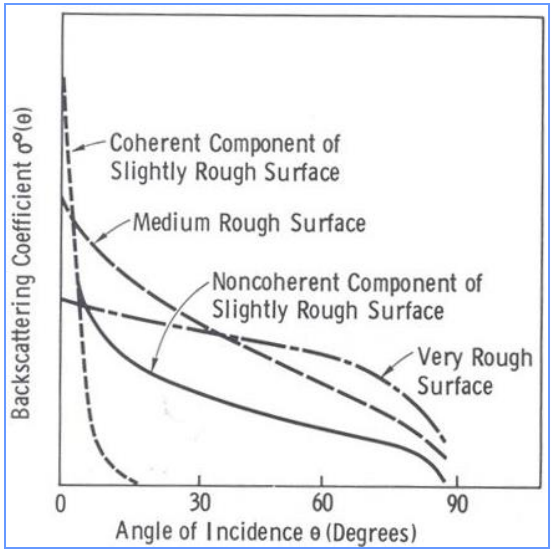
$\Rightarrow$ Synthetic Aperture !!!



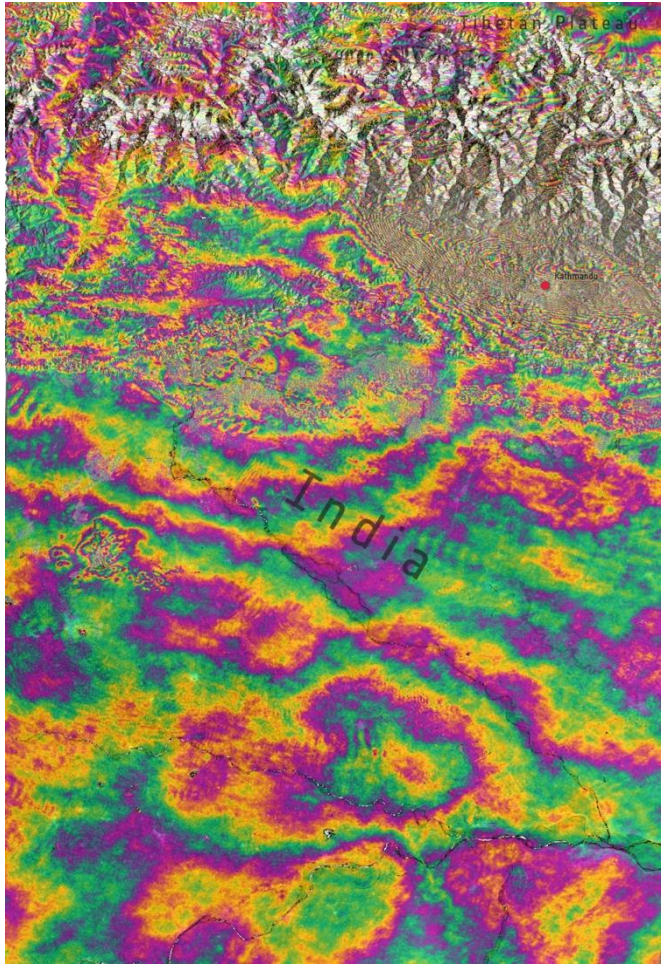
Imaging Radar: light reflectance, back-scattering



Surface rugosity is the second primary driver in radar signature

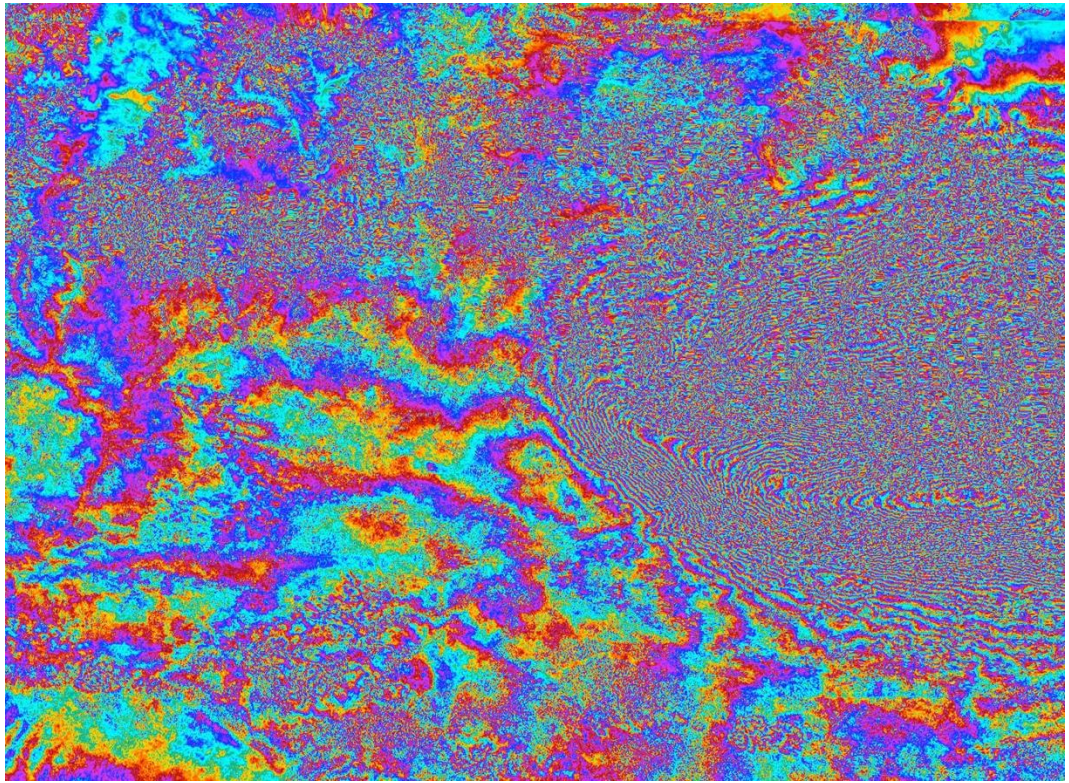


Sentinel 1 2015 - Nepal earthquake



- Combining two Sentinel-1A radar scans from 17 and 29 April 2015, this interferogram shows changes on the ground that occurred during the 25 April earthquake that struck Nepal. An overall area of 120x100 km has moved – half of that uplifted and the other half, north of Kathmandu subsided. Vertical accuracy is a few cm

