

“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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348 3804692

Sommario

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

➤ Mattino:

- Lunedì e Martedì 11-13 Aula B

➤ Pomeriggio:

- Lunedì e Martedì 14-18 Aula C, B

➤ Materiale

- Dispense (Italiano)
- Fotocopie (?) e file trasparenze (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:

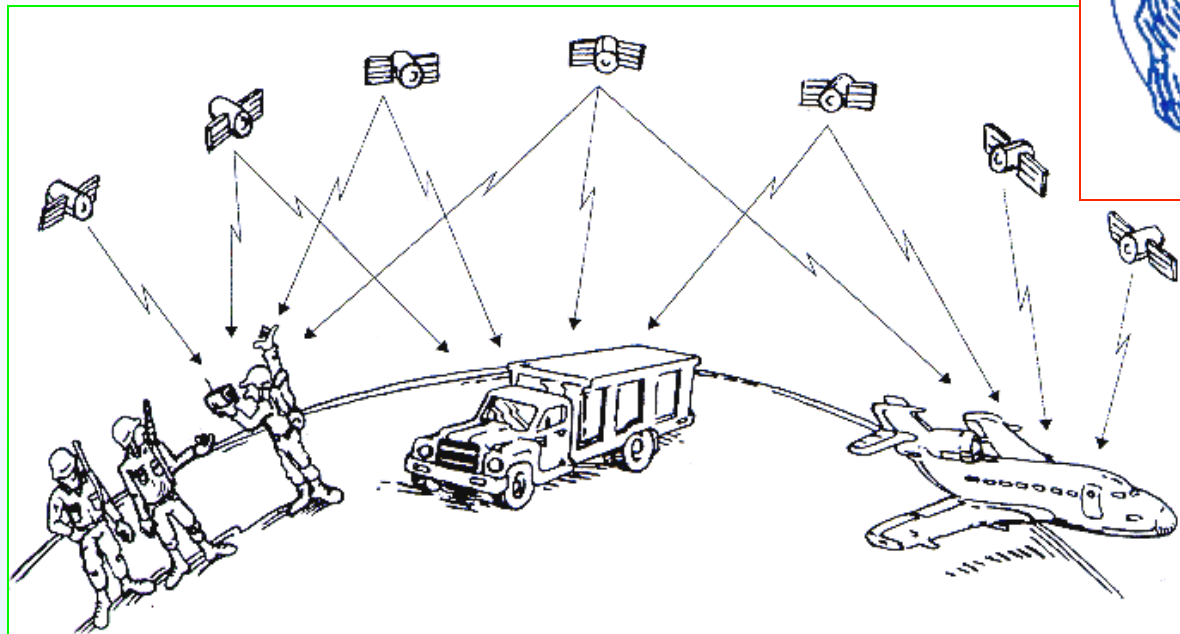
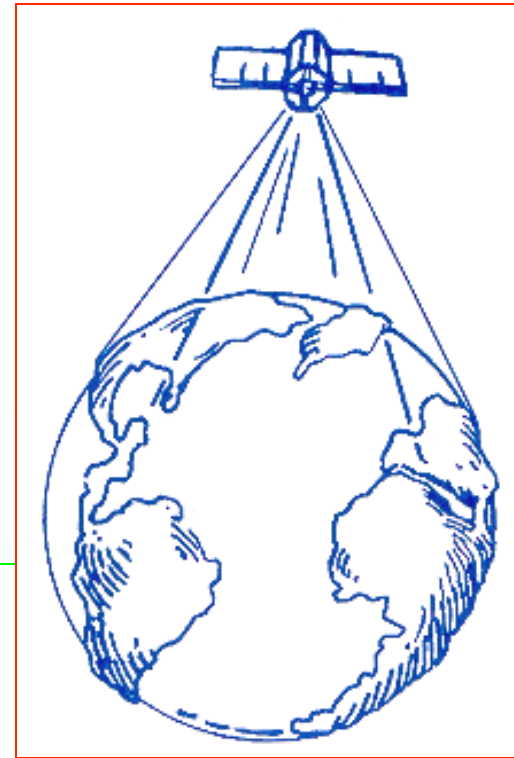
- E.mail o telefono, ricevimento all'Università (mer. 9-10)
- Richiesta: lista e-mail e un cellulare di (almeno) una persona di riferimento

➤ Altro:

- PC a disposizione? E.mail & mac-address

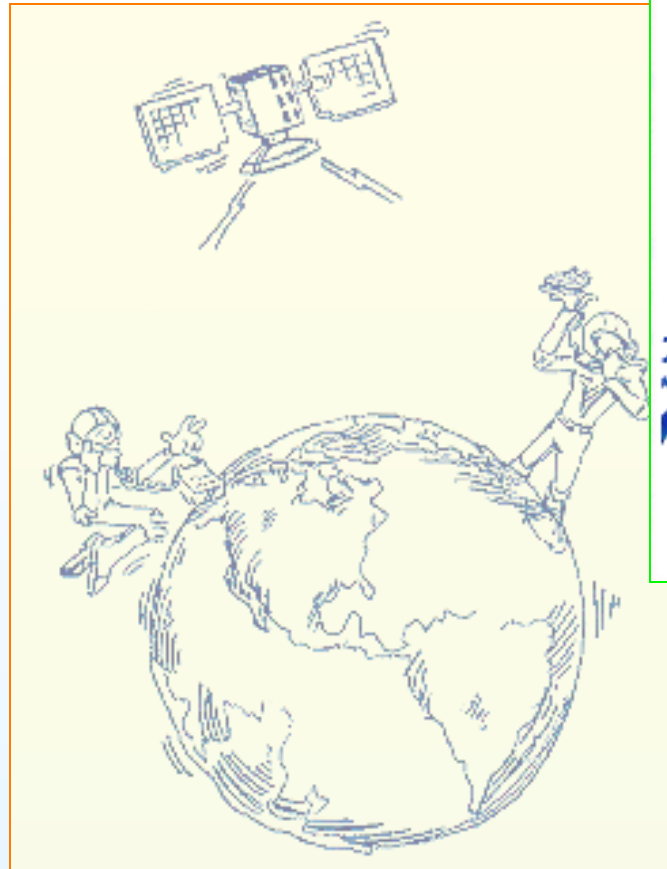
Motivazioni 1/2

- Osservazioni della Terra
- Comunicazioni
- Navigazione



Motivazioni 2/2

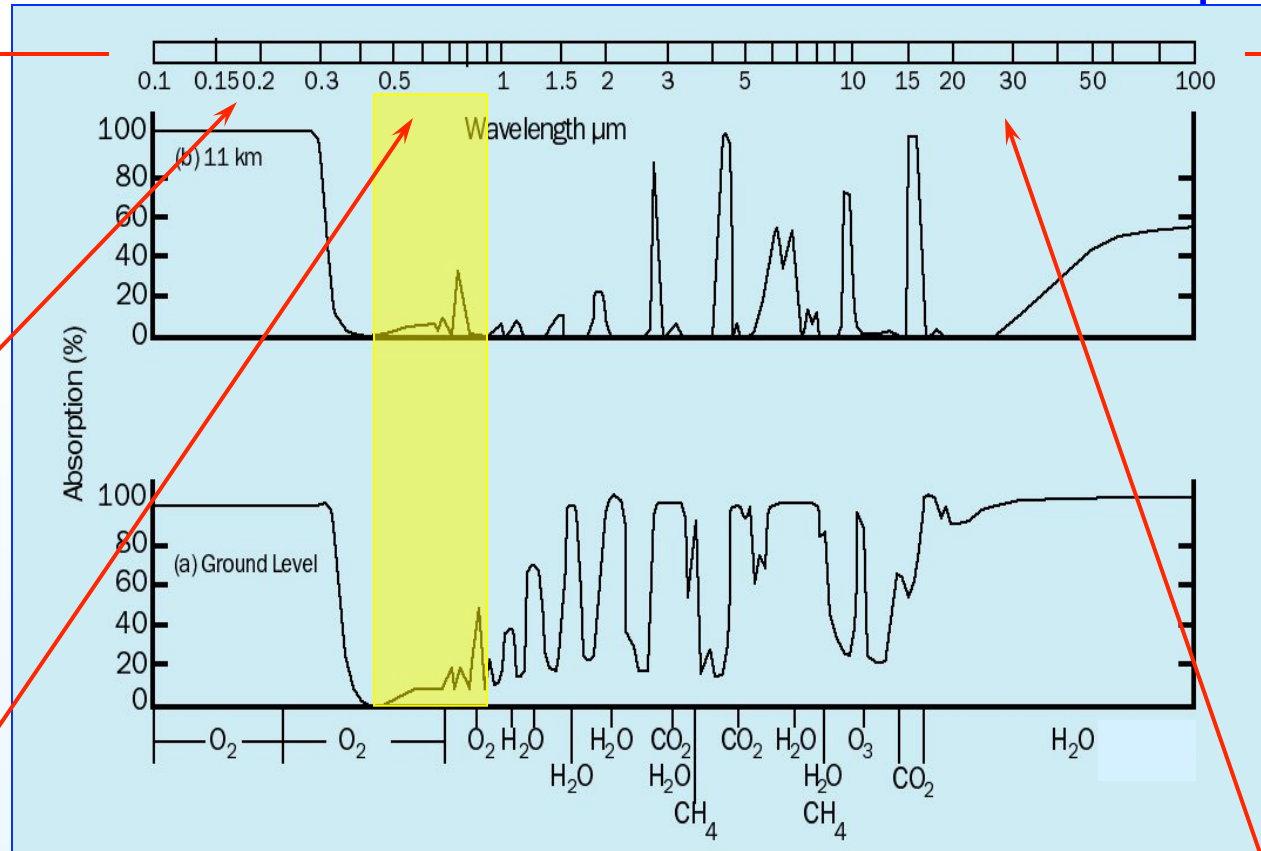
- Scienza
- Esplorazione



Atmosfera

Raggi X / γ : gas intergalattico,
dischi accrescimento

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



UV: stelle
calde

Visibile: stelle fredde

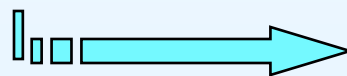
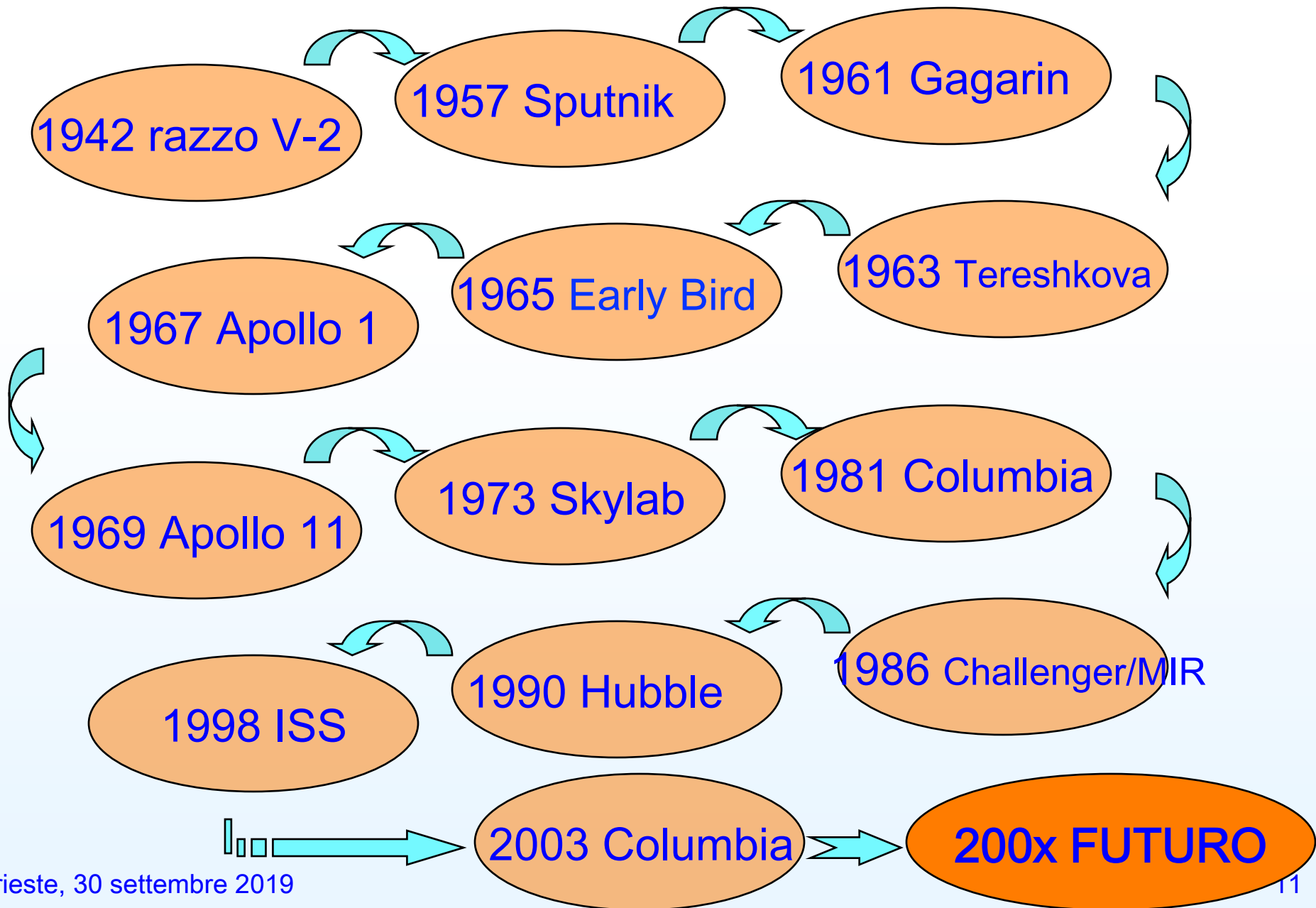
IR: polveri cosmiche, comete

Storia 1

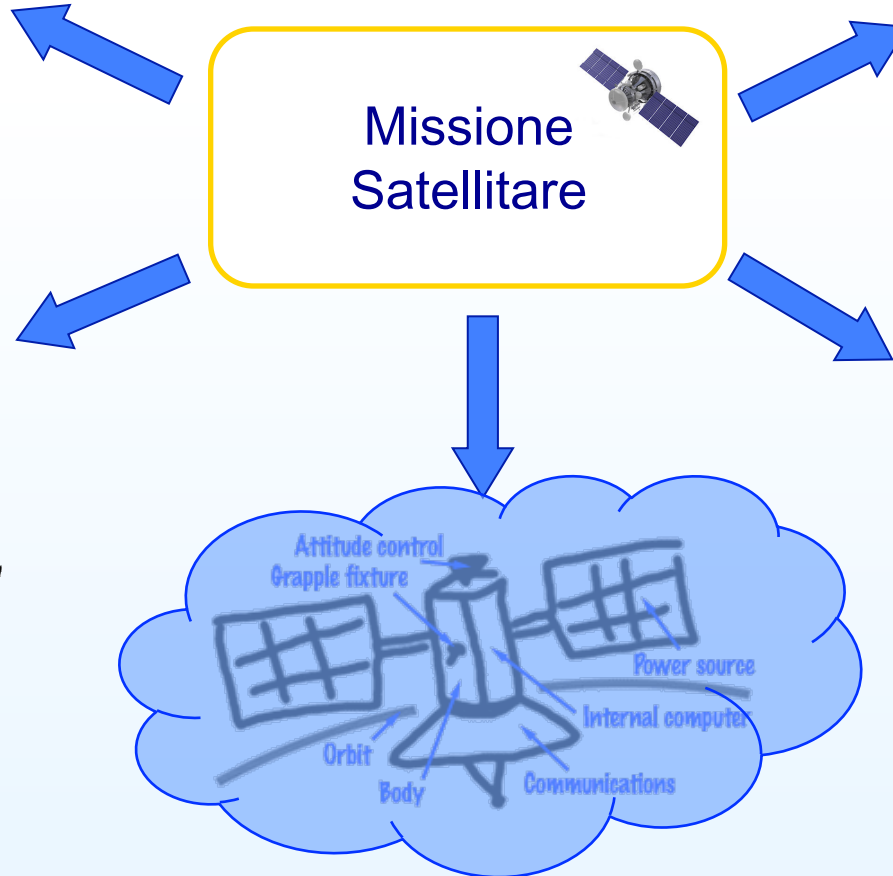
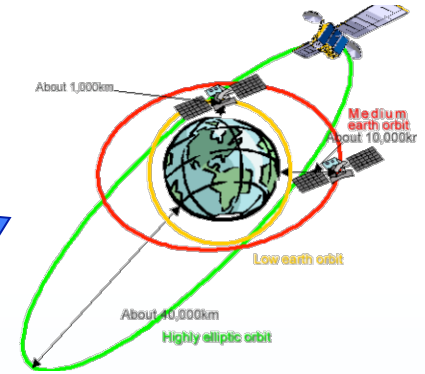


YouTube “Escape Velocity - A Quick History of Space Exploration”