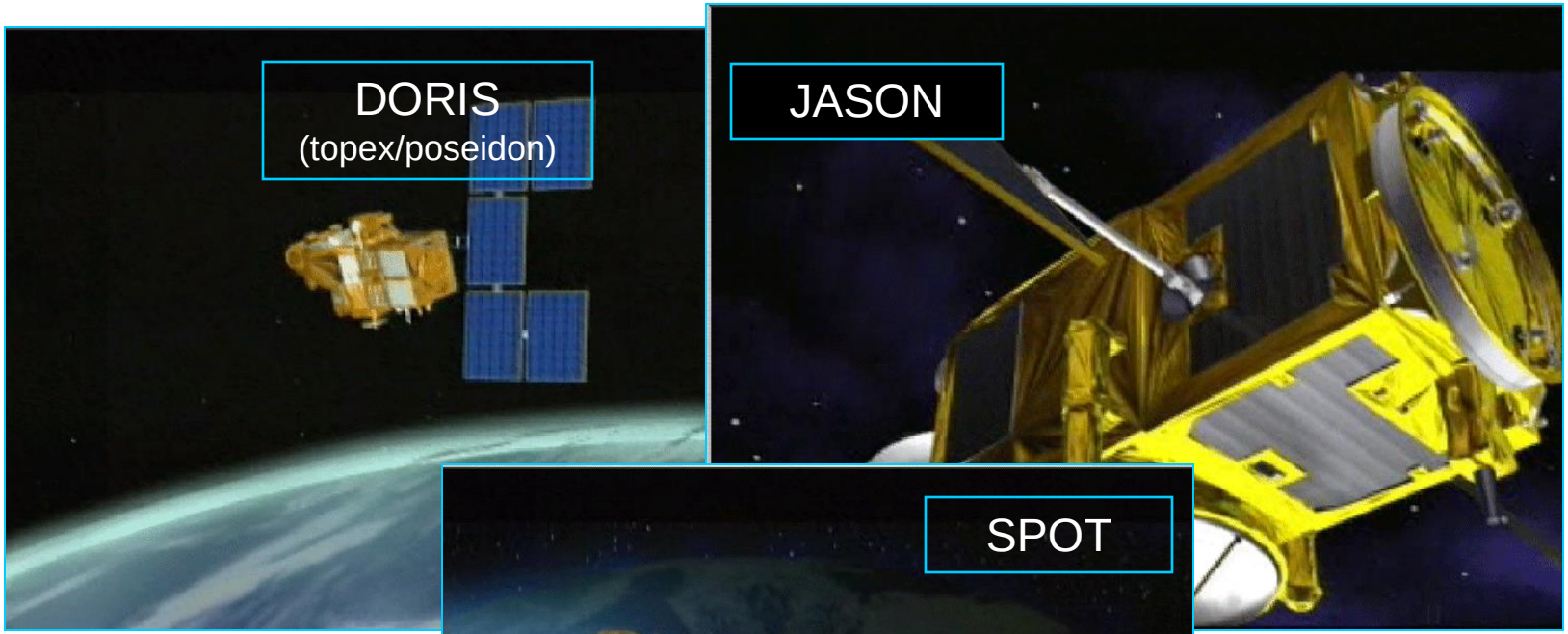
Sentinel 1 2015 - Nepal earthquake



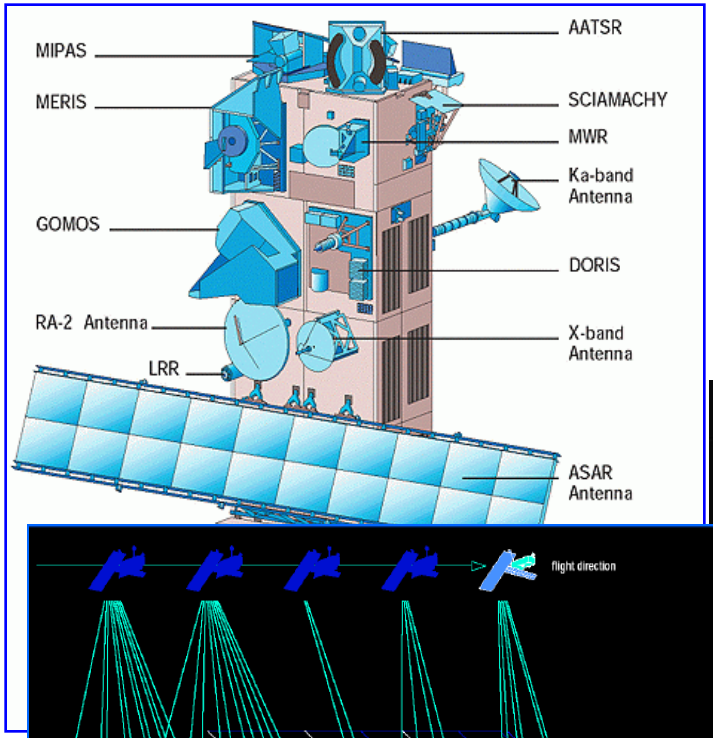
Interferogram over Kathmandu generated from two Sentinel-1A scans on 17 and 29 April 2015 – before and after the 25 April earthquake.

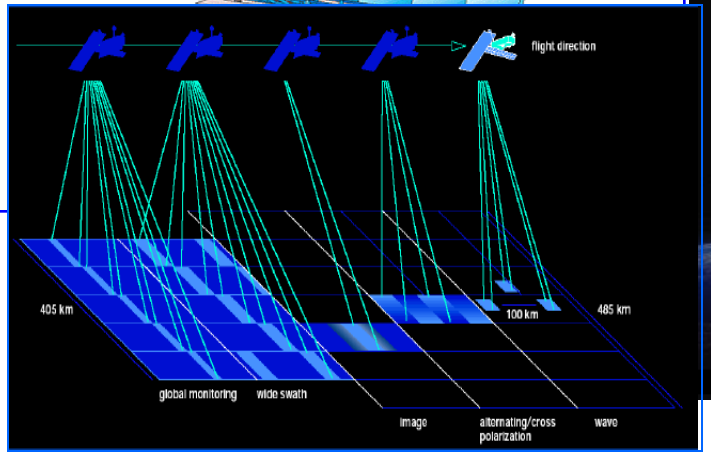
Each ‘fringe’ of colour represents about 3 cm of deformation. The large amount of fringes indicates a large deformation pattern with ground motions of 1 m or more