Storia 2



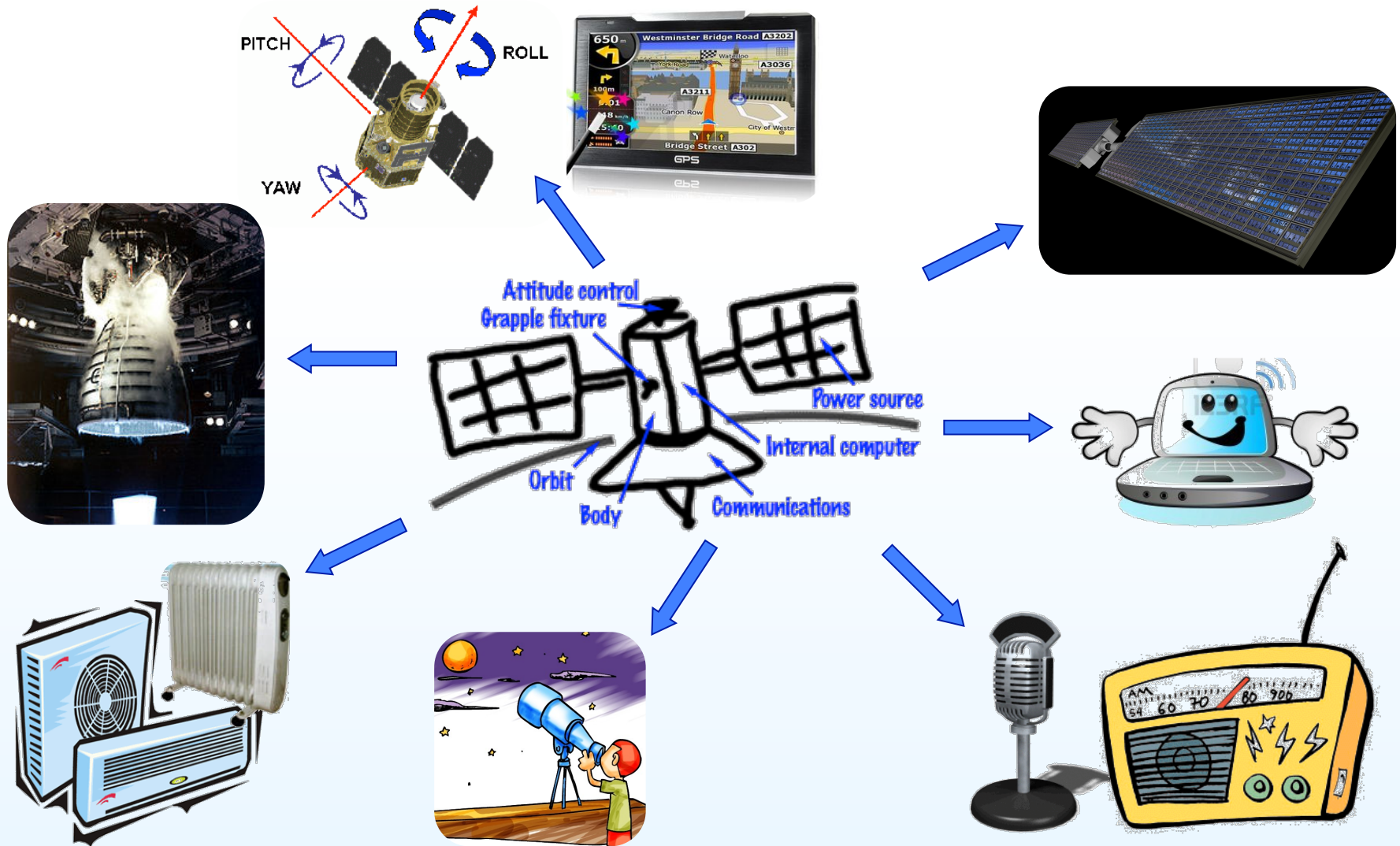
Una Missione Satellitare



© Alex Bannykh * www.ClipartOf.com/73729

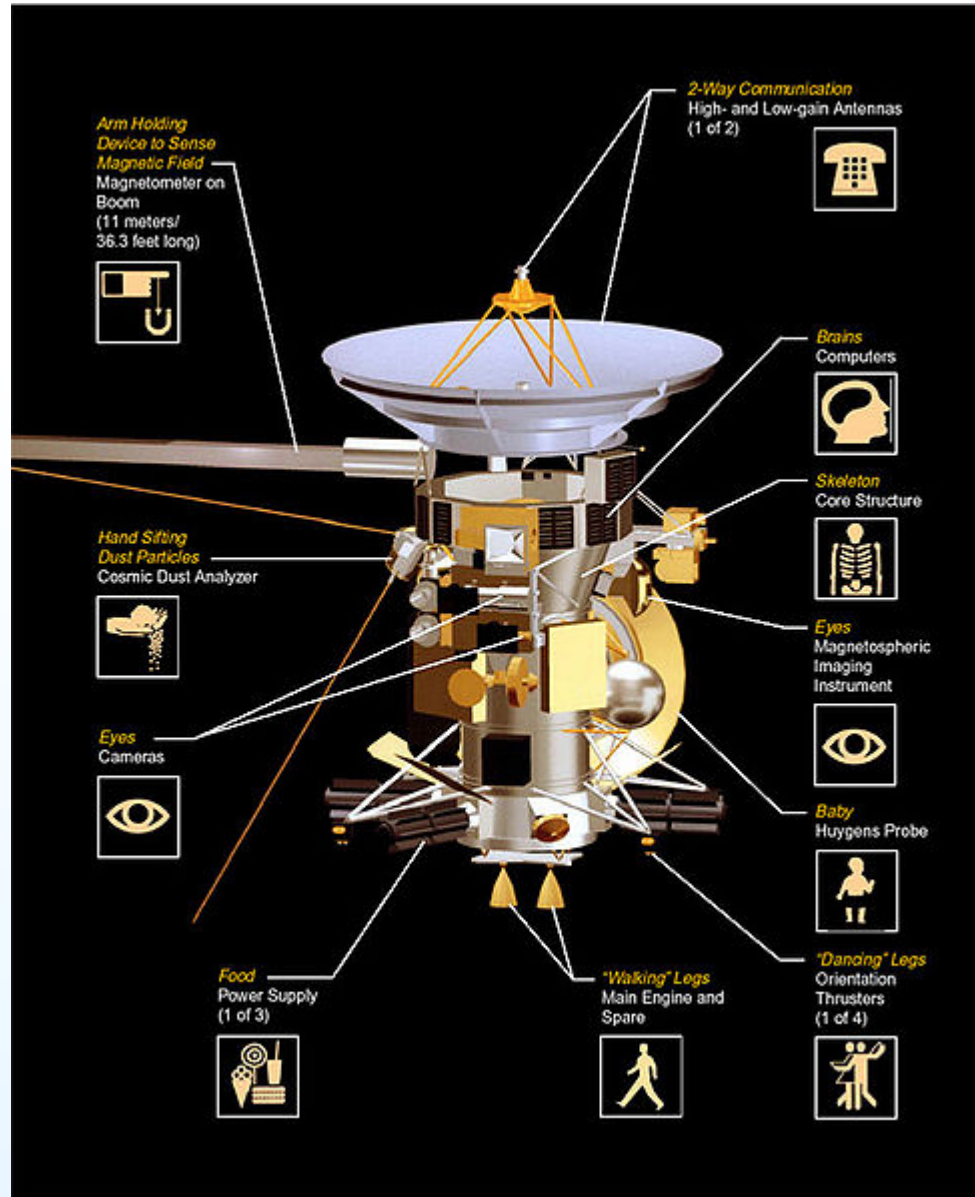


I Sistemi di un Satellite 1/3



I Sistemi di un Satellite 2/2

Cassini – Huygens



Difficoltà Tecniche 1/2

- Condizioni ostili ambiente spaziale:
 - o escursioni termiche
 - o vuoto
 - o dosi di radiazione cosmica
 - o 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

- Sciame Elettromagnetico – 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

Navette Spaziali (Shuttle)

- tempo in orbita breve
- recupero della strumentazione

Satelliti

- tempo in orbita lungo
- impossibilità di recupero della strumentazione

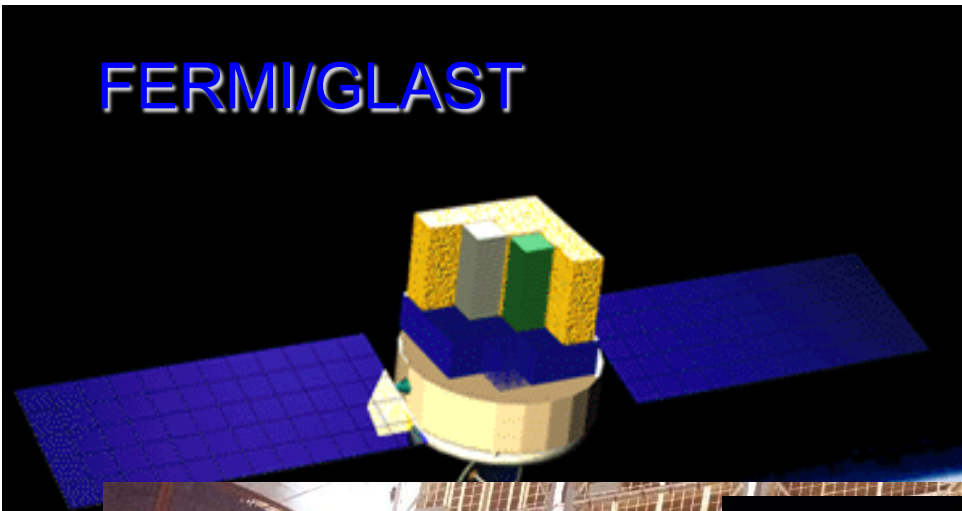
Stazione Spaziale Internazionale (ISS)

- tempo in orbita lungo
- recupero della strumentazione



Astrofisica: XMM - GLAST – AMS

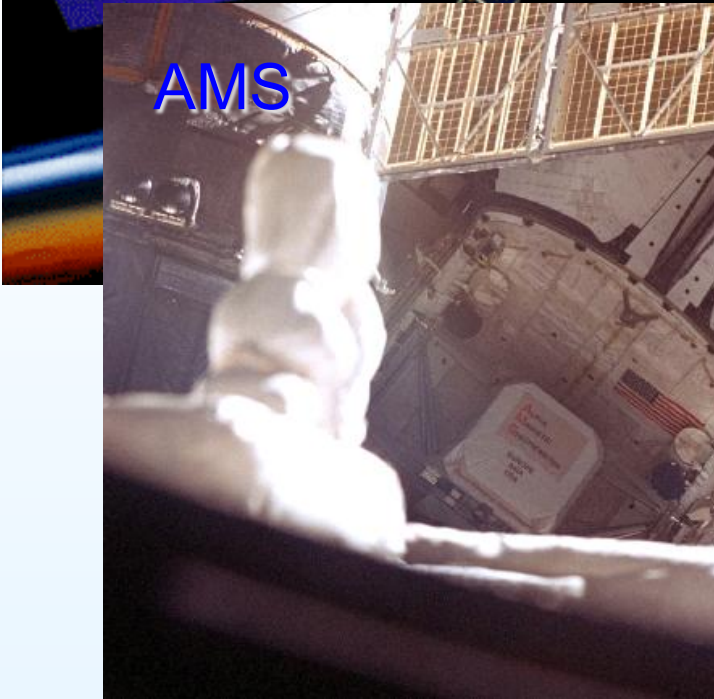
FERMI/GLAST



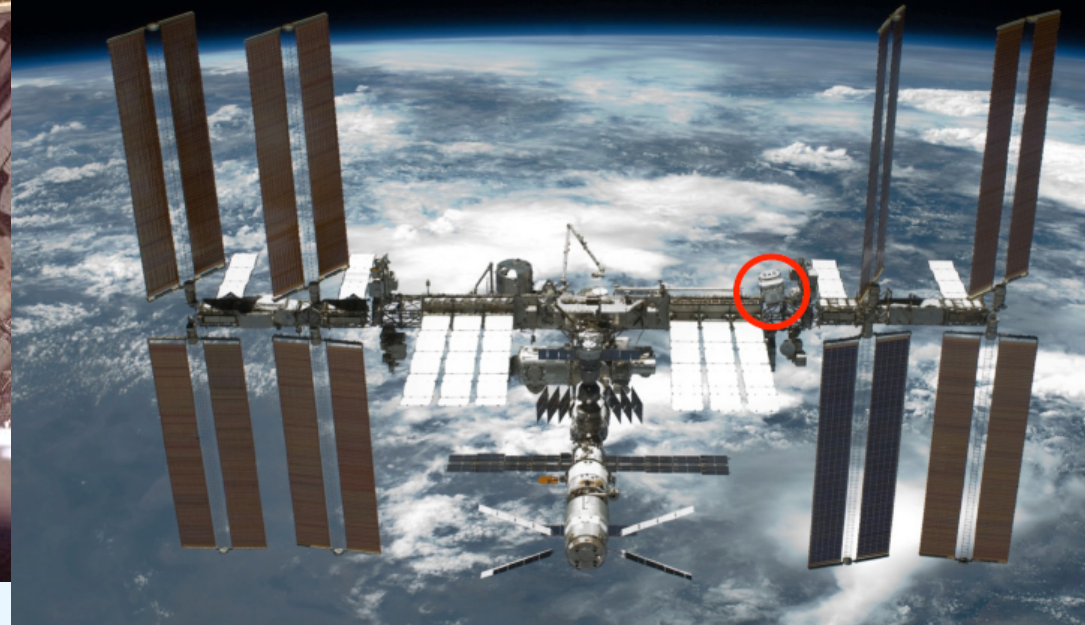
XMM



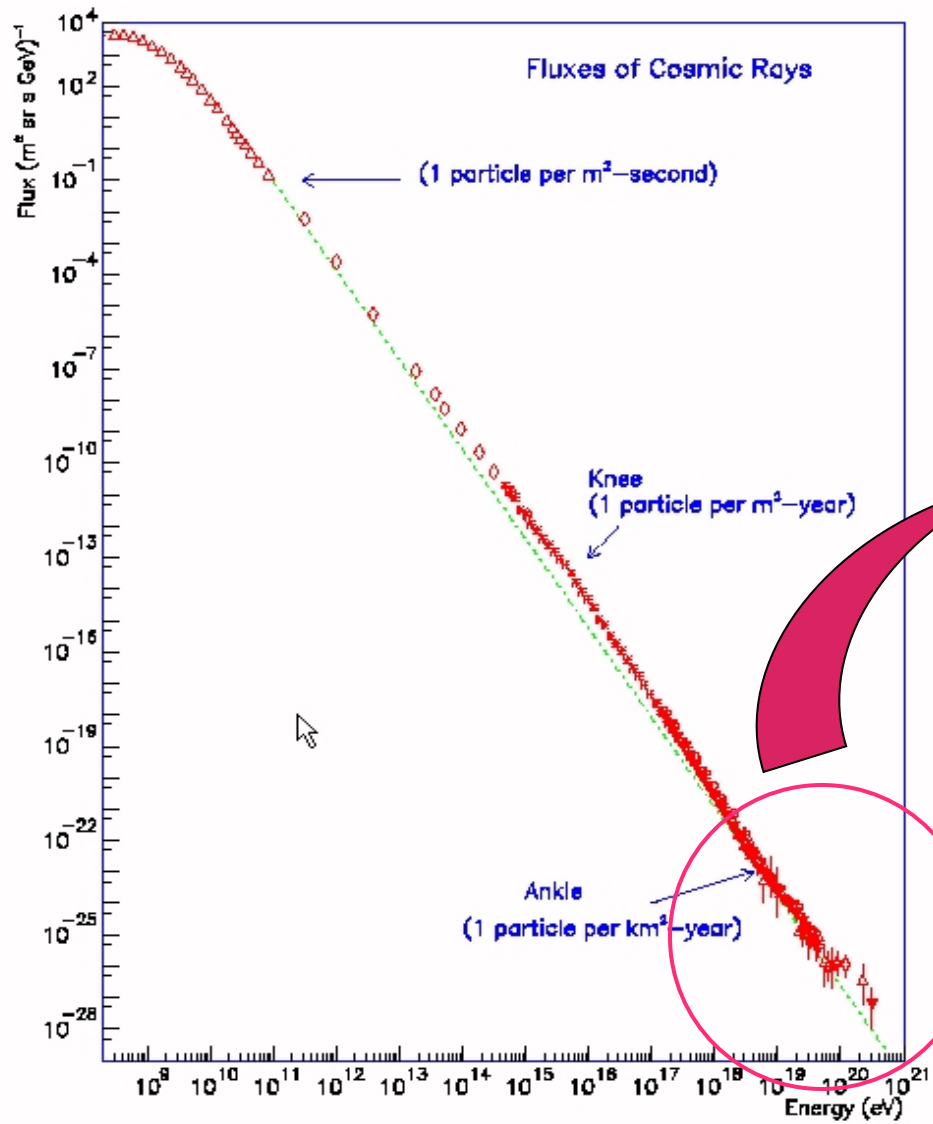
AMS



The Alpha Magnetic Spectrometer (AMS) Experiment



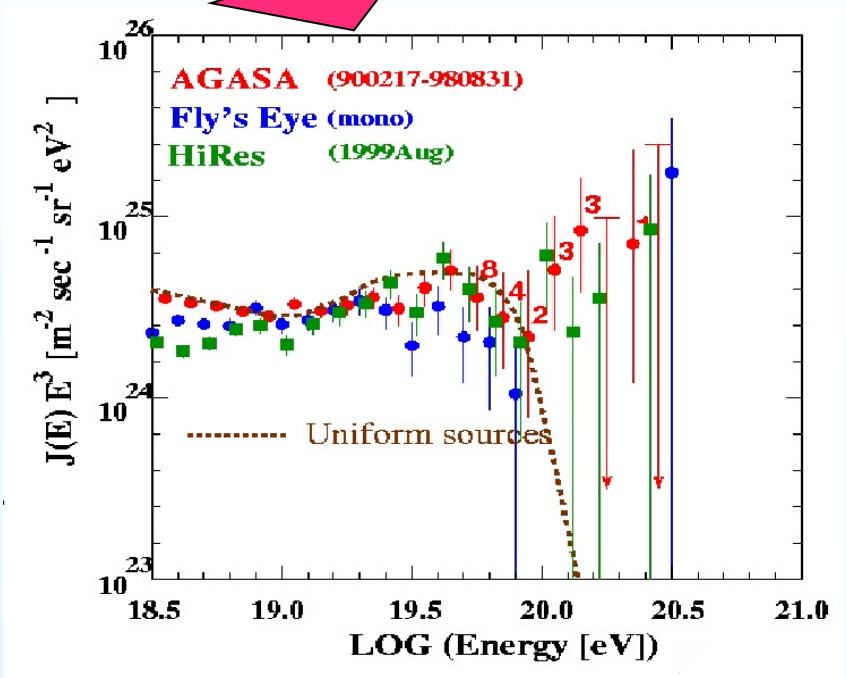
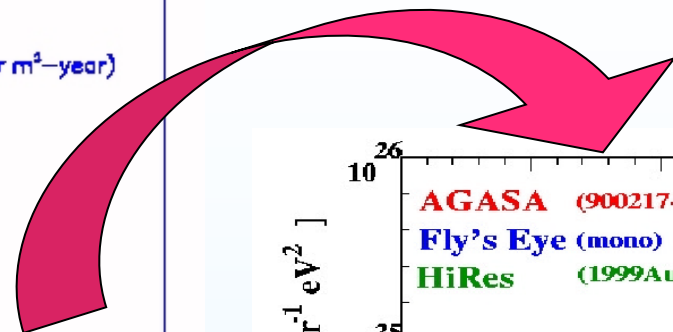
EUSO 1/2



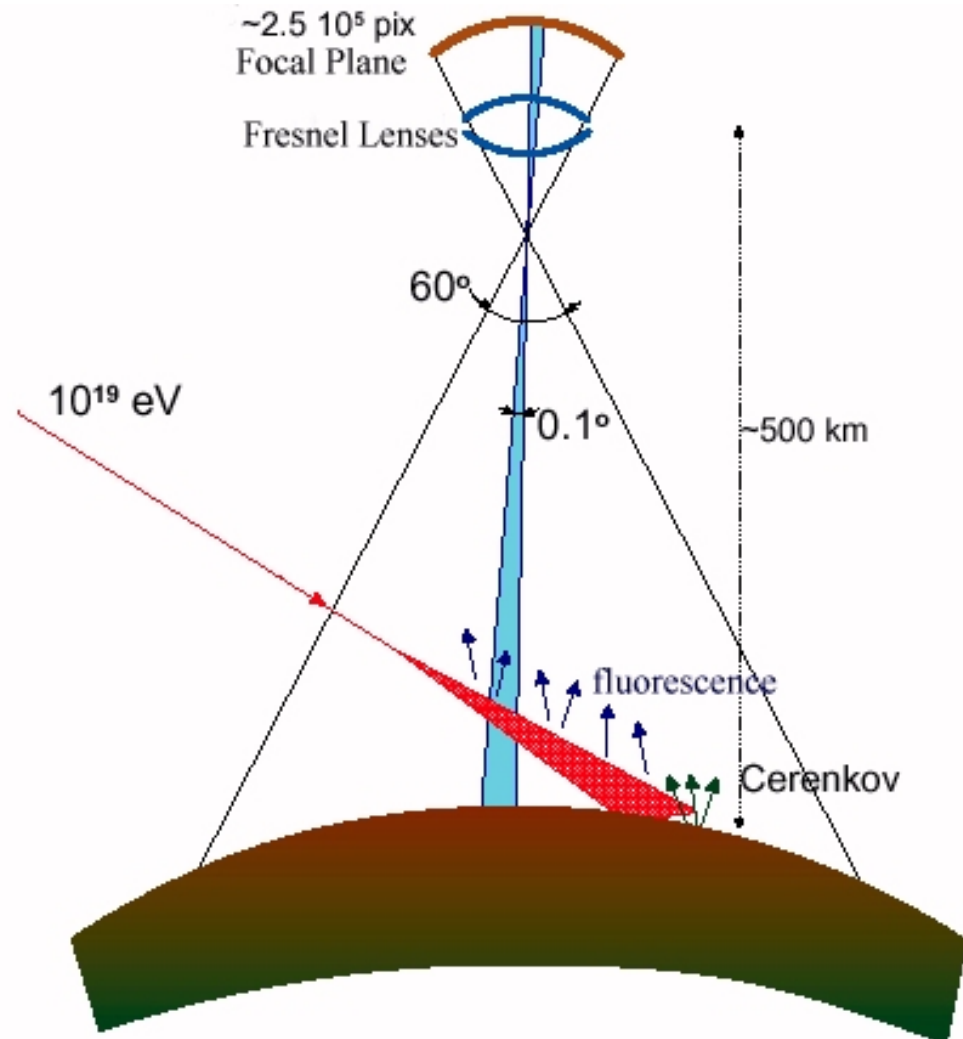
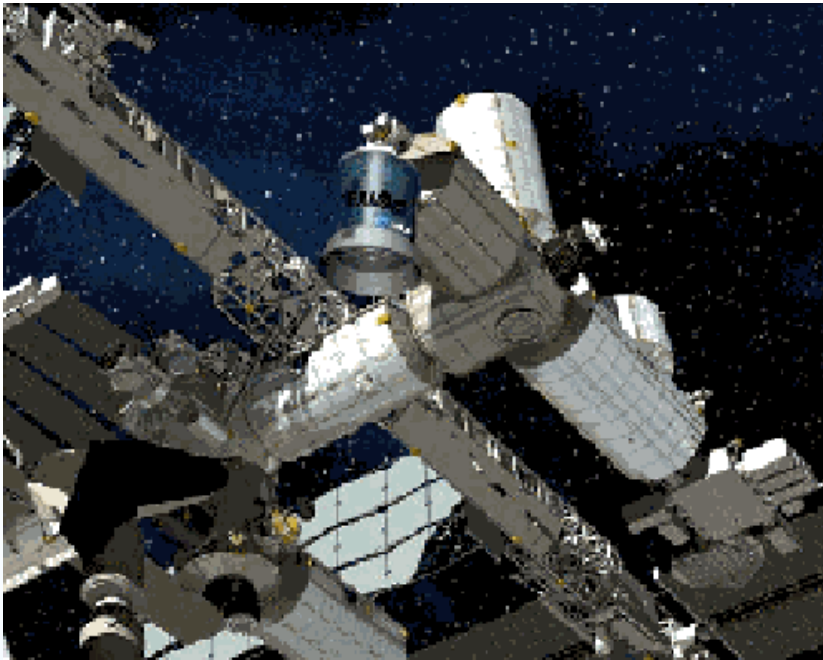
Flusso estremamente basso:
 ≈ 1 evento/sr/ km^2 /secolo