Osservazioni della Terra



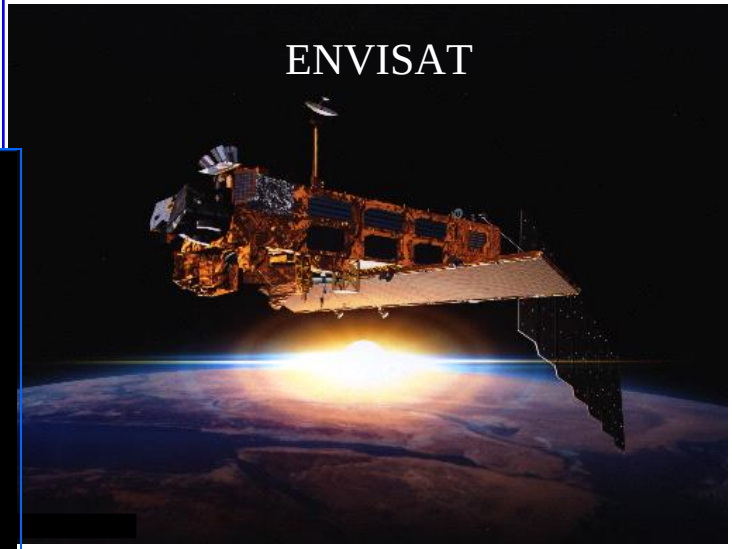
Strumenti di Envisat



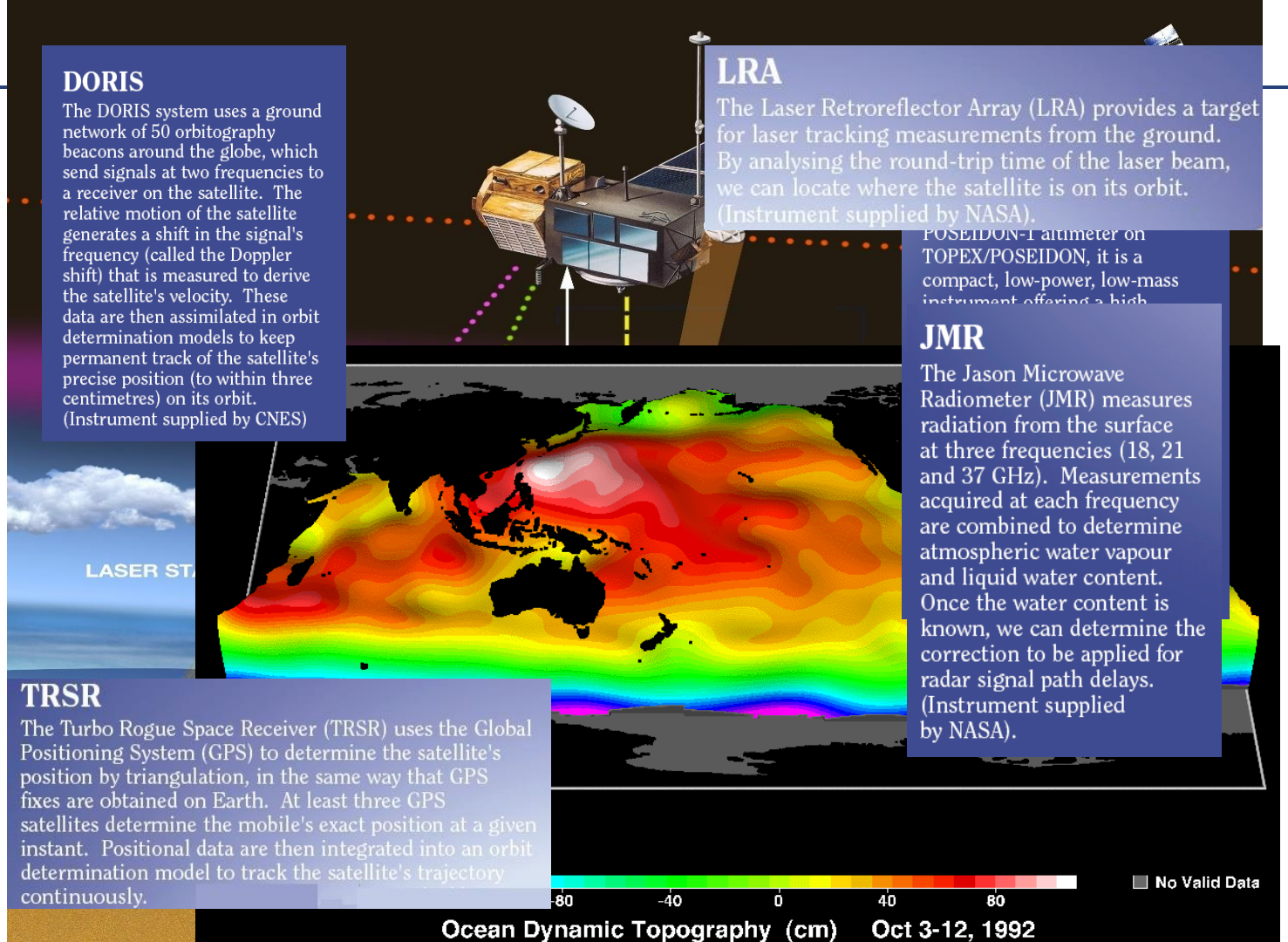


ASAR: Advanced Synthetic Aperture Radar

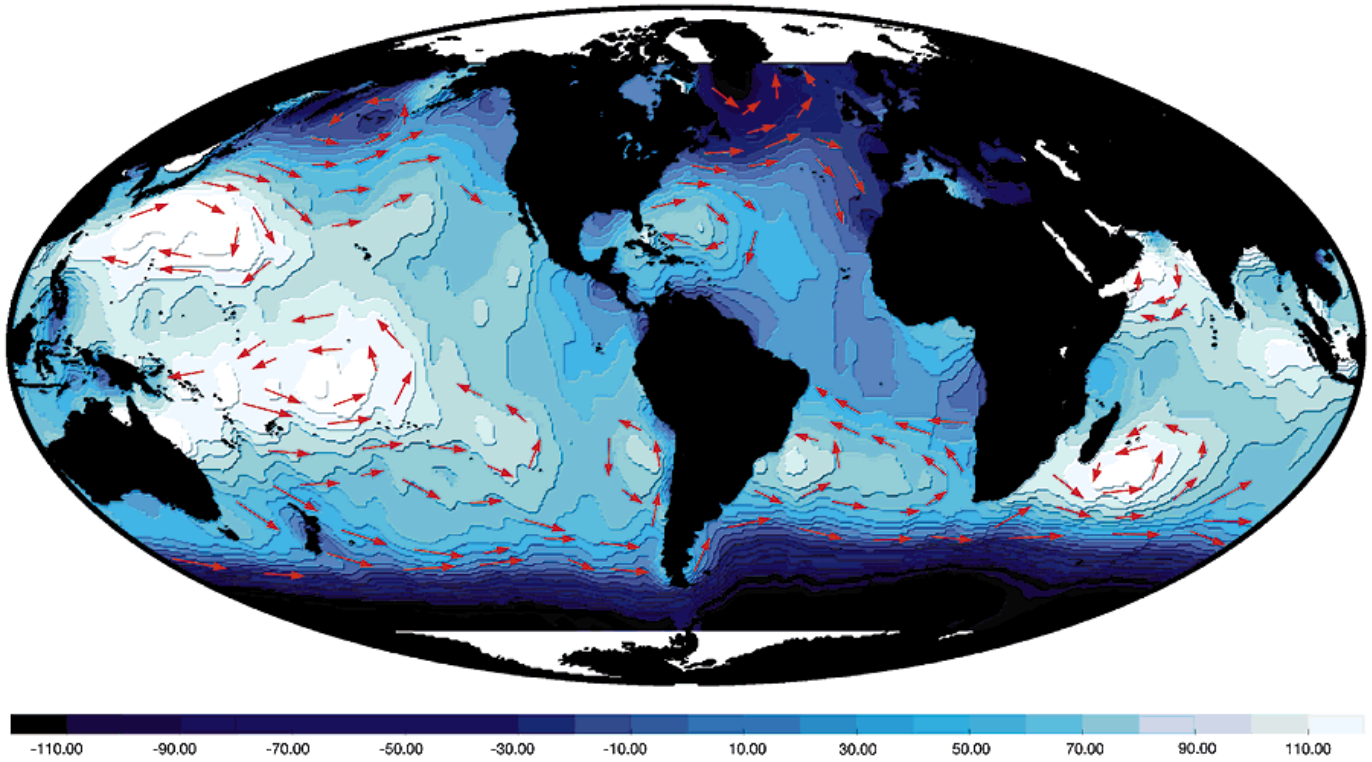
Immagini radar ad alta risoluzione dell'ambiente terrestre in qualsiasi condizione ambientale e di illuminazione



TOPEX-POSEIDON: Studio degli Oceani

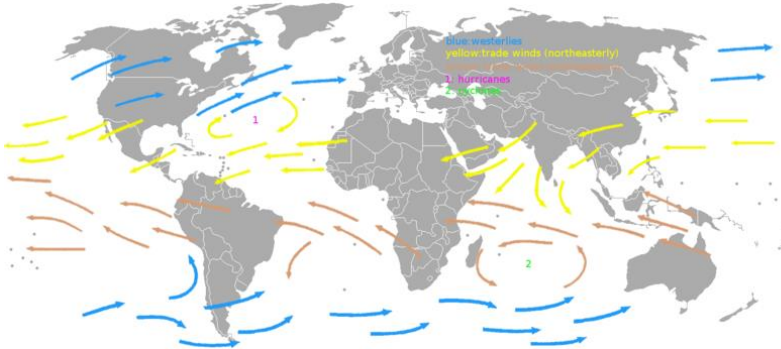

DORIS
The DORIS system uses a ground network of 50 orbitography beacons around the globe, which send signals at two frequencies to a receiver on the satellite. The relative motion of the satellite generates a shift in the signal's frequency (called the Doppler shift) that is measured to derive the satellite's velocity. These data are then assimilated in orbit determination models to keep permanent track of the satellite's precise position (to within three centimetres) on its orbit. (Instrument supplied by CNES)
LRA
The Laser Retroreflector Array (LRA) provides a target for laser tracking measurements from the ground. By analysing the round-trip time of the laser beam, we can locate where the satellite is on its orbit. (Instrument supplied by NASA).
POSEIDON-1 altimeter on TOPEX/POSEIDON, it is a compact, low-power, low-mass
JMR
The Jason Microwave Radiometer (JMR) measures radiation from the surface at three frequencies (18, 21 and 37 GHz). Measurements acquired at each frequency are combined to determine atmospheric water vapour and liquid water content. Once the water content is known, we can determine the correction to be applied for radar signal path delays. (Instrument supplied by NASA).
LASER ST
TRSR
The Turbo Rogue Space Receiver (TRSR) uses the Global Positioning System (GPS) to determine the satellite's position by triangulation, in the same way that GPS fixes are obtained on Earth. At least three GPS satellites determine the mobile's exact position at a given instant. Positional data are then integrated into an orbit determination model to track the satellite's trajectory continuously.
-80
-40
0
40
80
No Valid Data
Ocean Dynamic Topography (cm) Oct 3-12, 1992