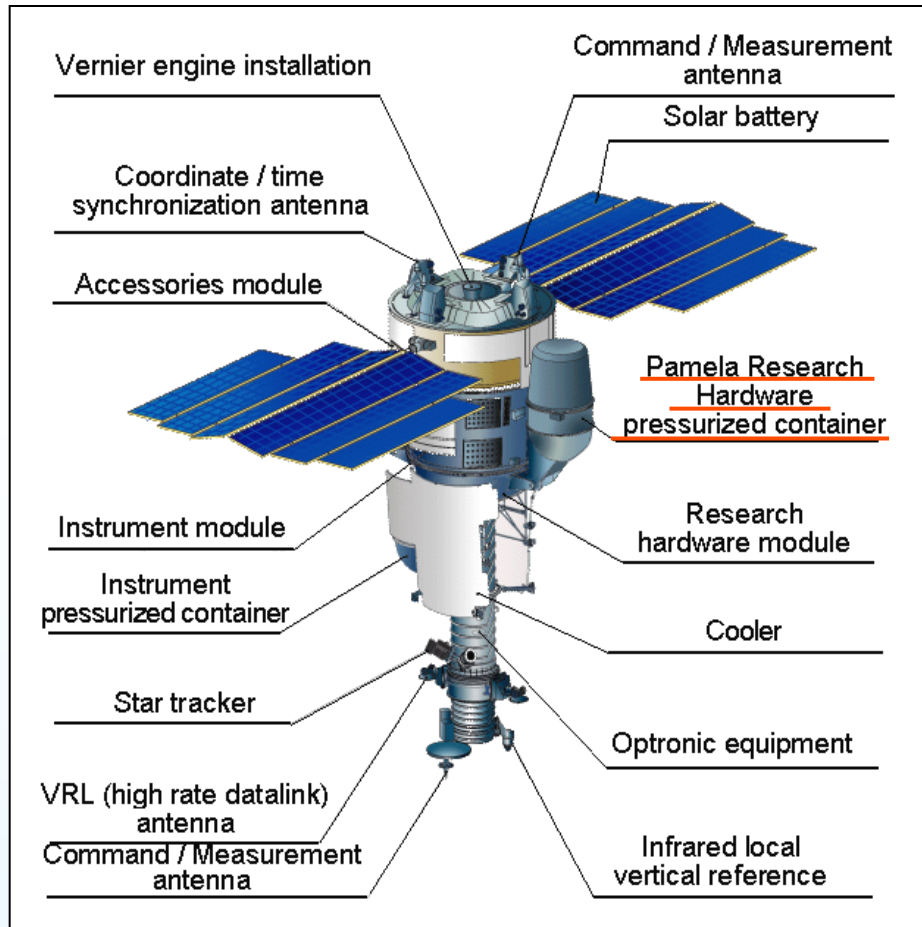
300 eventi



EUSO 2/2



PAMELA 1/4

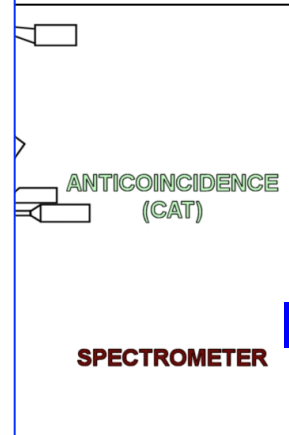


- Multi-spectral remote sensing of earth's surface
 - near-real-time high-quality images
- Built by the Space factory TsSKB Progress in Samara (Russia)
- Operational orbit parameters:
 - inclination $\sim 70^\circ$
 - altitude $\sim 360-600$ km (elliptical)
- Mass: 6.7 tons
- Active life >3 years
- Launch: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

PAMELA 2/4

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

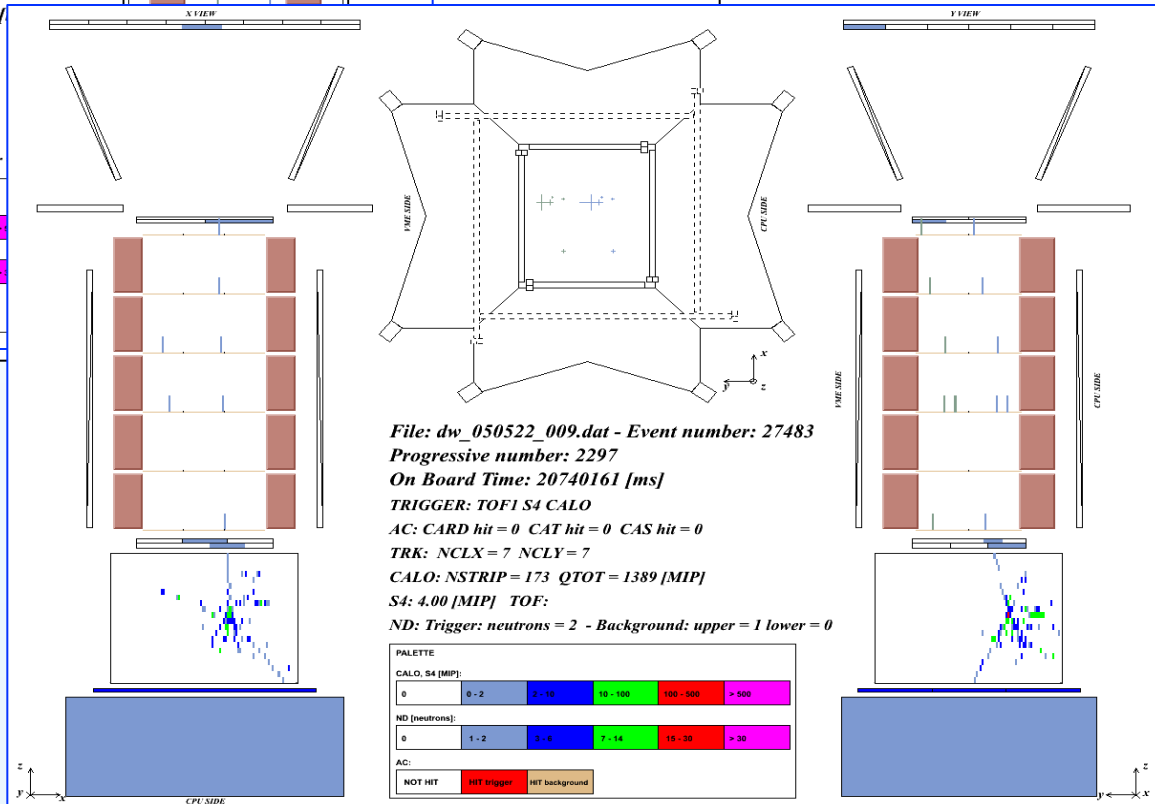
Interacting event



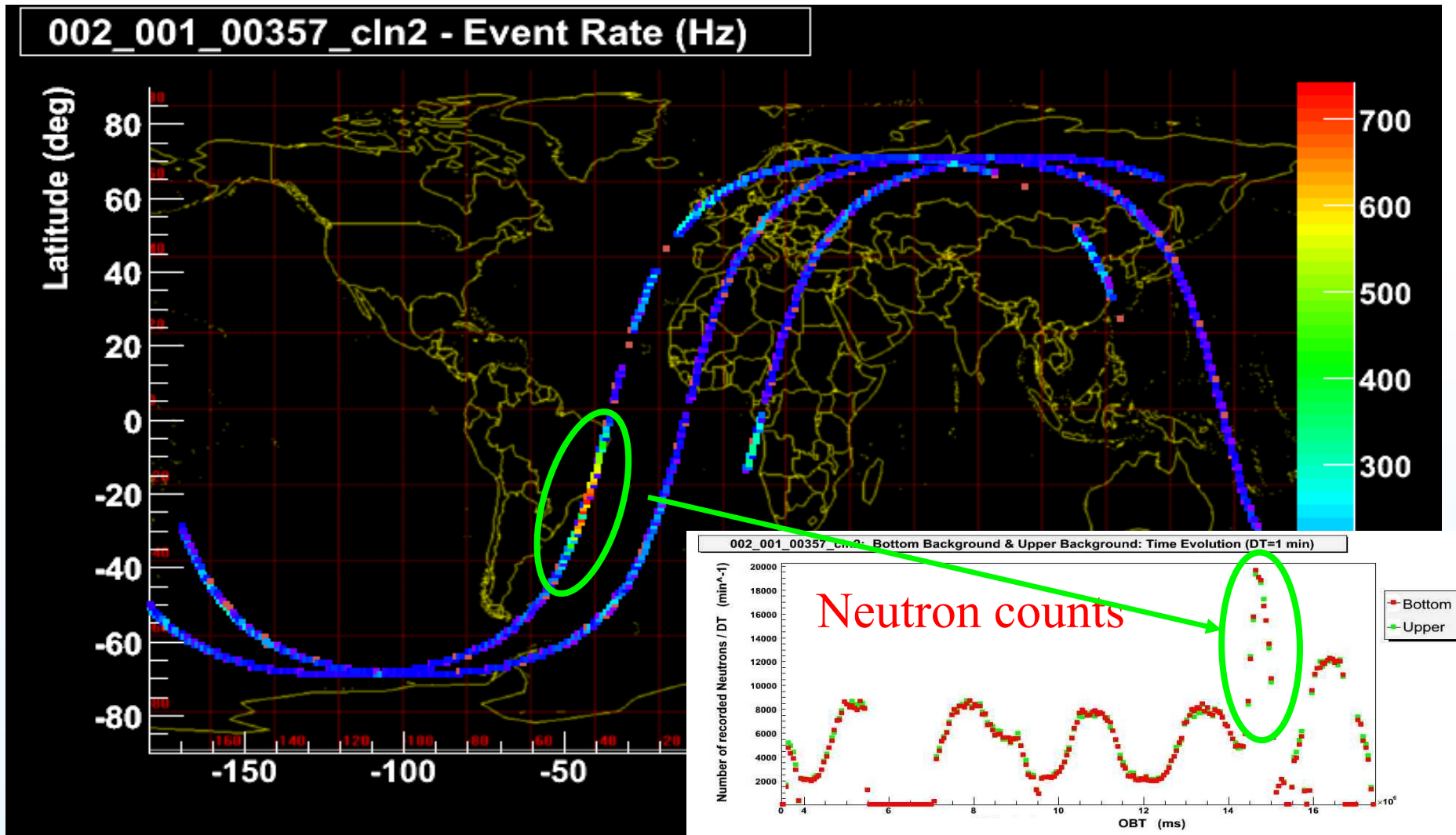
File: dw_050520_002.dat - Event number: 515
 Progressive number: 158
 On Board Time: 2020906 (delta: 1444) [ms]
 TRIGGER: TOF1 S4
 AC: CARD hit = 0 CAT hit = 0 CAS hit = 0
 TRK: NCLX = 8 NCLY = 8
 CALO: NSTRIP = 50 QTOT = 97 [MIP]
 S4: 2.00 [MIP] TOF:
 ND: Trigger: neutrons = 0 - Background: upper

PALETTE					
CALO, S4 [MIP]:	0 - 2	2 - 10	10 - 100	100 - 500	> 500
ND [neutrons]:	0	1 - 2	3 - 6	7 - 14	15 - 30
AC:	NOT HIT	HIT trigger	HIT background		

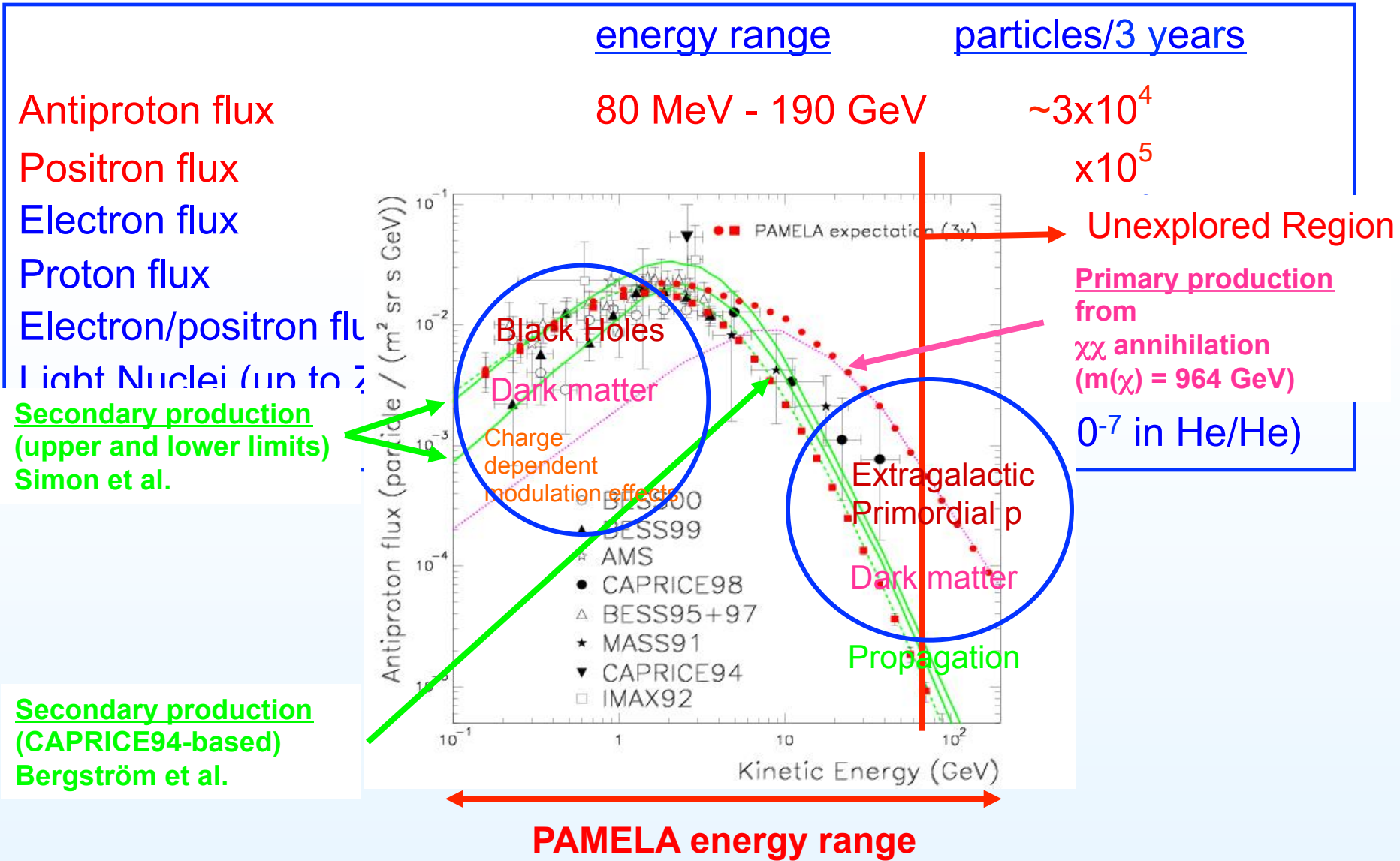
Non-interacting event



PAMELA 3/4

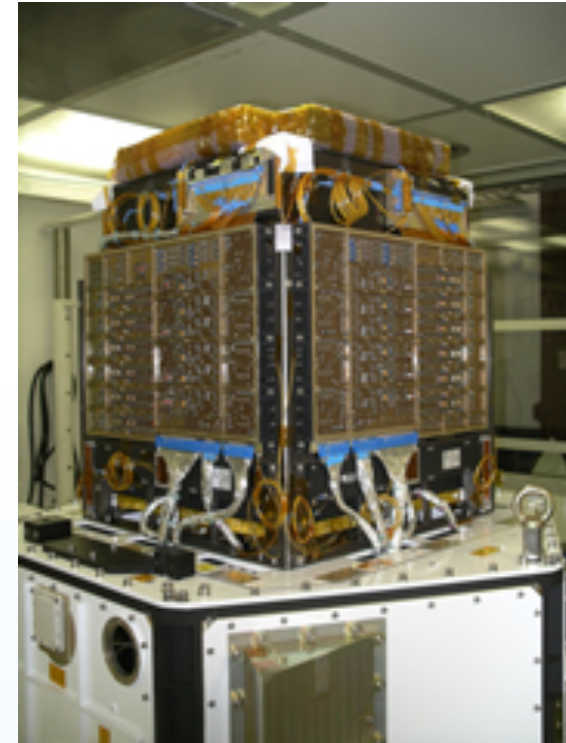


PAMELA 4/4



Astrorivelatore Gamma Immagini LEggero

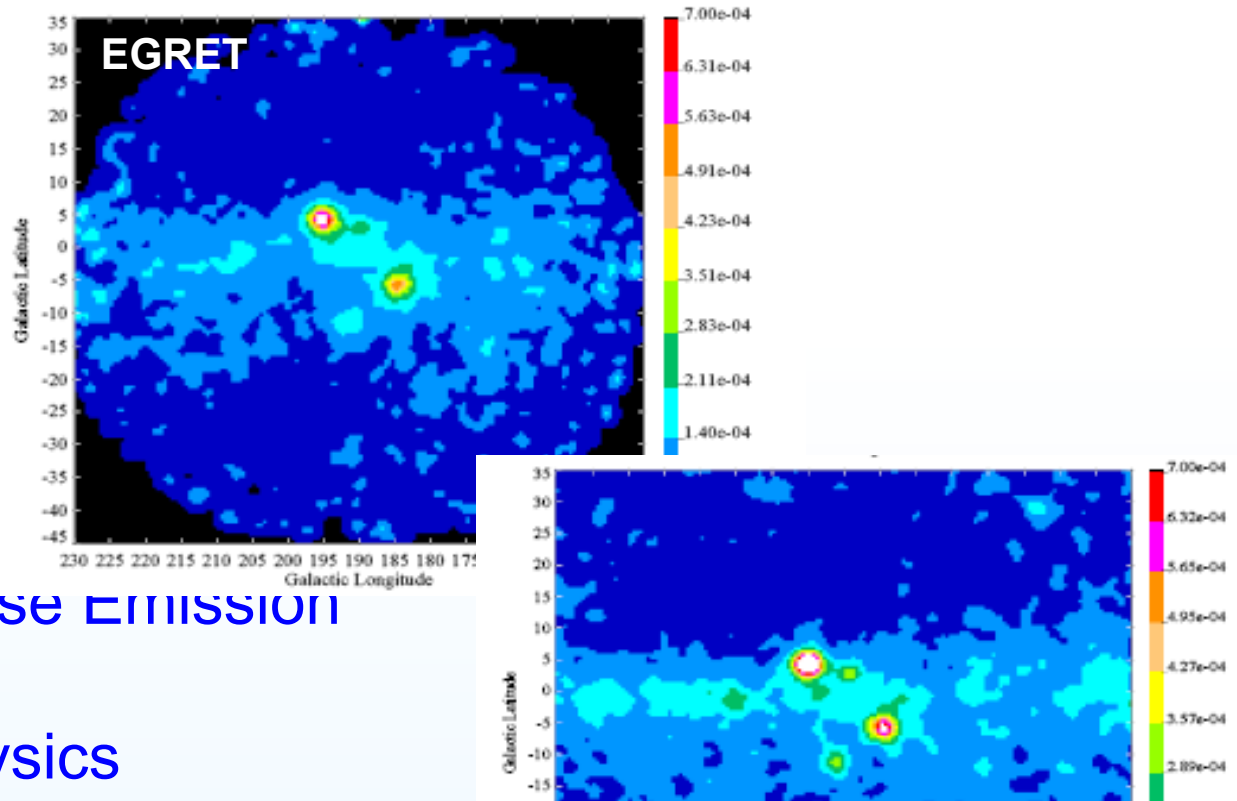
- Missione dedicata all'astrofisica gamma
- Optimal imaging capabilities in both the gamma-ray energy range (30 MeV-30 GeV) and hard X-ray range (15-60 keV)
- Scientific Team: researchers and engineers of INAF-IASF, INFN, and several Italian Universities. The project is headed by M. Tavani (Principal 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 Universe
- Supernova Remnants
- Compact Objects
- Gamma-ray Diffuse EMISSION
- TeV Sources
- Fundamental Physics



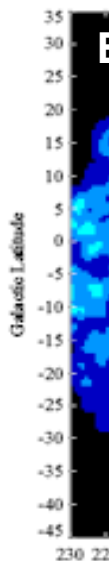
AGILE was successfully launched on April 23, 2007 by the Indian PSLV-C8 rocket from the Sriharikota base (Chennai-Madras).