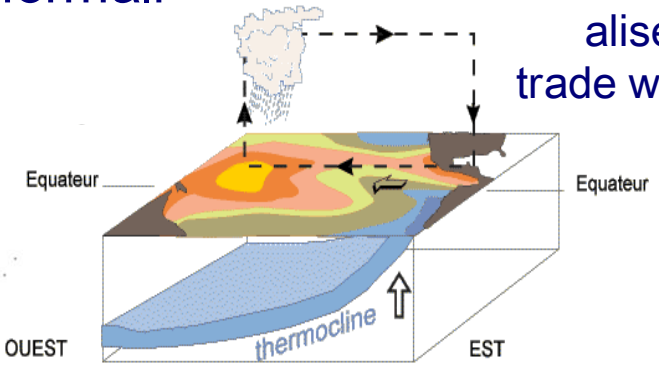
Dinamica degli Oceani



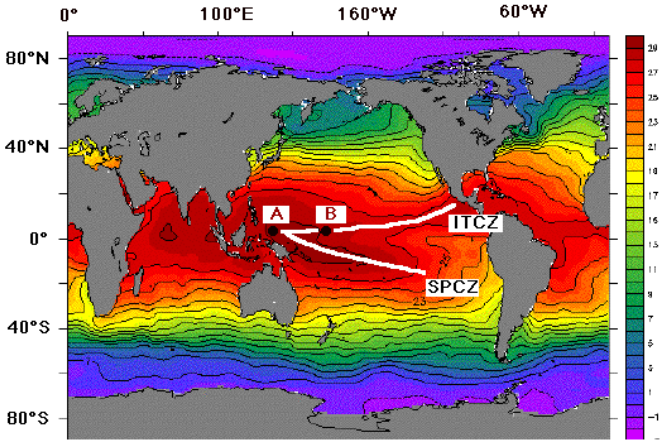
El Niño / La Niña

Condizioni normali



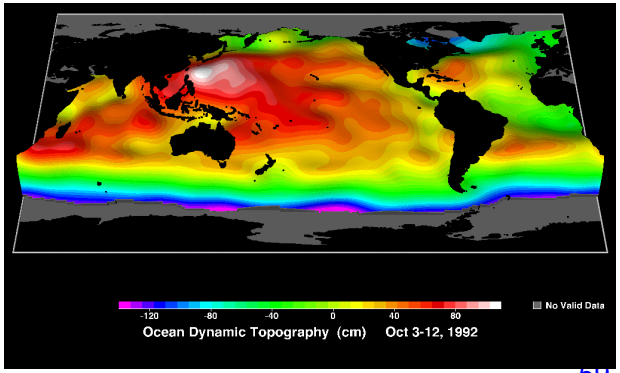


alisei
trade winds



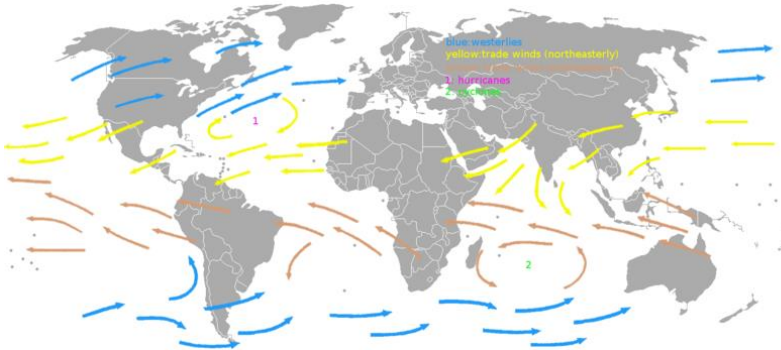
ITCZ – InterTropical Convergence Zone

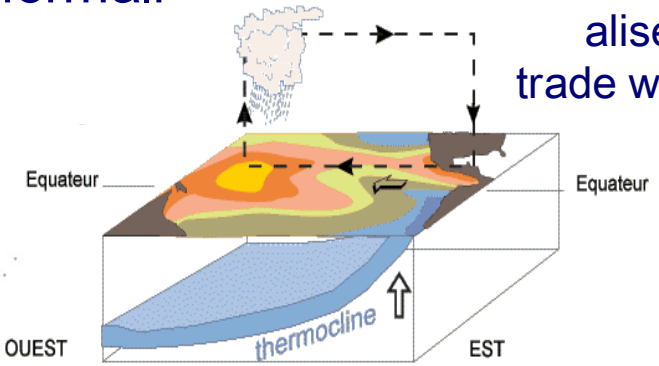
SPCZ – South Pacific Convergence Zone



El Niño / La Niña

Condizioni normali

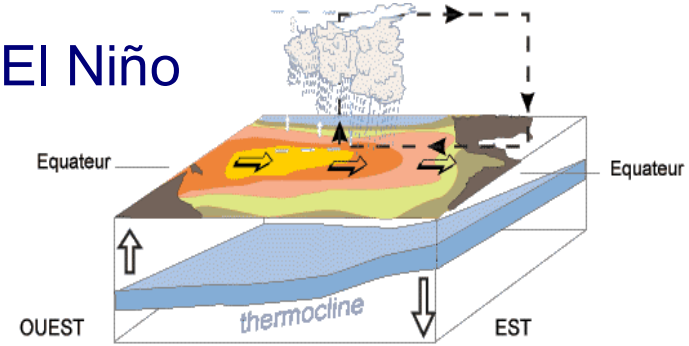




Fine primavera/inizio estate: monsoni (Indian Ocean monsoons) NE→ SW

ENSO:
El Niño Southern Oscillations

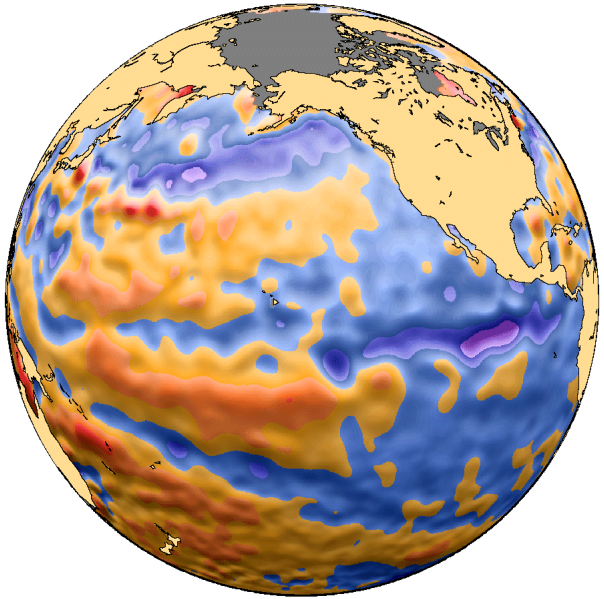
El Niño



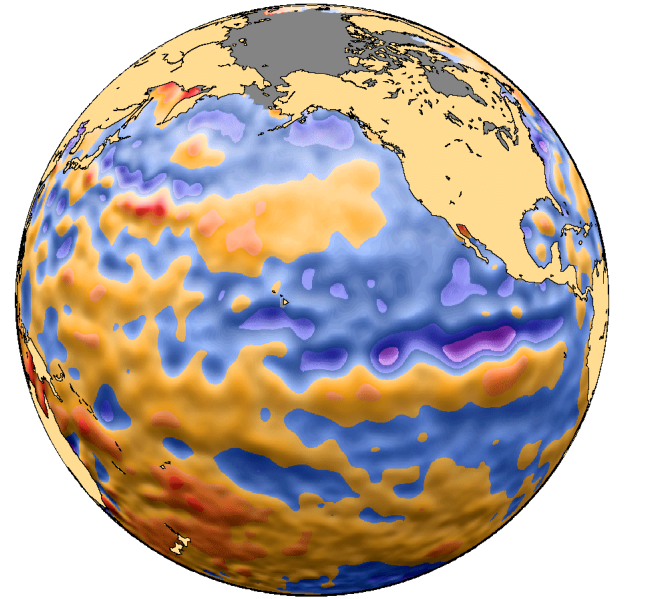
“Previsioni ...”

Esempio del 2002

situation au
2 janvier 2002



situation au
23 janvier 2002



Programmi Commerciali: IRIDIUM

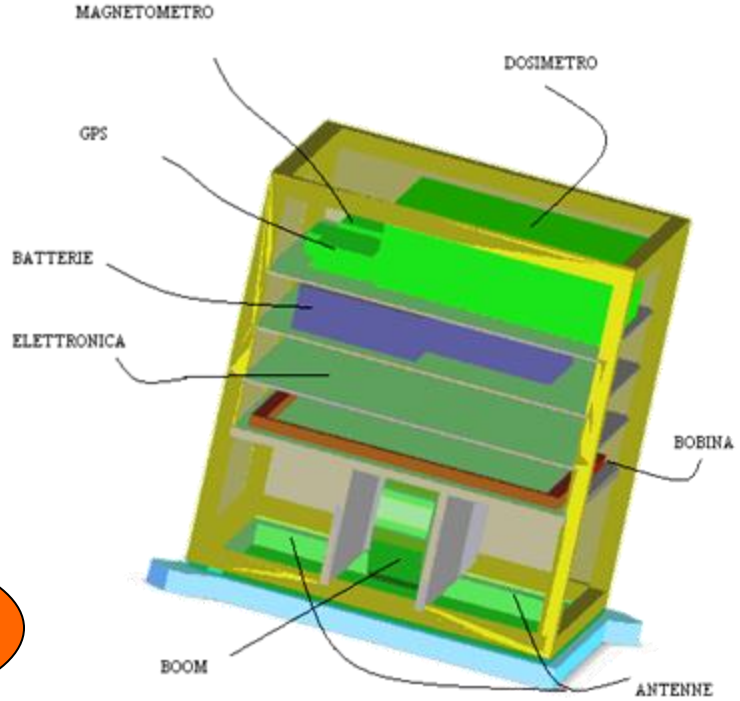
GOAL: Costruire una MAPPA precisa di

Campo Magnetico Terrestre

Flusso di Radiazione che incide su AtmoCube

e ...