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

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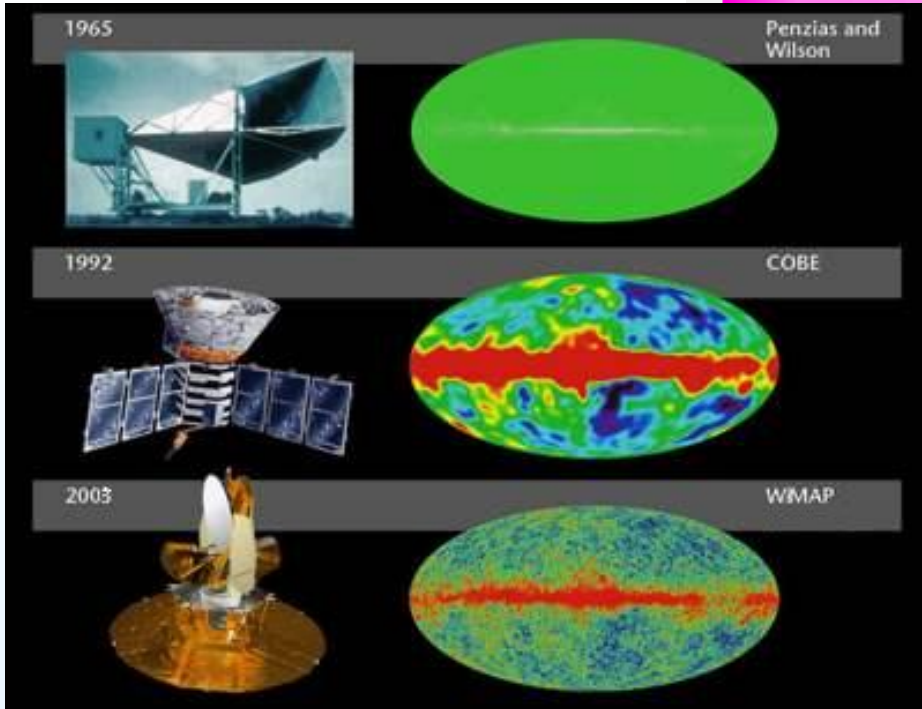
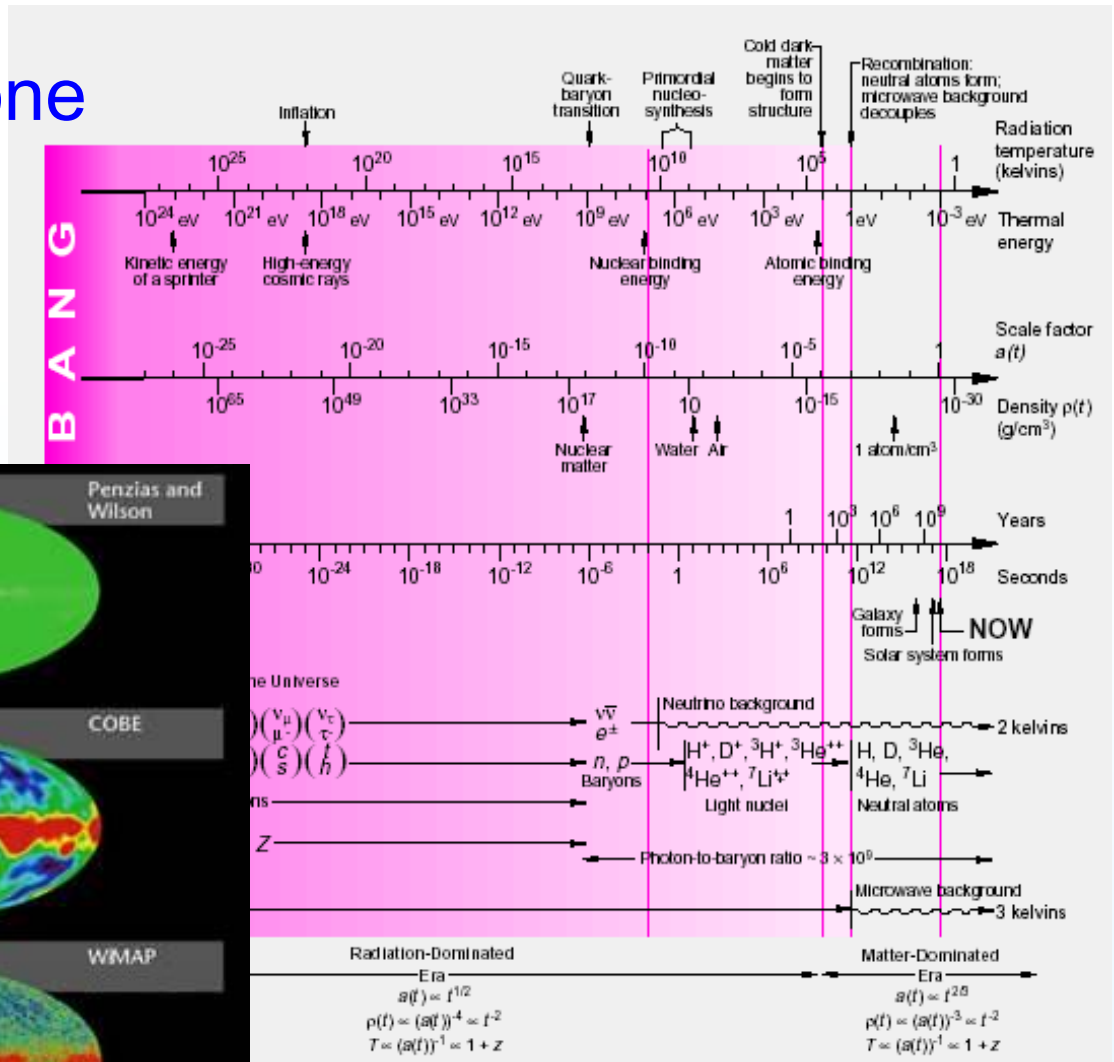
Gamma-ray Imaging Detector (GRID)		
Energy Range	30 MeV – 50 GeV	
Field of view	~ 3 sr	
Sensitivity at 100 MeV (ph cm ⁻² s ⁻¹ MeV ⁻¹)	6 × 10 ⁻⁹	(5σ in 10 ⁶ s)
Sensitivity at 1 GeV (ph cm ⁻² s ⁻¹ MeV ⁻¹)	4 × 10 ⁻¹¹	(5σ in 10 ⁶ s)
Angular Resolution at 1 GeV	36 arcmin	(68% cont. radius)
Source Location Accuracy	~5–20 arcmin	S/N~10
Energy Resolution	ΔE/E~1	at 300 MeV
Absolute Time Resolution	~ 1 μs	
Deadtime	~ 200 μs	
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	ΔE<4 keV	
Absolute Time Resolution	~ 4 μs	
Deadtime (for each of the 16 readout units)	~ 4 μs	
Mini-Calorimeter		
Energy Range	0.3 – 200 MeV	
Energy Resolution	~ 1 MeV	above 1 MeV
Absolute Time Resolution	~ 3 μs	
Deadtime (for each of the 30 CsI bars)	~ 20 μs	

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.

PLANCK 1/3

Fondo di Radiazione



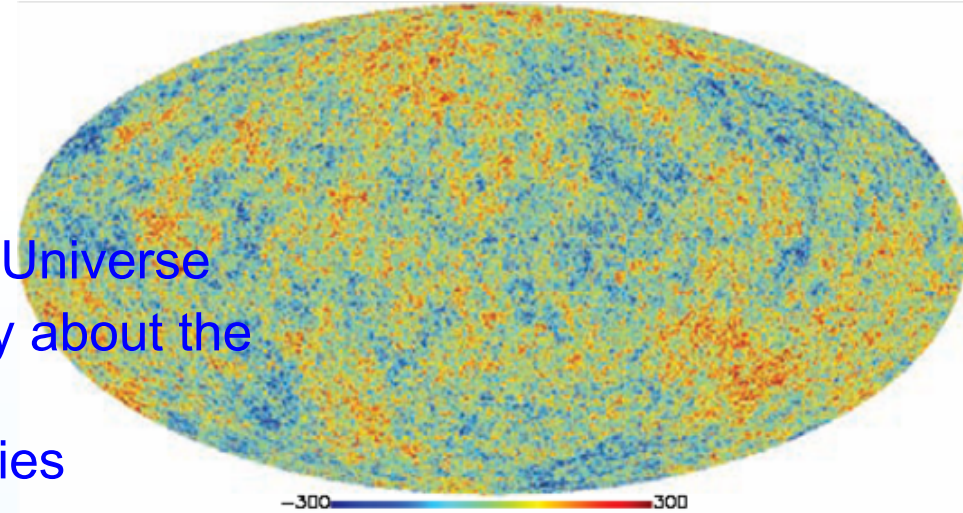
PLANCK 2/3

Planck is 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:

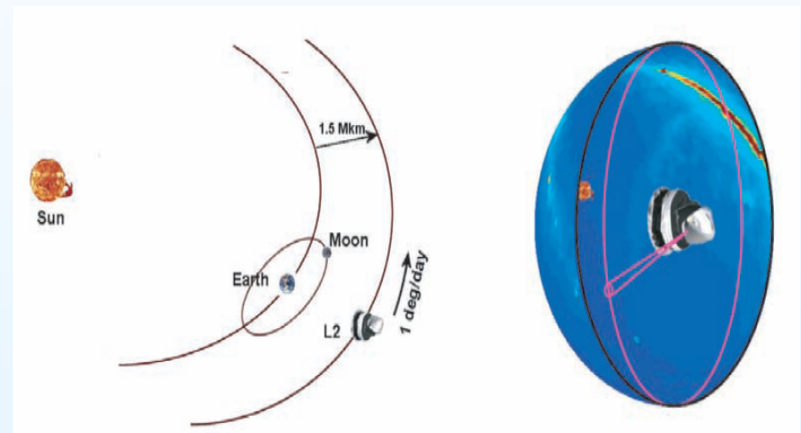
- Determination of geometry of the Universe
- Determination of the correct theory about the Universe origin and evolution
- Complete map of CMB anisotropies



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

Distance from the Earth: 1.5×10^6 km

Spin axis: opposite direction respect to the Sun



PLANCK 2/3

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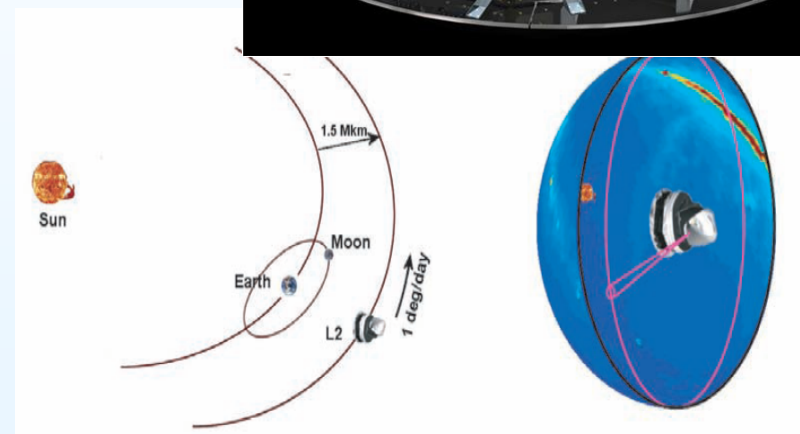
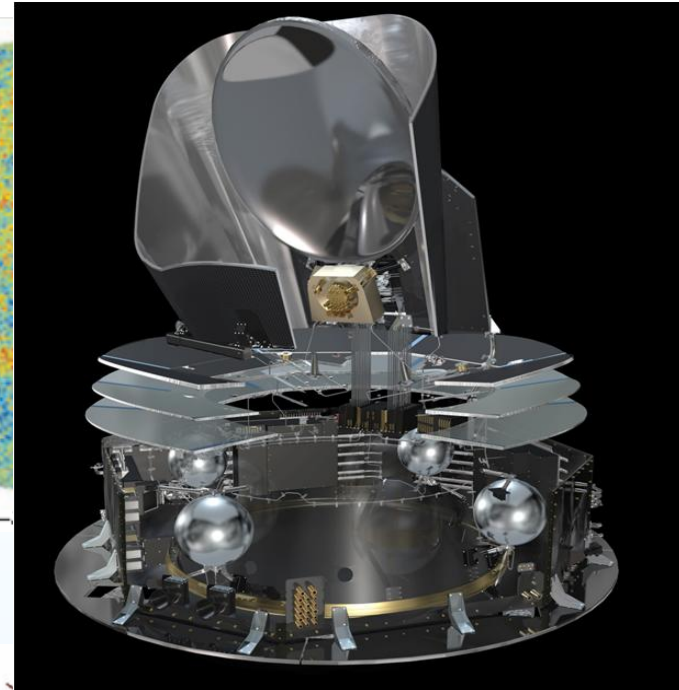
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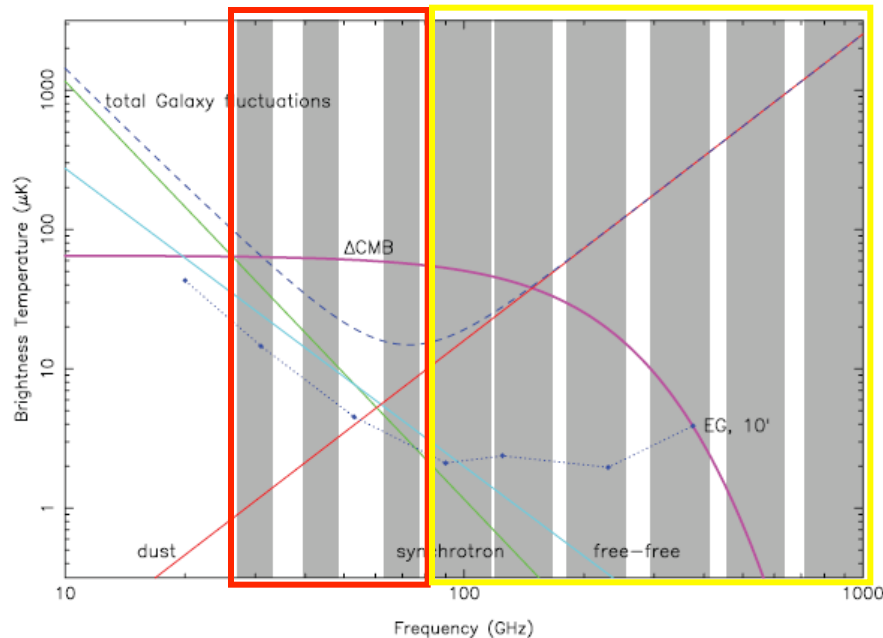
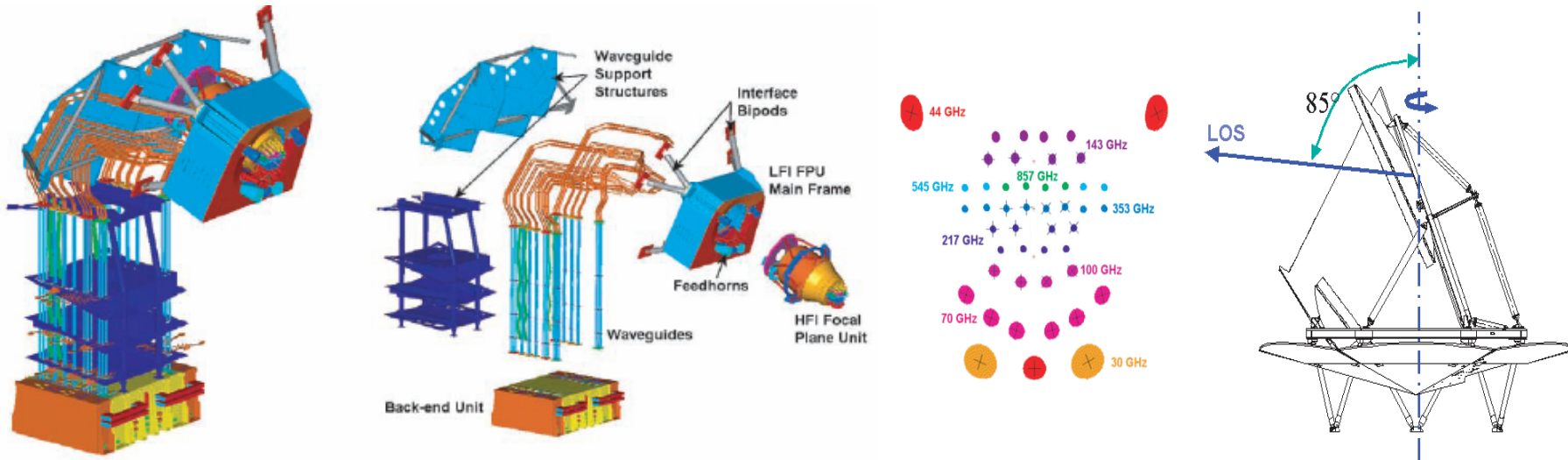
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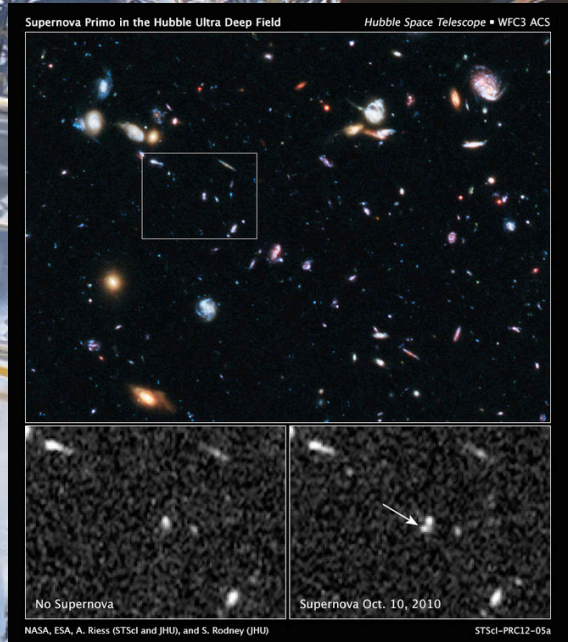


PLANCK 3/3



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

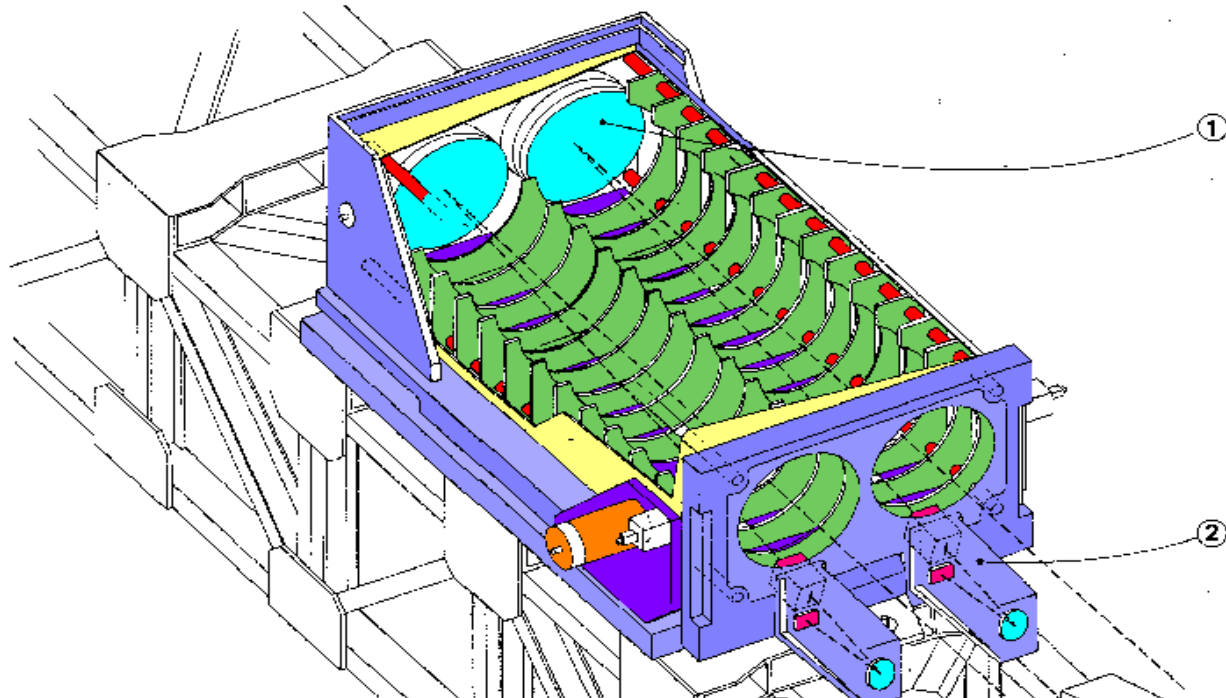
Astronomia: Hubble



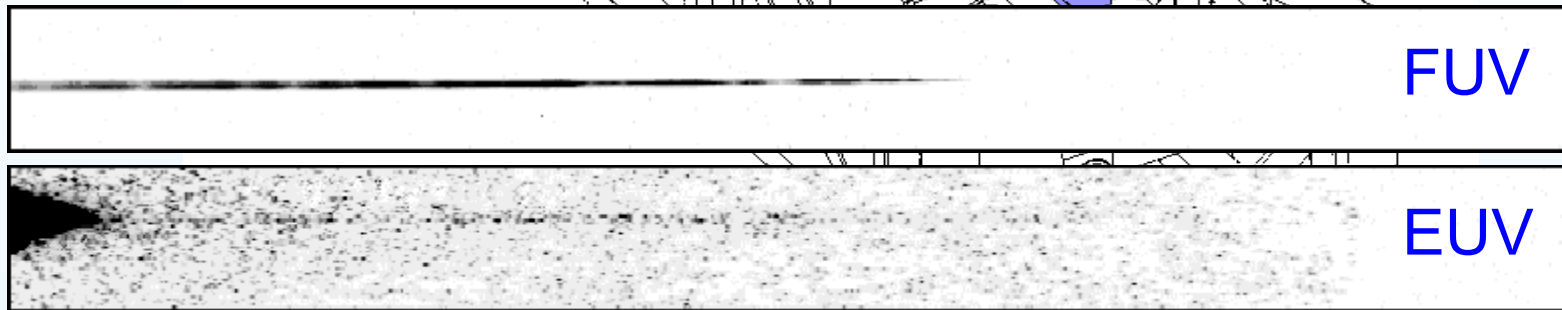
Supernova Primo in the Hubble Ultra Deep Field Hubble Space Telescope • WFC3 ACS

No Supernova Supernova Oct. 10, 2010

Astronomia: UVSTAR 1/4



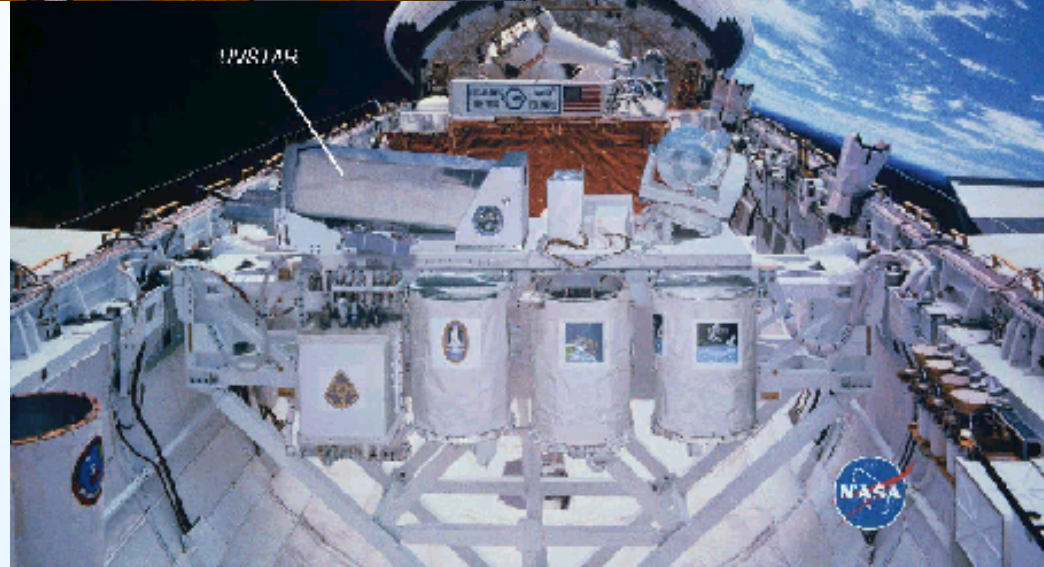
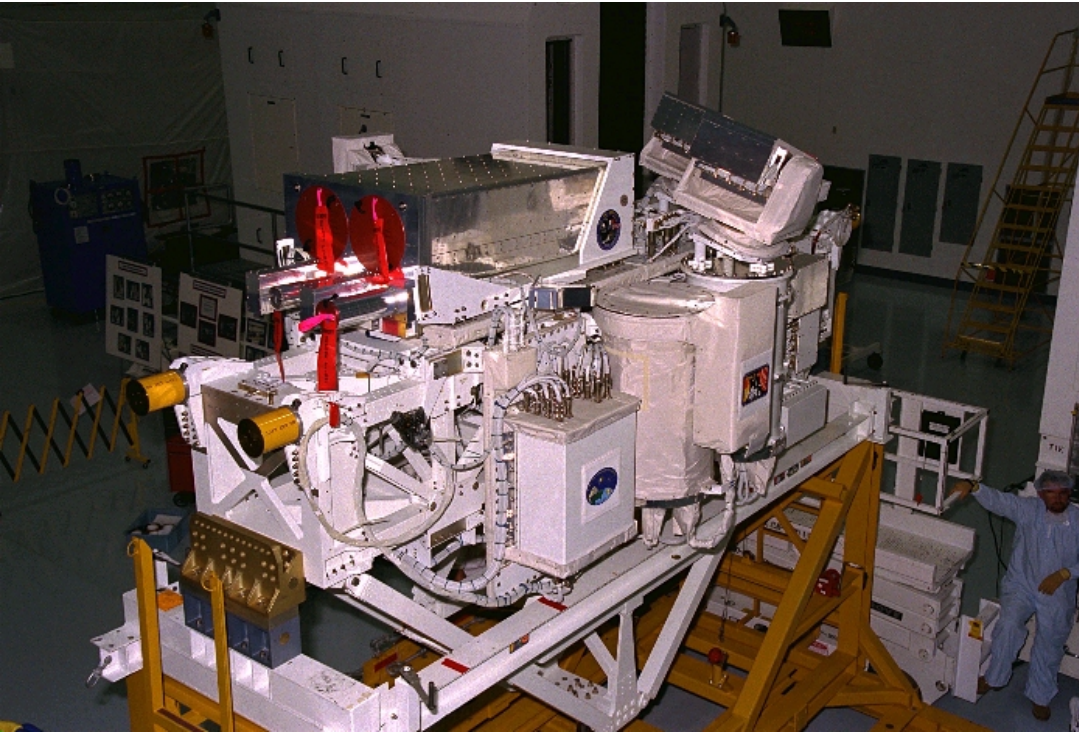
s
p
a
z
i
o



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

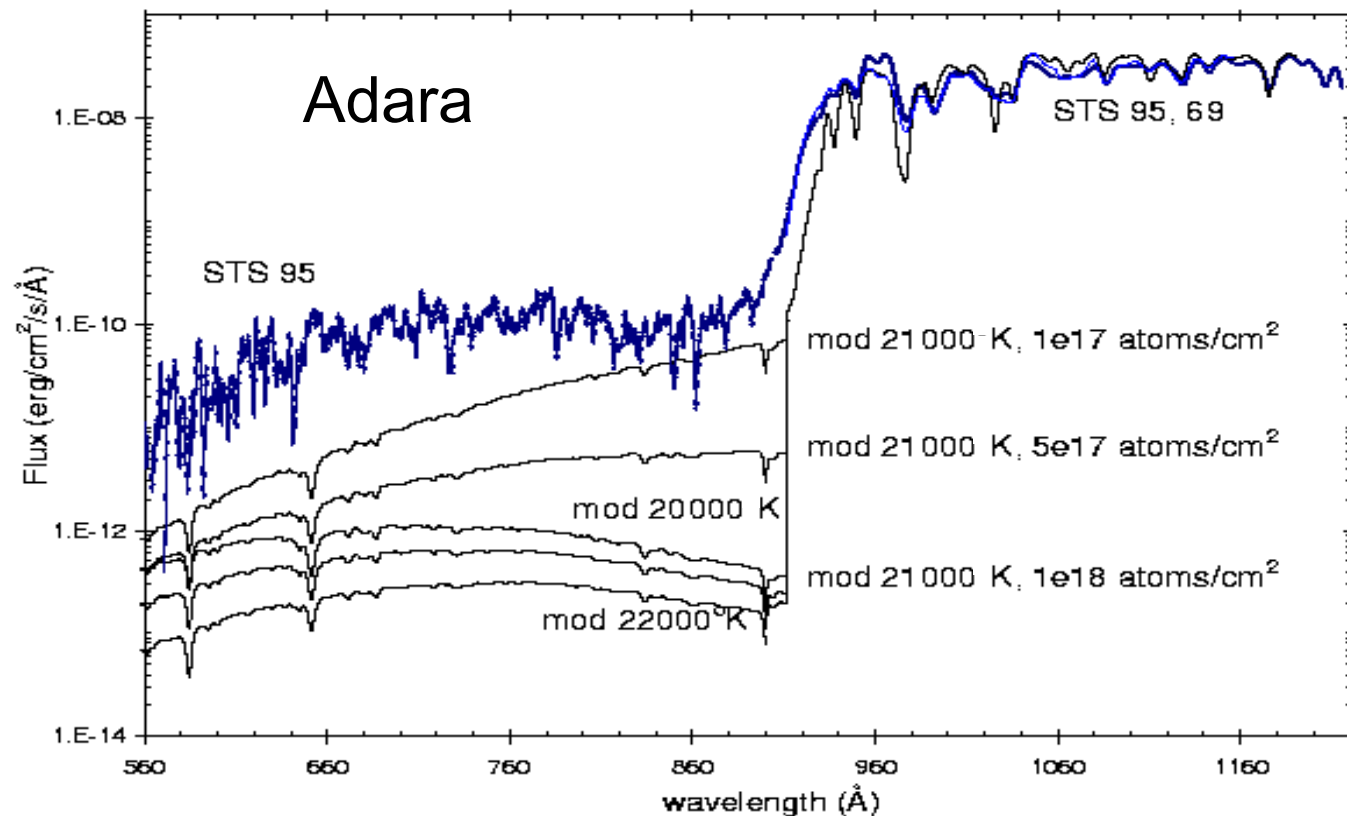
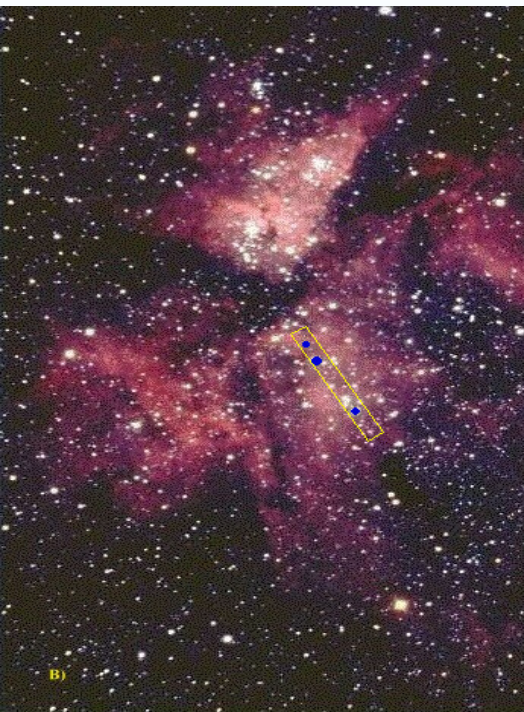
Lunghezza
d'onda

Astronomia: UVSTAR 2/4

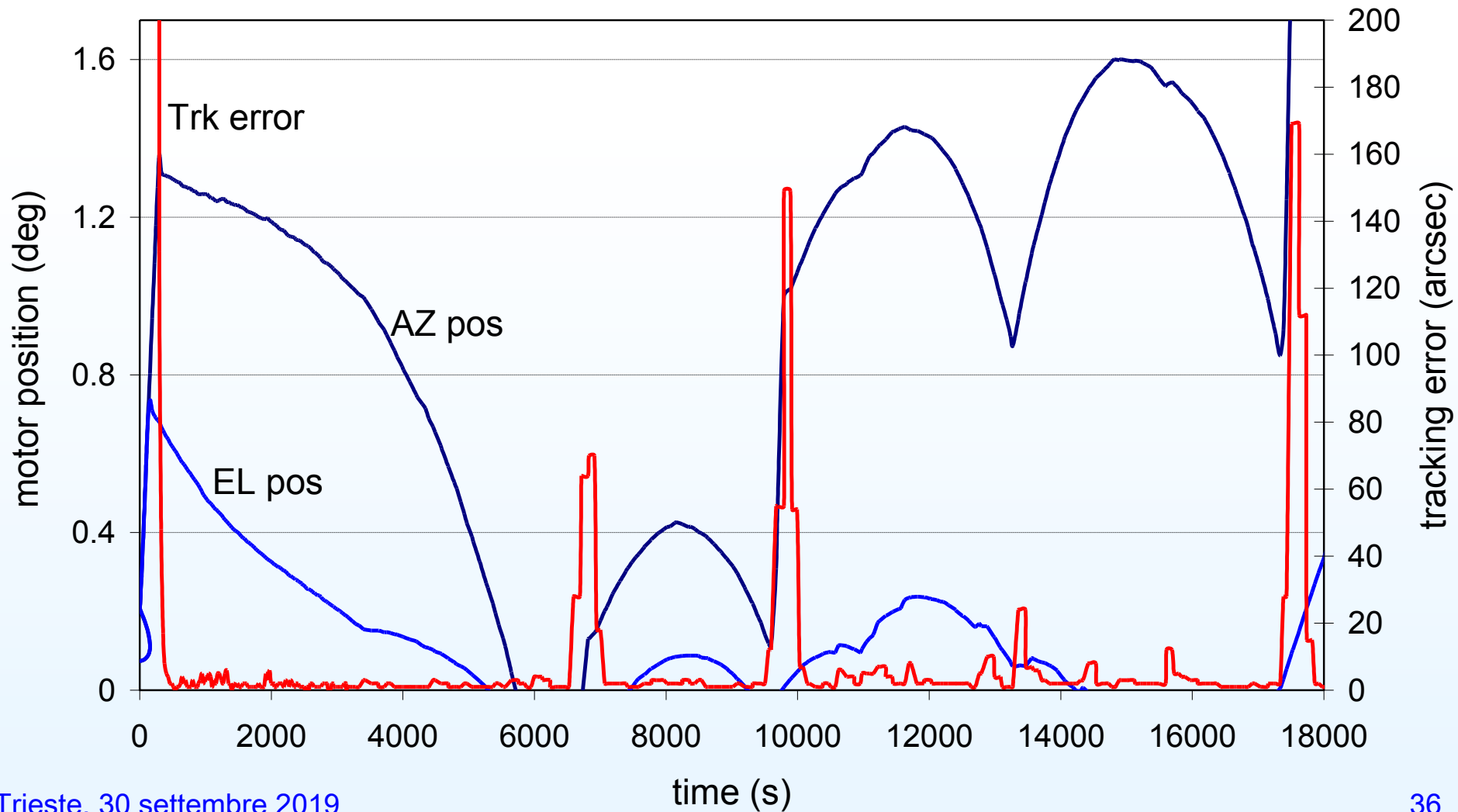


Astronomia: UVSTAR 3/4

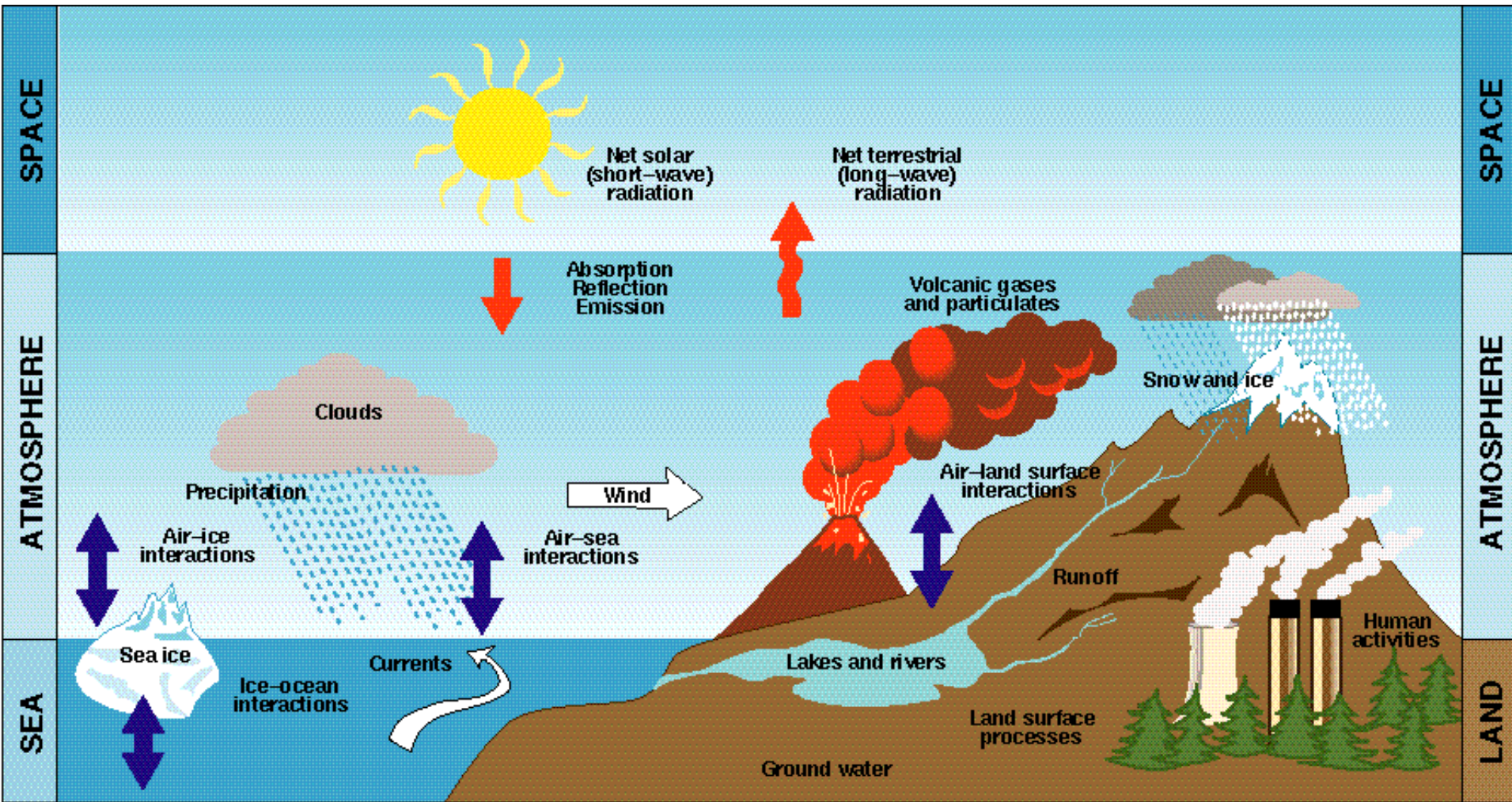
- sistema di movimentazione autonomo munito di 2 telescopi ausiliari per la direzione di puntamento
- osserva atmosfere stellari, regioni HII, anelli di IO, comete
- analisi spettrale del flusso nelle varie componenti UV (FUV/EUV)