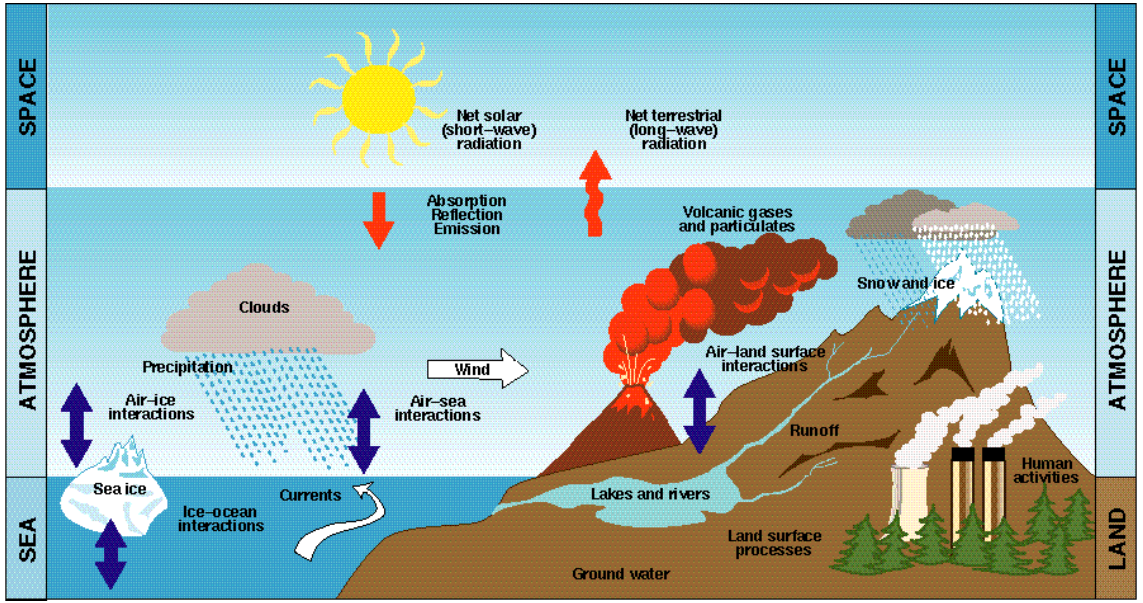
COINVOLGERE STUDENTI !



SPACE WEATHER 1/3

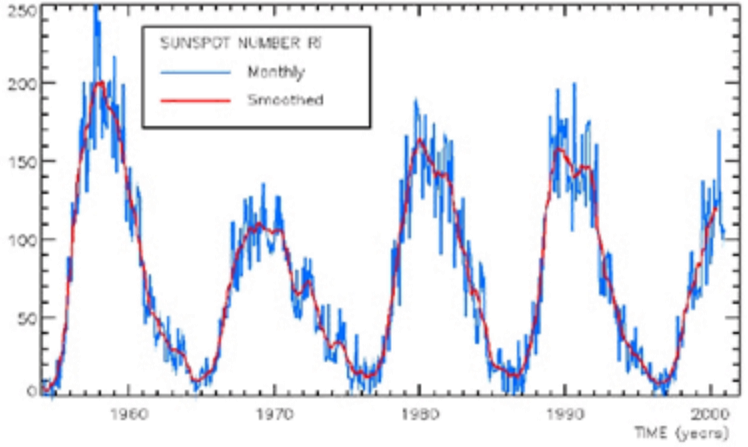
"Space Weather: condizioni sul Sole e sul vento solare, sulla magnetosfera, ionosfera, termosfera, che possono influenzare le prestazioni e l'affidabilità dei sistemi tecnologici nello spazio e a terra e possono mettere in pericolo la vita e la salute umana."

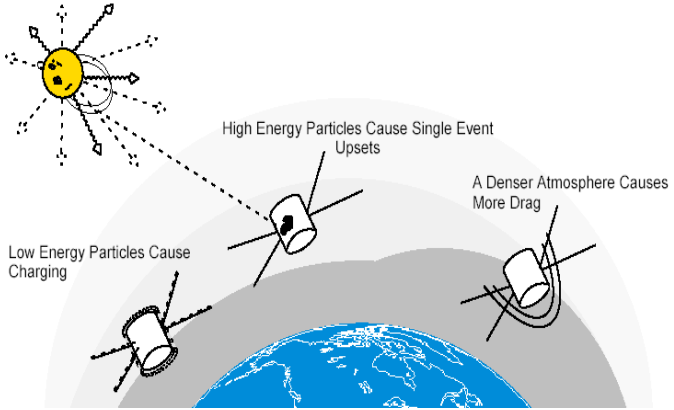
ESA website: www.esa.int

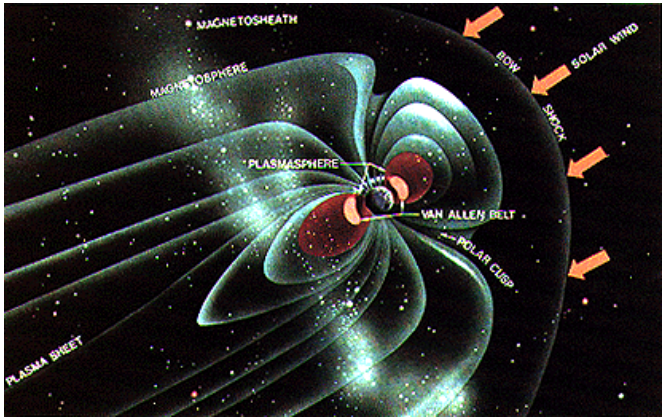


SPACE WEATHER 2/3

Sole: nel visibile
COSTANTE MA ….