Risultati tecnologici: sistema di puntamento



Fisica della Terra

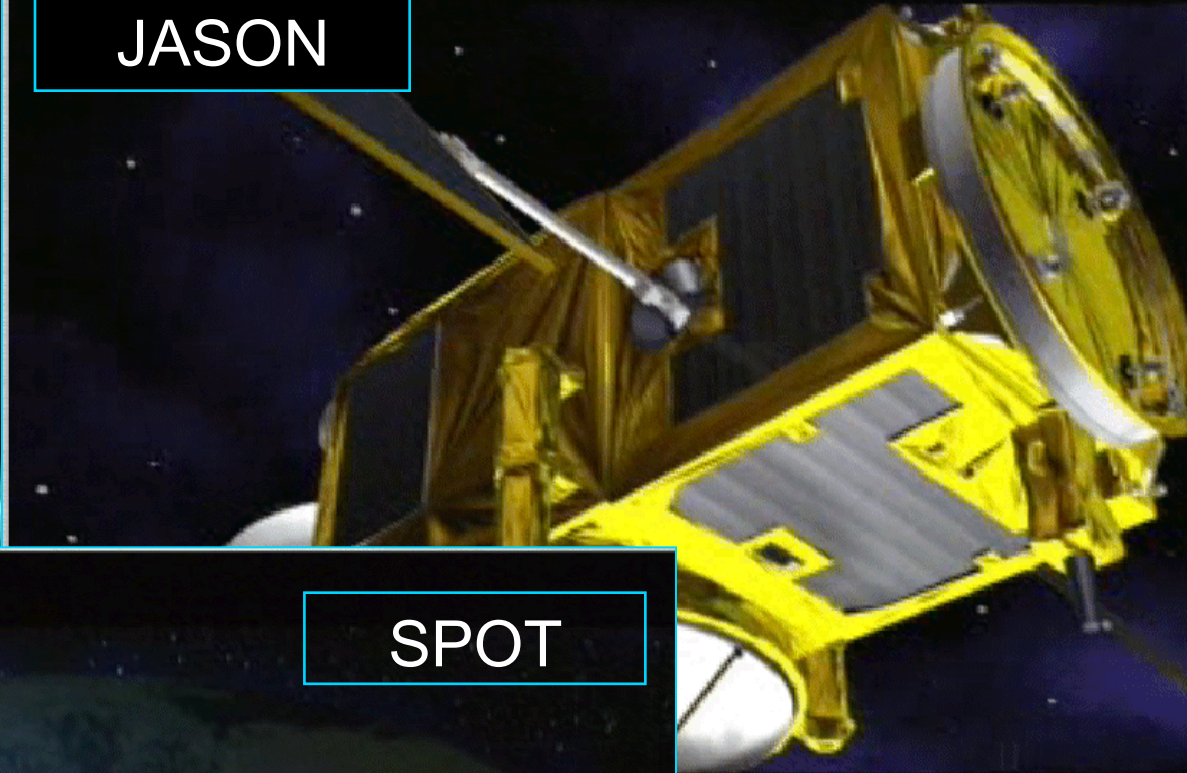


Osservazioni della Terra

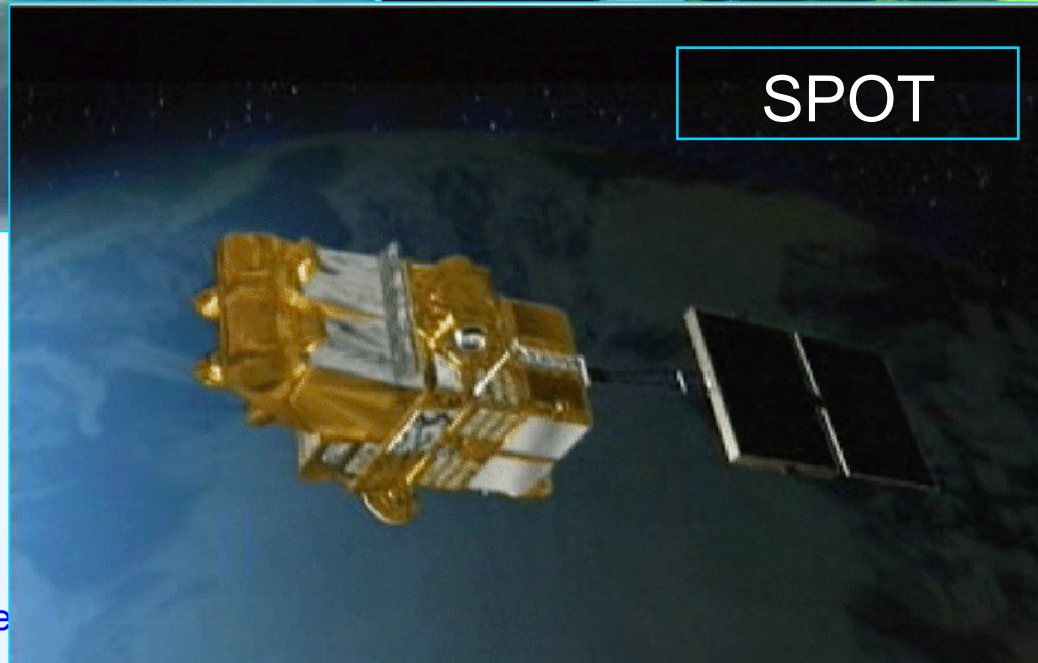
DORIS
(topex/poseidon)



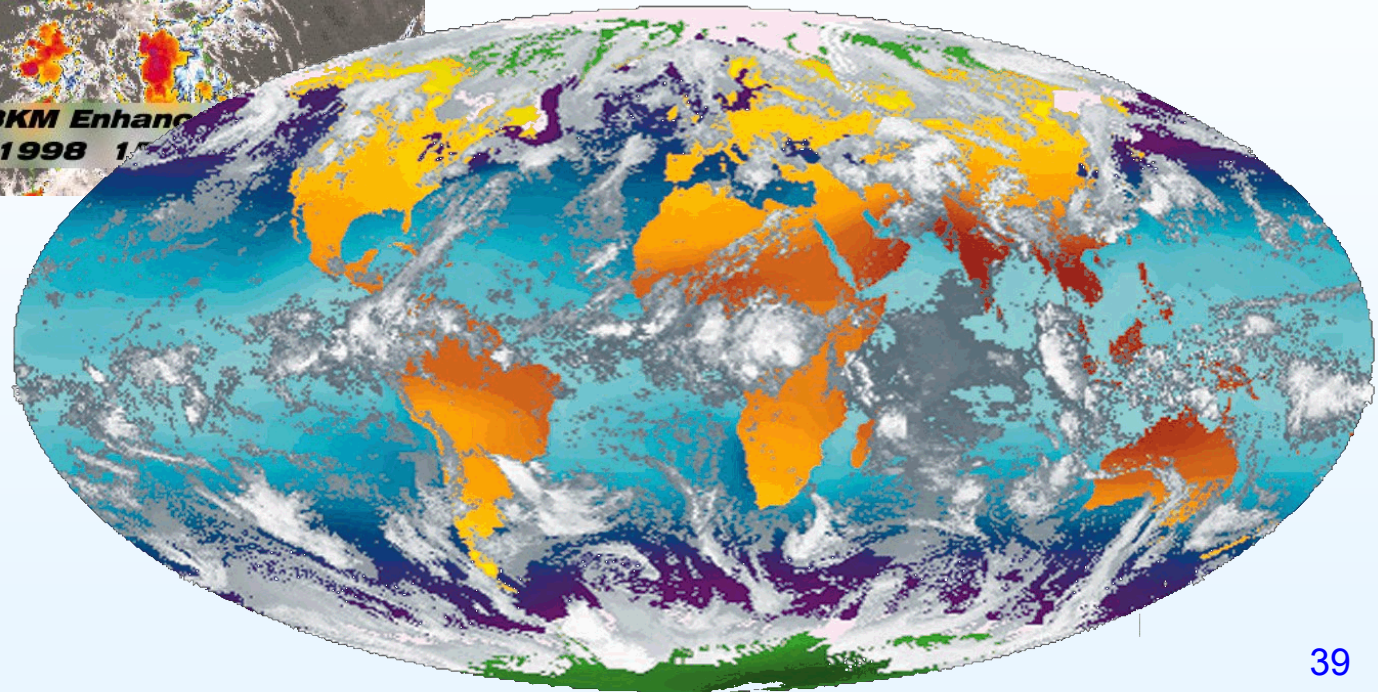
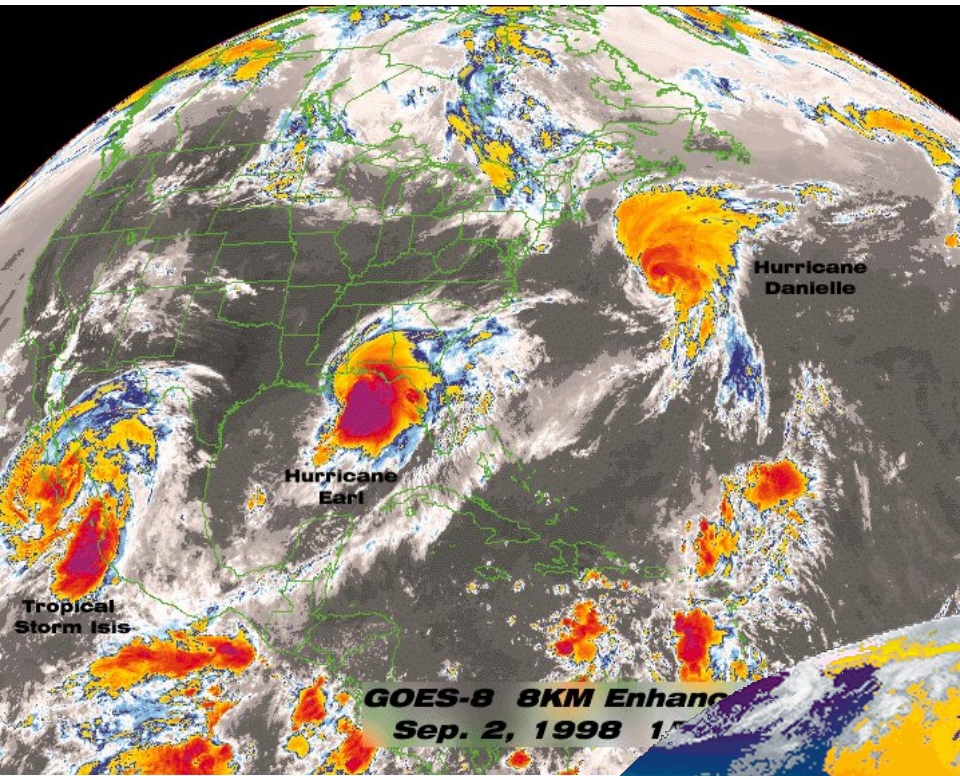
JASON



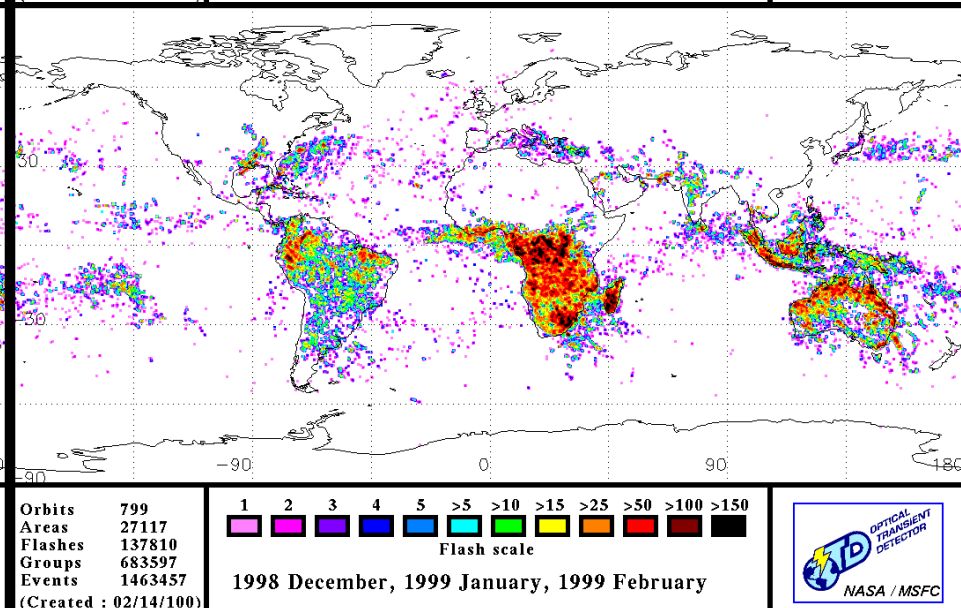
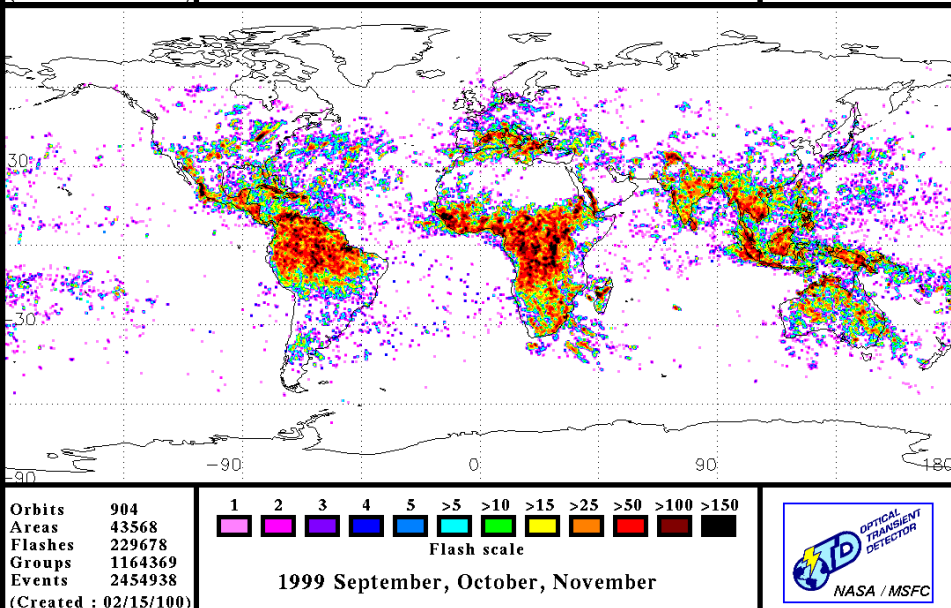
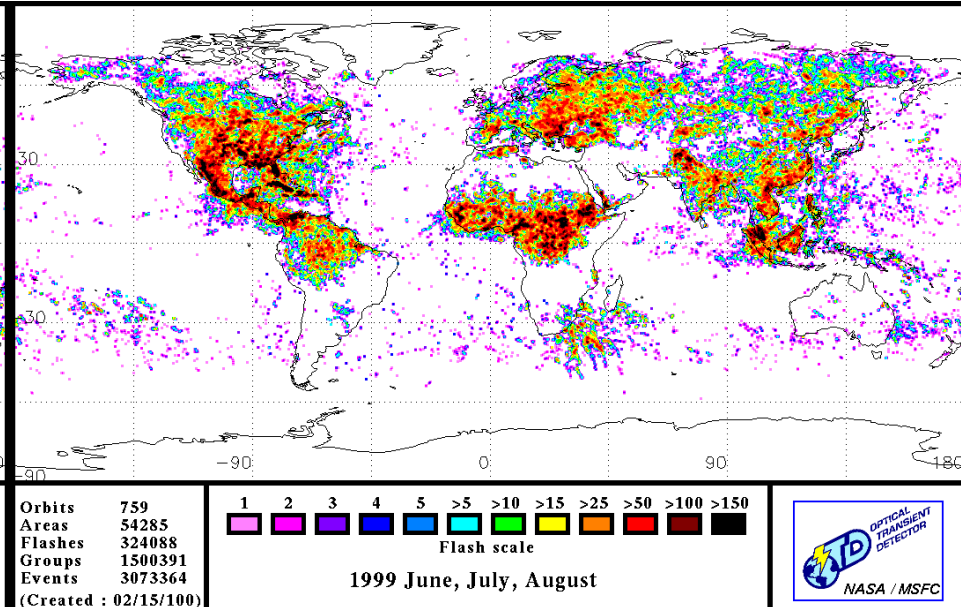
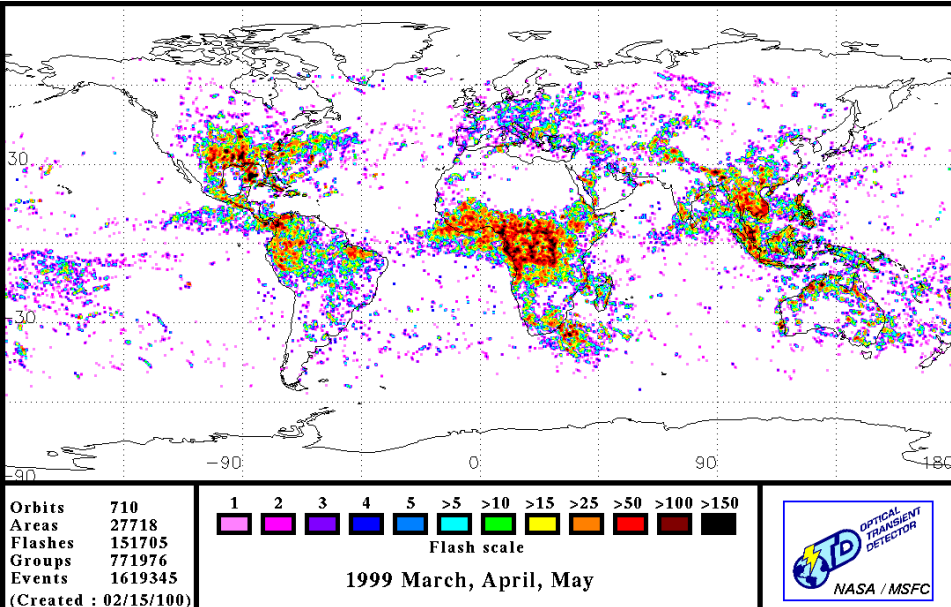
SPOT



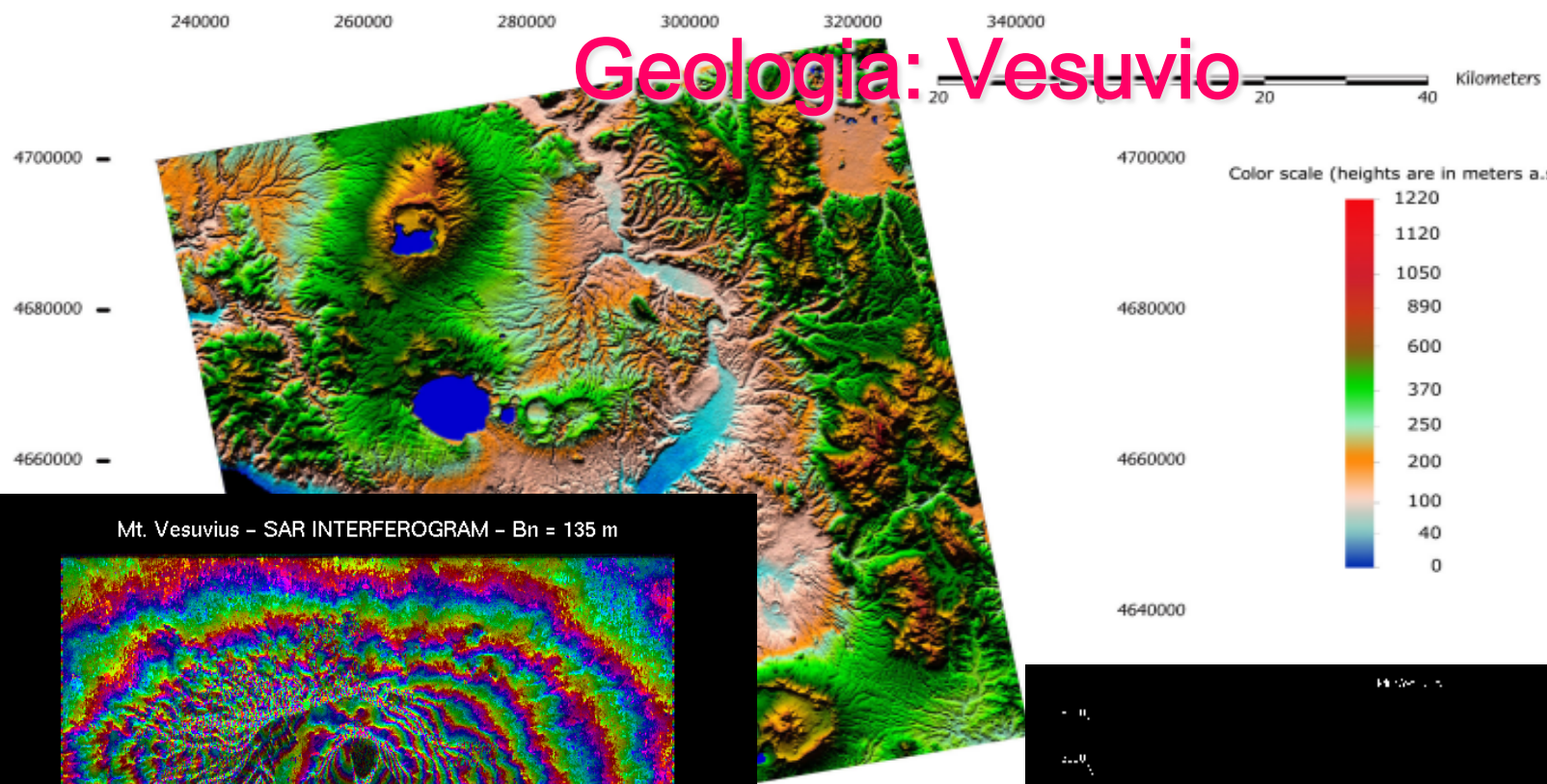
Meteorologia



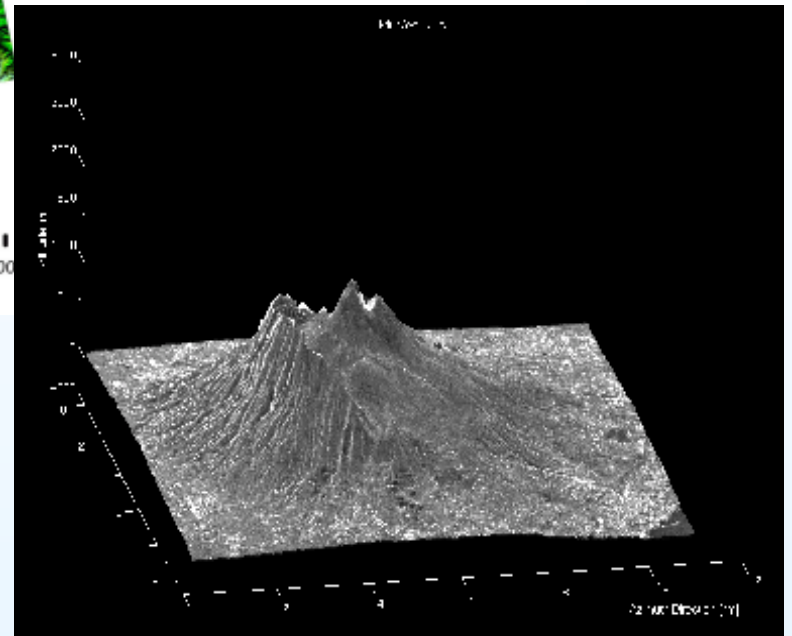
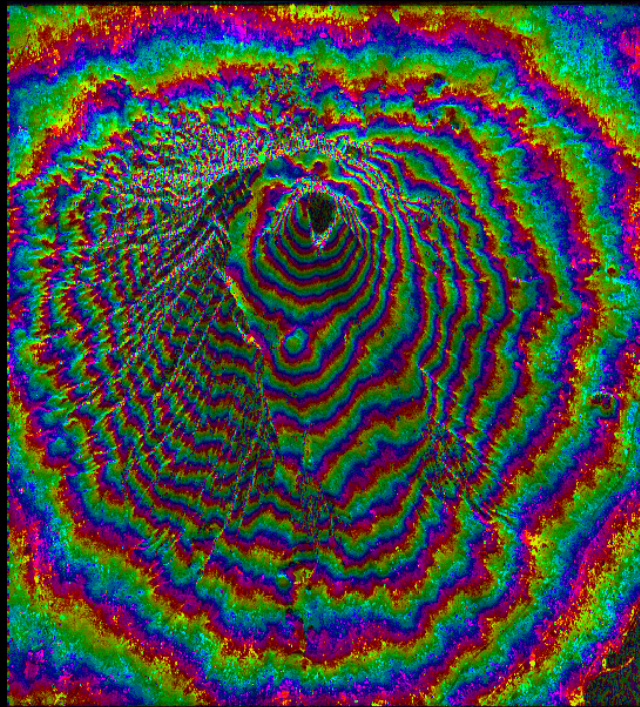
Meteorologia



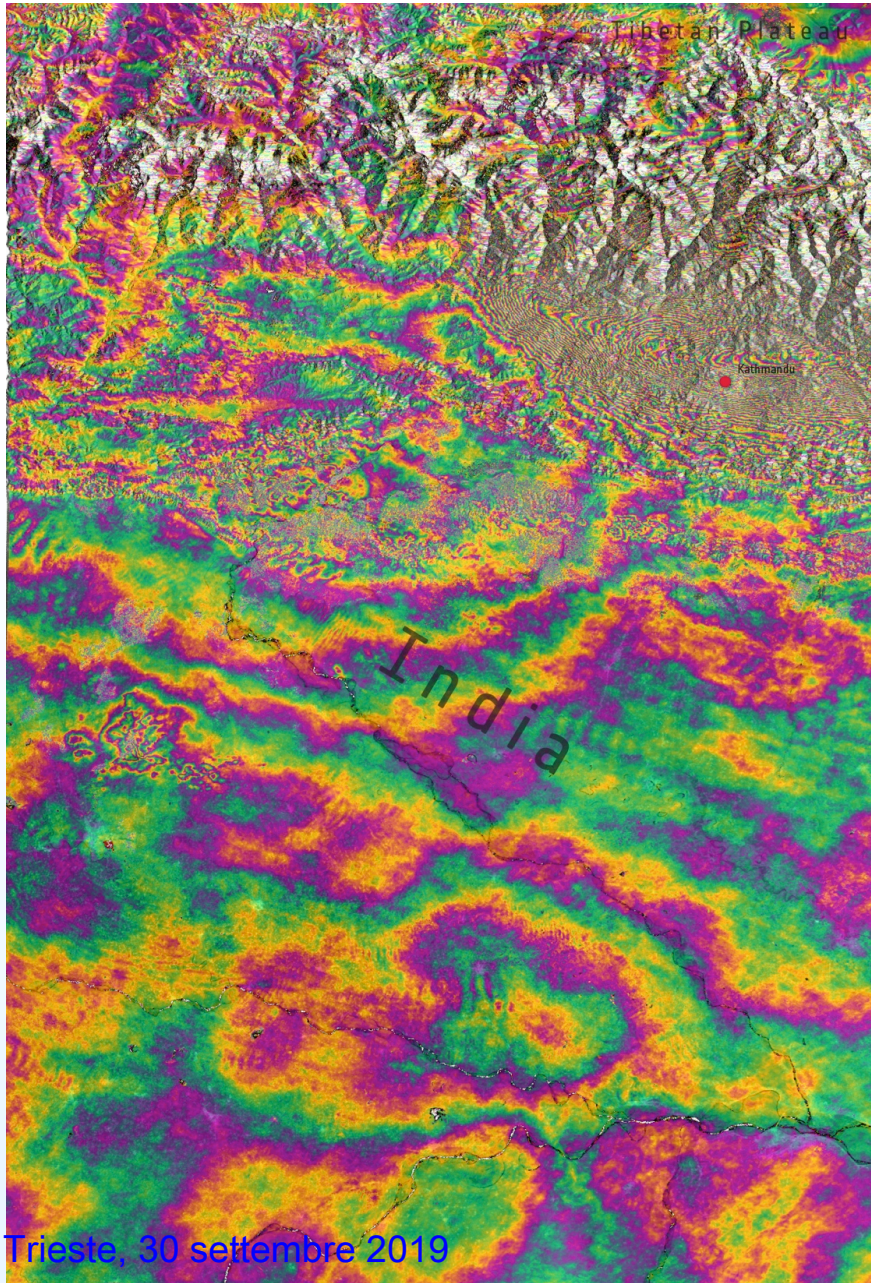
Geologia: Vesuvio



Mt. Vesuvius - SAR INTERFEROGRAM - Bn = 135 m

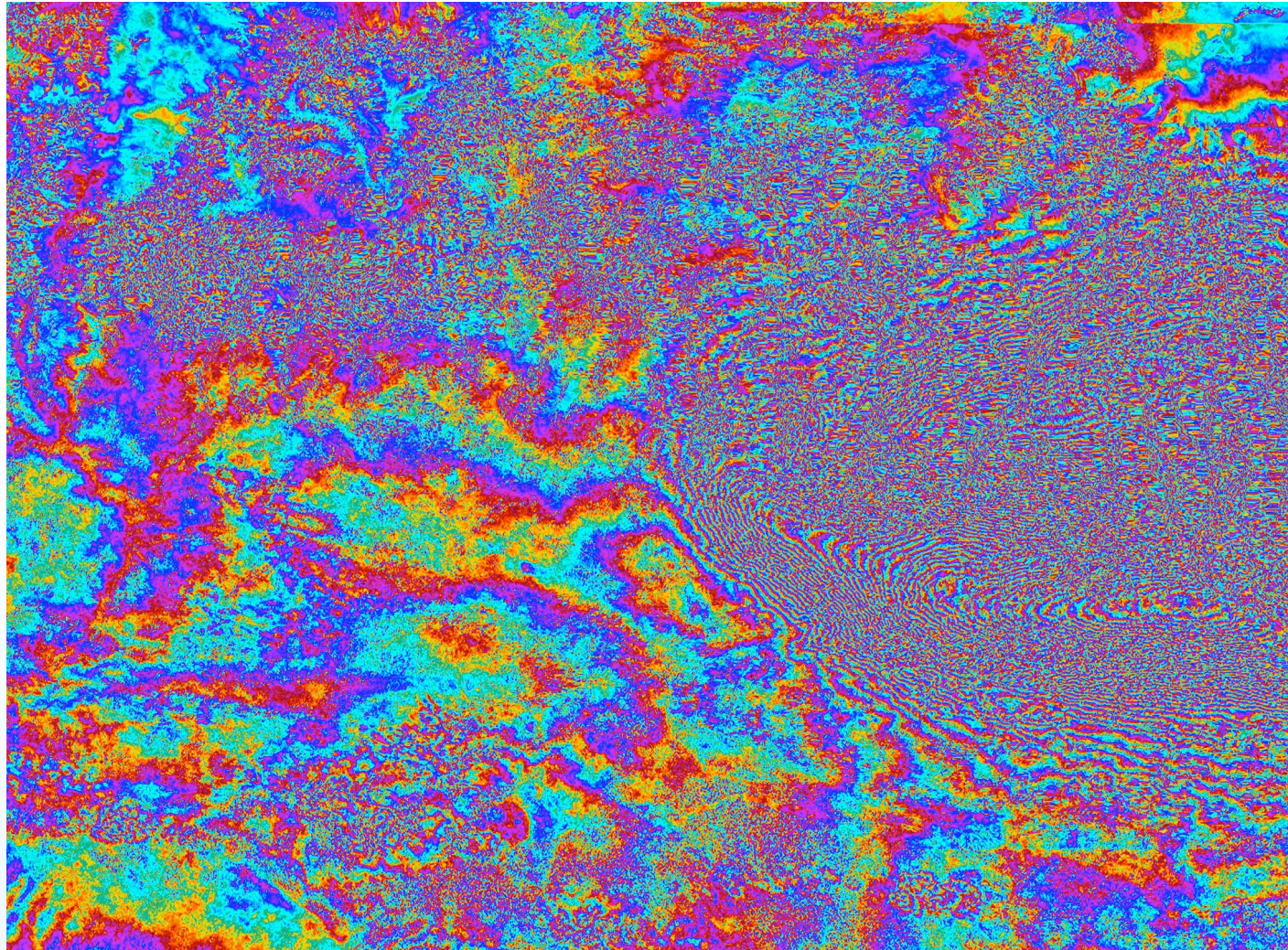


Sentinel 1 2015 - Nepal earthquake



- 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



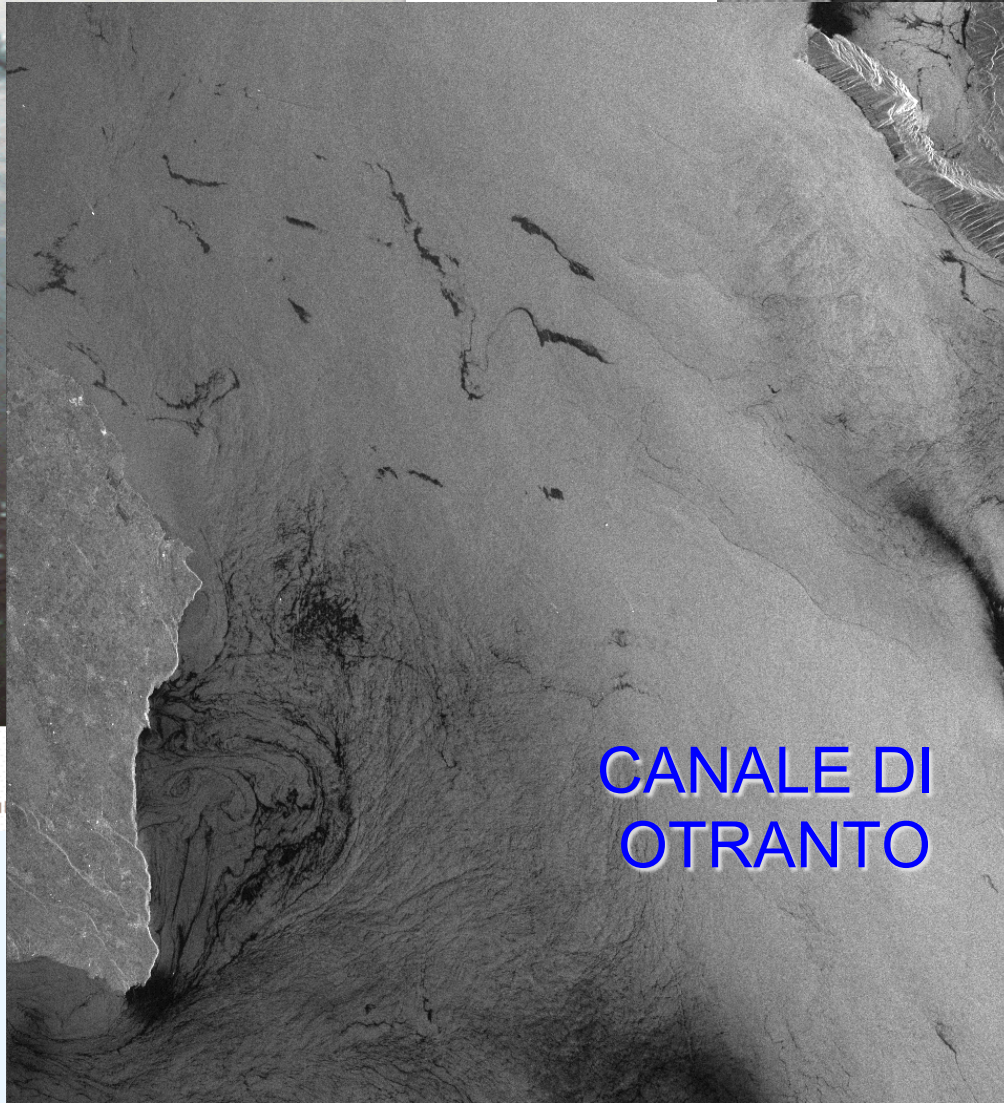
Interferogram over Kathmandu generated from two Sentinel-1A scans on 17 and 29 April 2015 – before and after the 25 April earthquake.

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

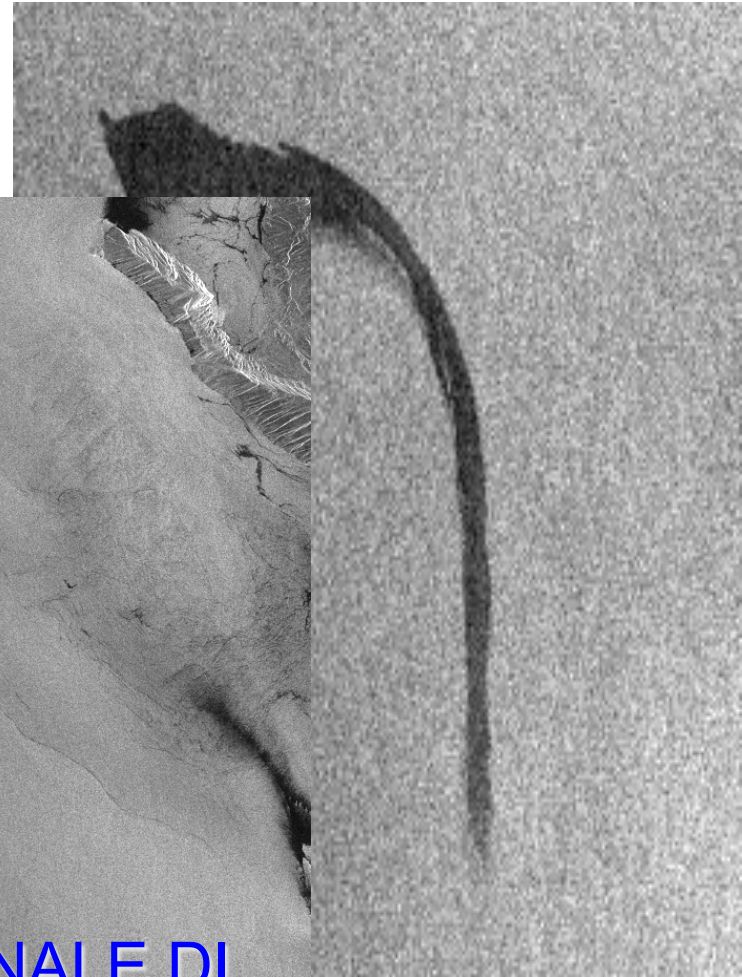
Ambiente: Inquinamento



Thames Water Authority dump sewage in the North Sea.
Copyright Greenpeace / Morga