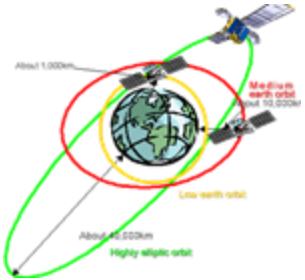




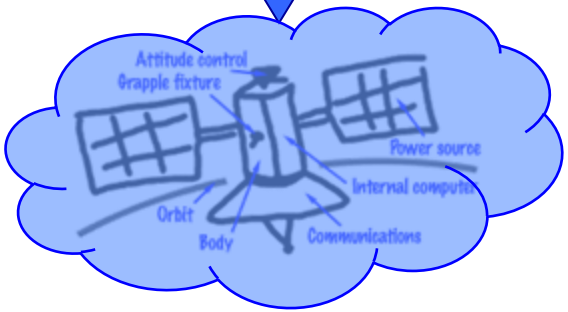
SPACE WEATHER 3/3

- Effetti su S/C & aerei (total dose, lattice displacement, single events upsets (SEU), sensor bkg, spacecraft charging, drag)
- Reti distribuzione energia (guasti su linee di alimentazione, effetti di corrosione nelle condutture -Quebec marzo 1989)
- Sistemi comunicazione (cambiamenti struttura della ionosfera: aumento assorbimento, riflessioni inattese, interferenza radio, interruzioni comunicazioni)
- Rischi per la salute umana (astronauti e equipaggi aerei soggetti a dosi elevate di radiazione)
- Cambiamenti climatici (emissioni solari UV modificano strato ozono ed influenzano circolazione dell'aria su grande scala, raffiche vento solare modificano proprietà elettriche parte superiore dell'atmosfera e influenzano gli strati bassi dell'atmosfera, nel minimo solare vento solare -più debole-permette agli GCR di penetrare più facilmente nell'atmosfera terrestre promuovendo formazione nubi di bassa quota)

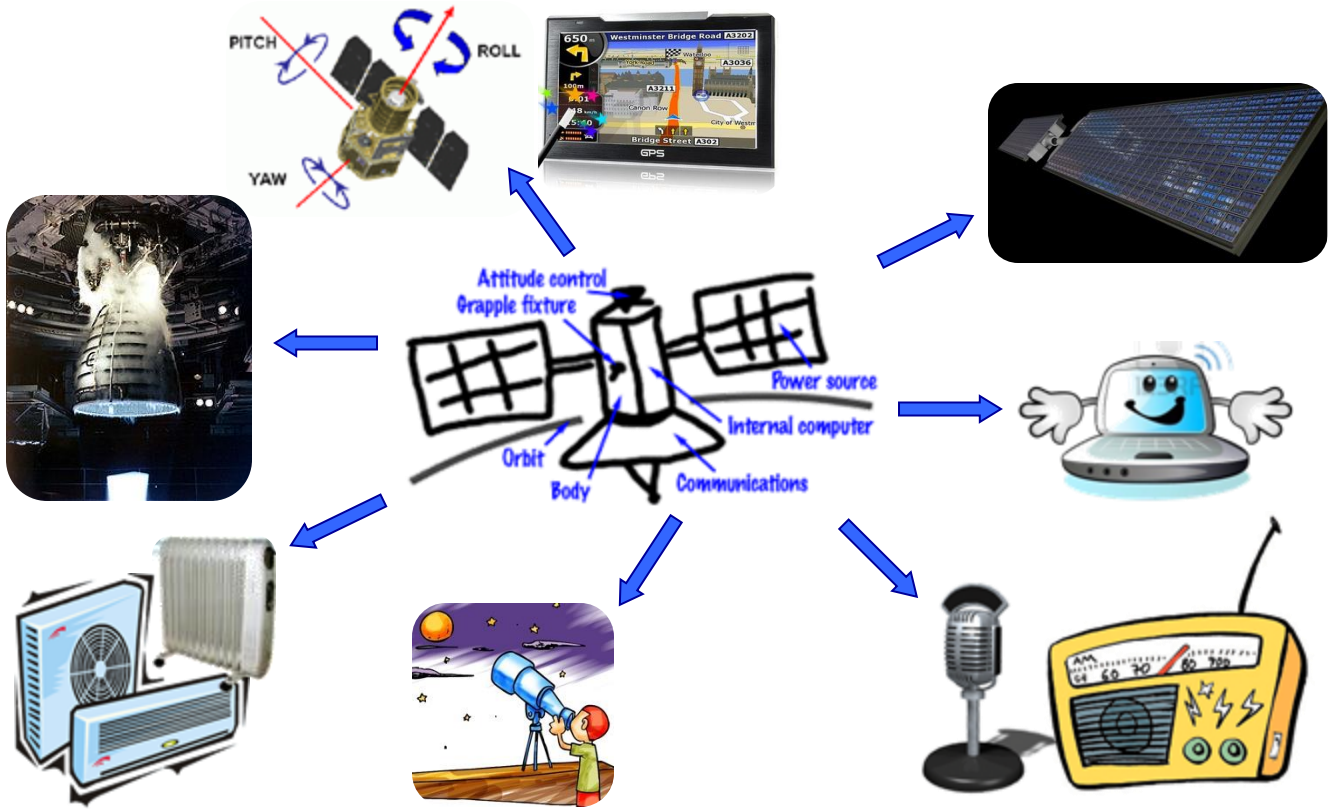
Una Missione Satellitare



Missione Satellitare

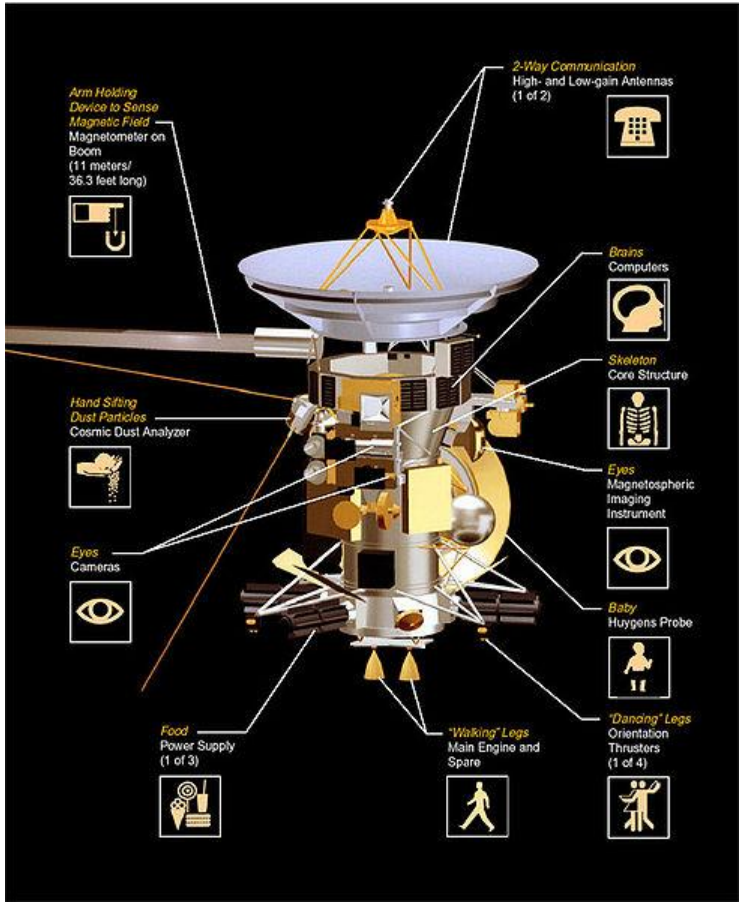


I Sistemi di un Satellite 1/2

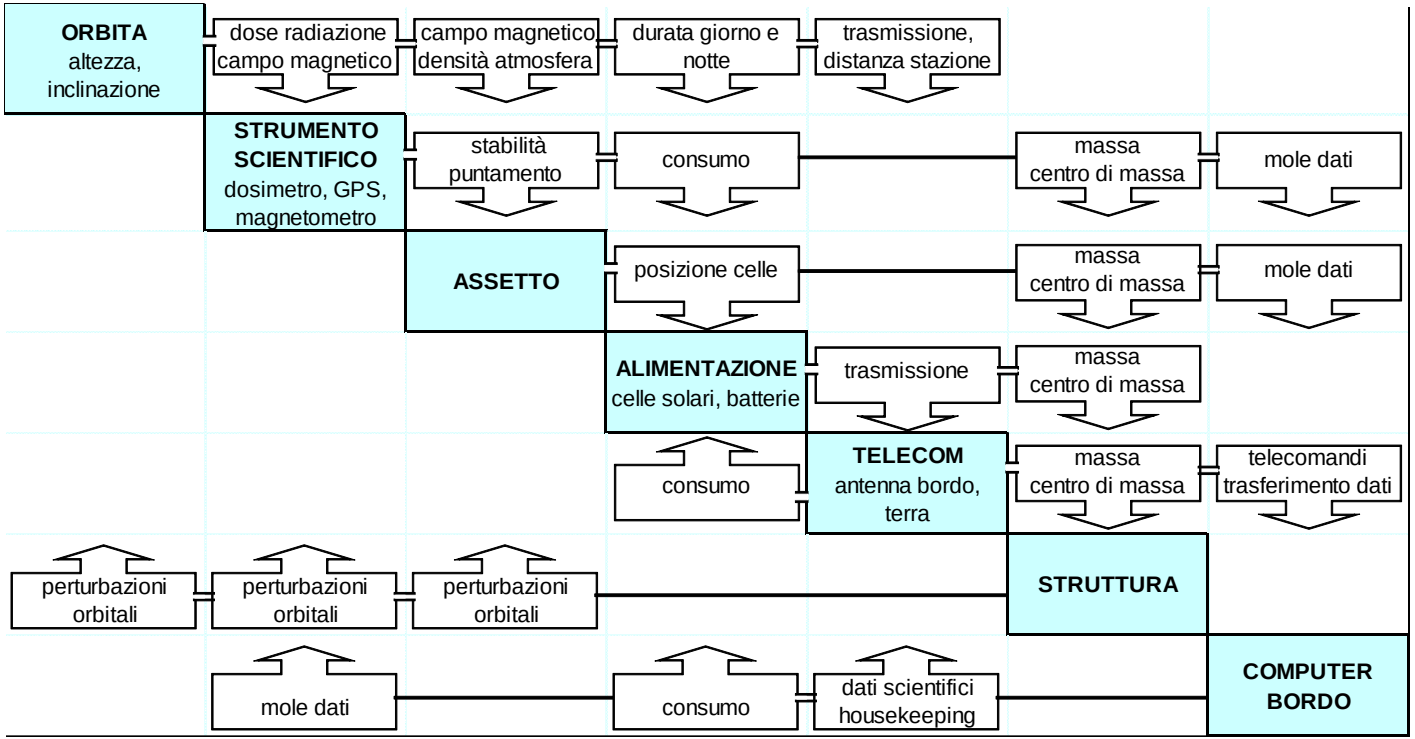


I Sistemi di un Satellite 2/2

Cassini – Huygens



I Sistemi di un Satellite 3/3



PROCESSO DI ANALISI

- **Misura scientifica: Studio dell'Atmosfera Terrestre "SPACE-WEATHER"**
  - Misura del Flusso di Radiazione sul satellite
  - Misura del Campo Magnetico in cui è immerso il satellite

- **Problematiche:**
  - Costi limitati: sistema molto semplice, molto piccolo e molto leggero
    - Cubo di lato 10 cm
    - Peso 1 kg
    - Potenza 2÷3 W
    - Evitare parti mobili se possibile
    - Utilizzo lanciatore (missile) disponibile: orbita non ottimizzata
  - Strumentazione non dedicata: commerciale
    - Accuratezza della misura limitata
    - Quantità di dati trasferibili limitata (banda radio-amatori)
  - Evitare interferenze con le misure (campo magnetico):
    - Uso limitato di sistemi elettromagnetici (bobine)
    - Separazione della strumentazione scientifica dall'elettronica: modulazione del satellite
  - Controllo dell'assetto del satellite
    - Gravity Gradient Boom + accessori

Planning di una Missione Spaziale

Fase A → Fase B → Fase C → Fase D

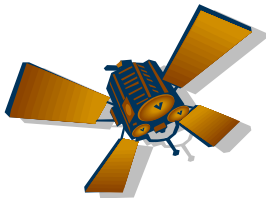
- studio di fattibilita'

- simulazioni
  - -aspetti ingegneristici
  - -aspetti scientifici
- costi

⇒ specifiche tecniche e scientifiche a istituti/industrie

- disegno finale

- costruzione
- test

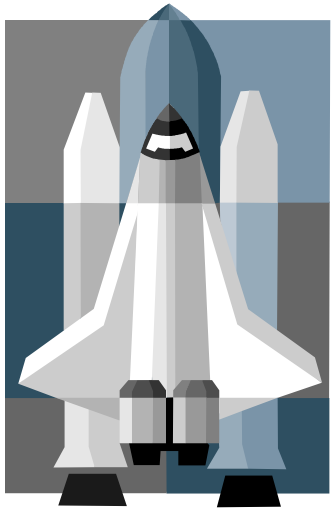


- Modello Strutturale
- Modello Elettrico (EMC)
- ….

Fase E

QM

FM



Fase F