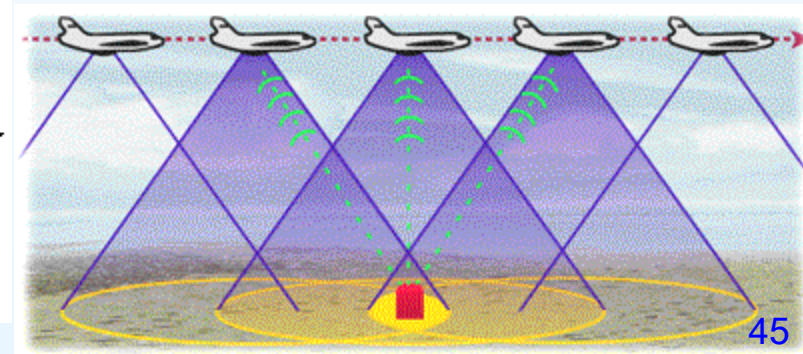
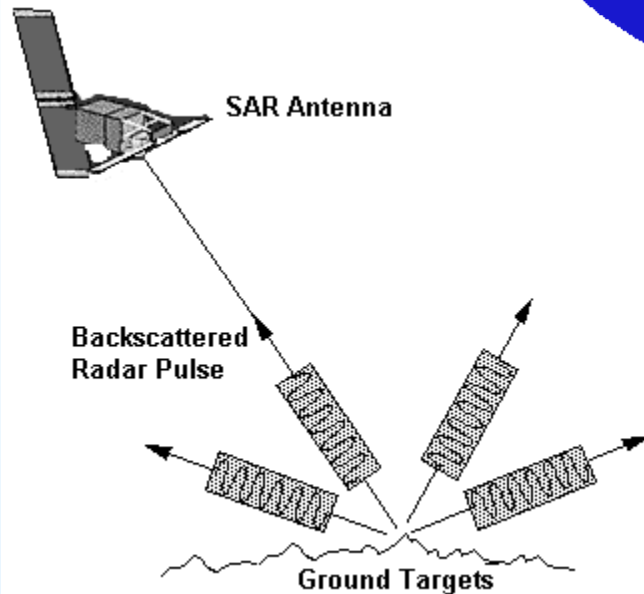
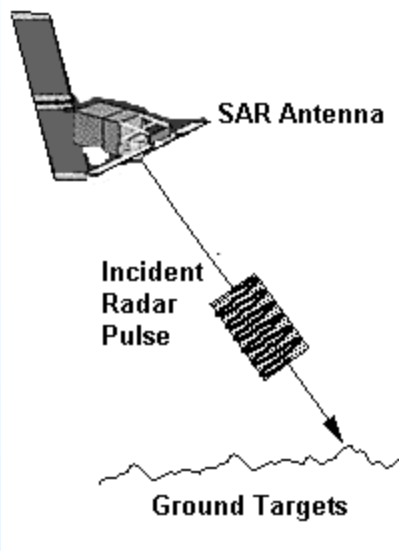
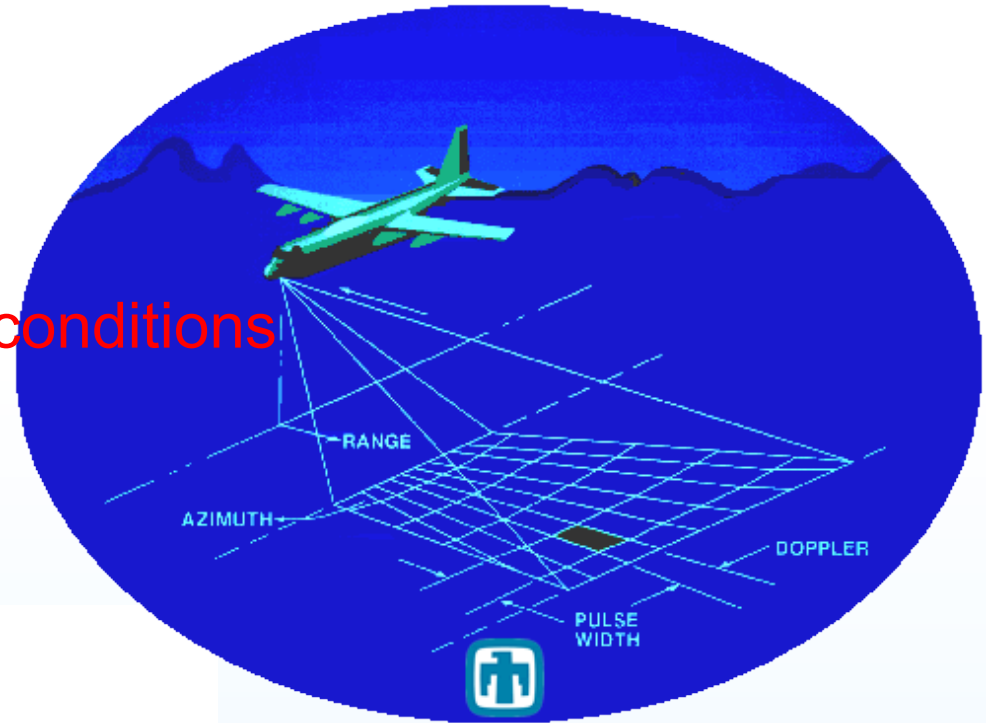
CANALE DI
OTRANTO



Synthetic Aperture Radar - SAR

Radio Signals

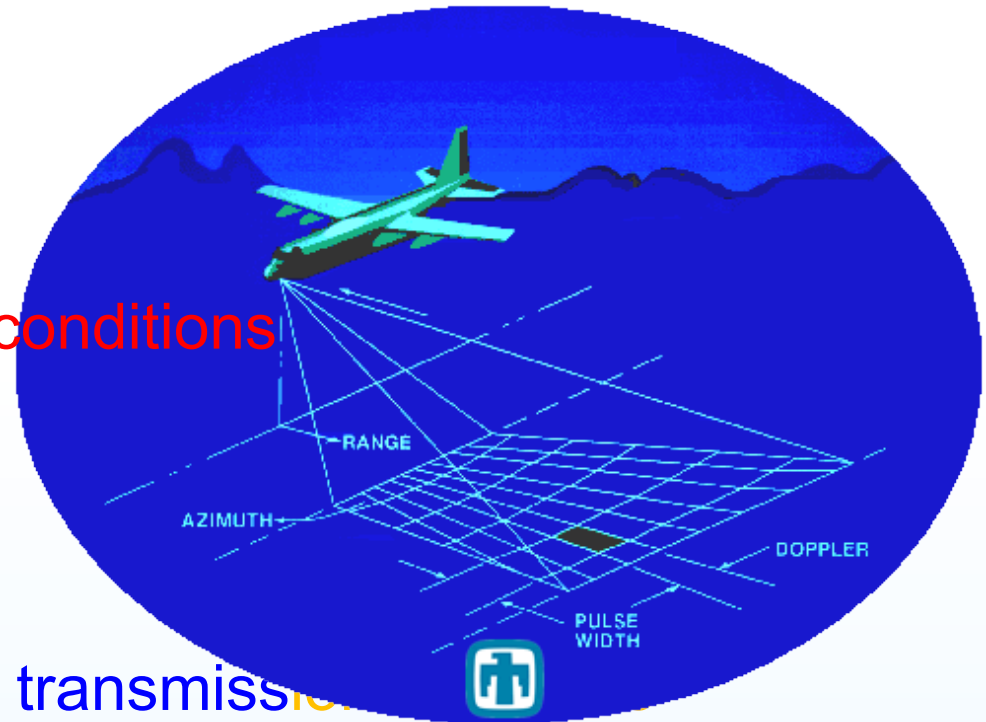
- Long range propagation characteristics
- Reduced effect of weather conditions
- Unique response of terrain



Synthetic Aperture Radar - SAR

Radio Signals

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



2-dim image

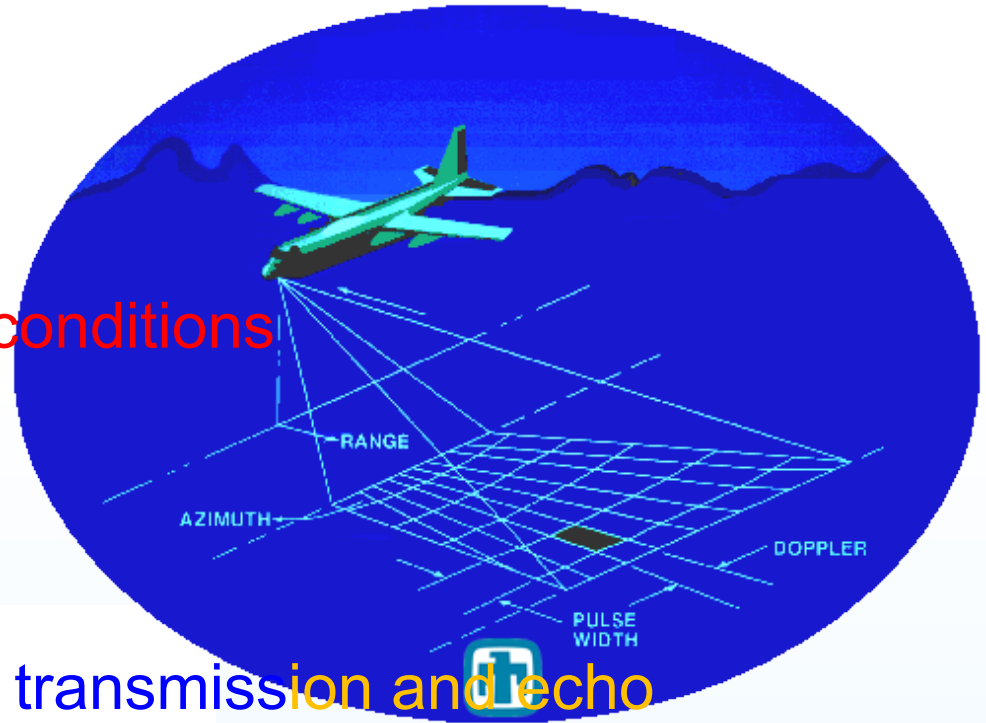
- Range: time between signal transmission and reception (resolution \propto signal width)
- Azimuth: doppler shift processing (resolution \propto beam dimension \propto 1/antenna length)
 - Resolution $\sim \lambda R/d$
 - $R \sim 50$ km, $\lambda \sim 0.03$ m, resolution ~ 1 m $\Rightarrow d \sim 1.5$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

\Rightarrow Synthetic Aperture !!!

Synthetic Aperture Radar - SAR

Radio Signals

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



2-dim image

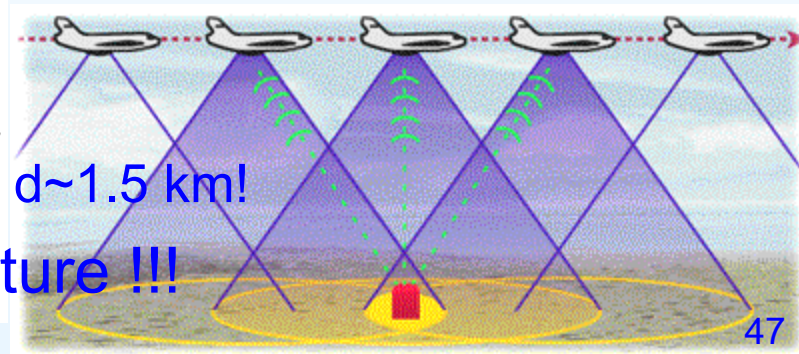
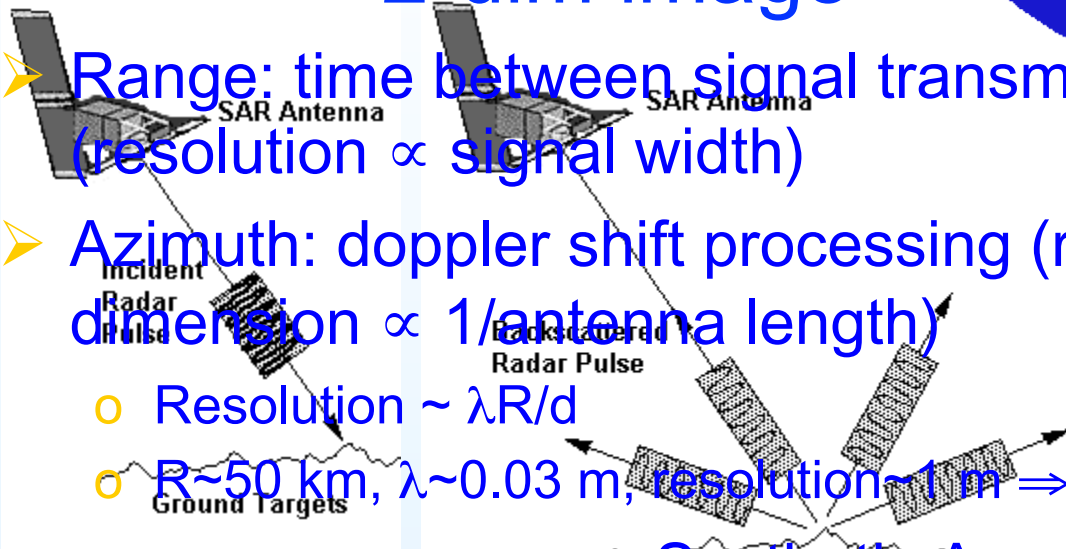
- Range: time between signal transmission and echo (resolution \propto signal width)

- Azimuth: doppler shift processing (resolution \propto beam dimension \propto 1/antenna length)

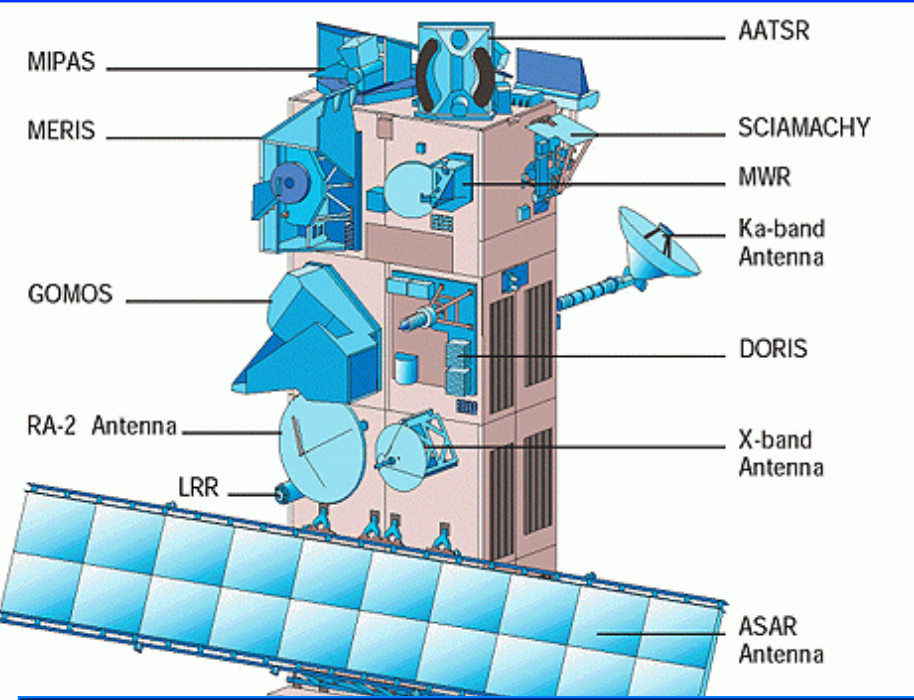
○ Resolution $\sim \lambda R/d$

○ $R \sim 50$ km, $\lambda \sim 0.03$ m, resolution ~ 1 m $\Rightarrow d \sim 1.5$ km!

\Rightarrow Synthetic Aperture !!!

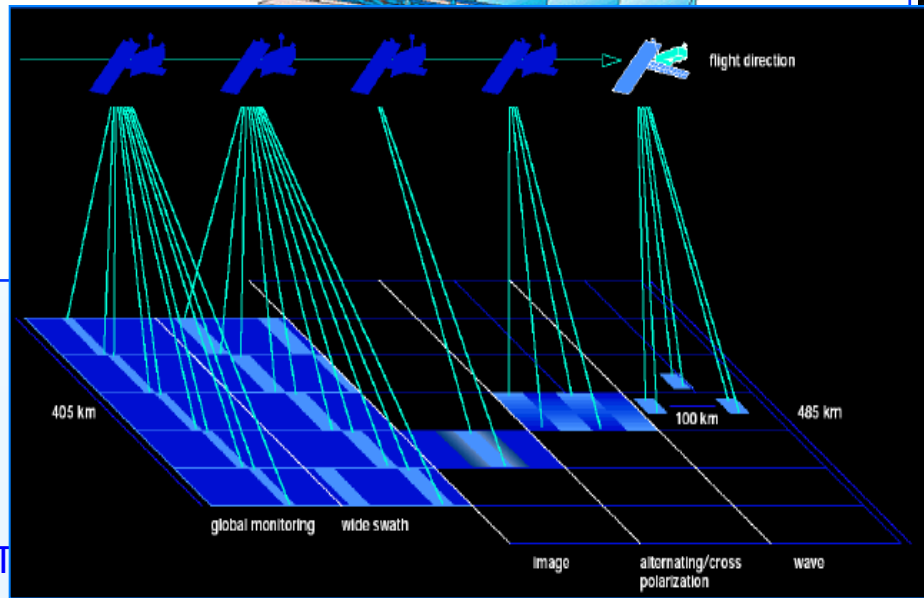


Strumenti di Envisat

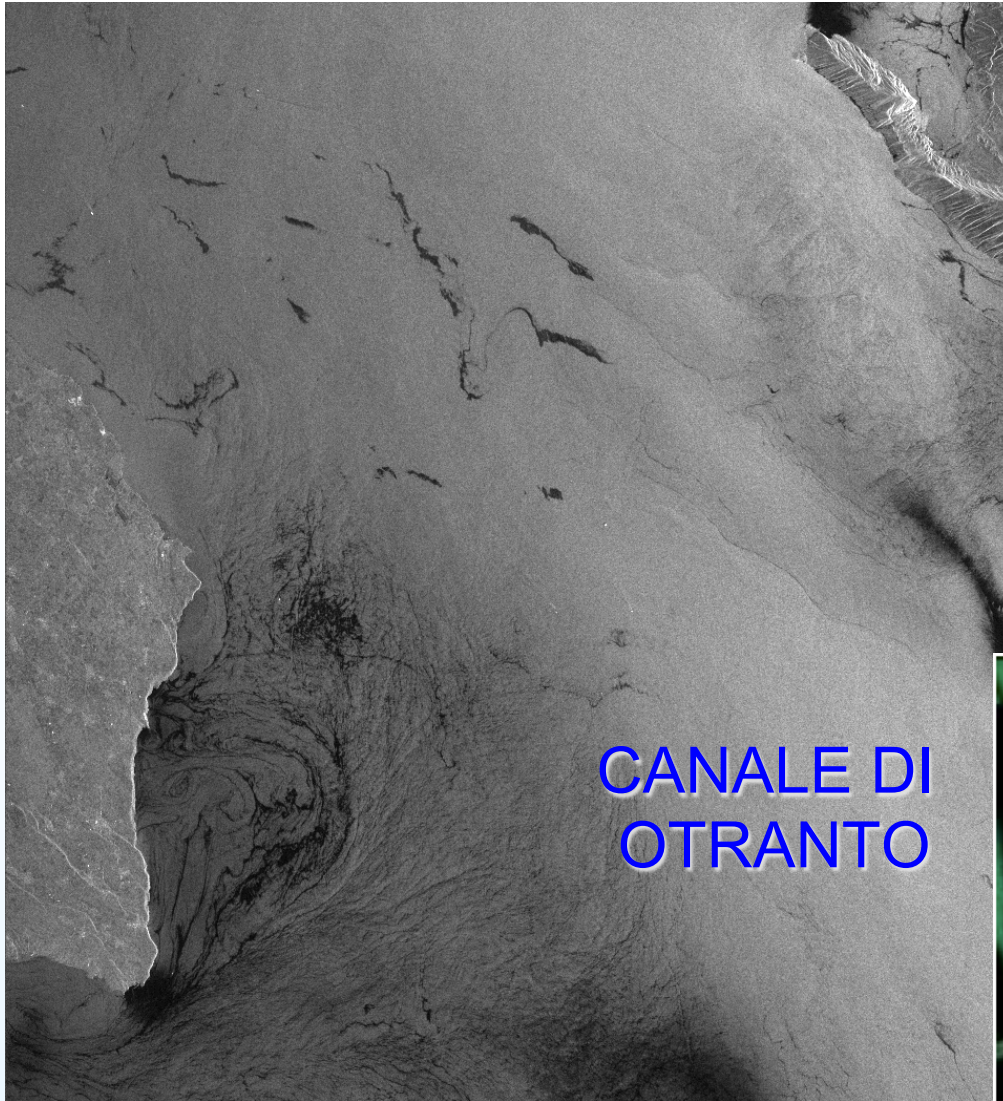


ASAR: Advanced Synthetic Aperture Radar

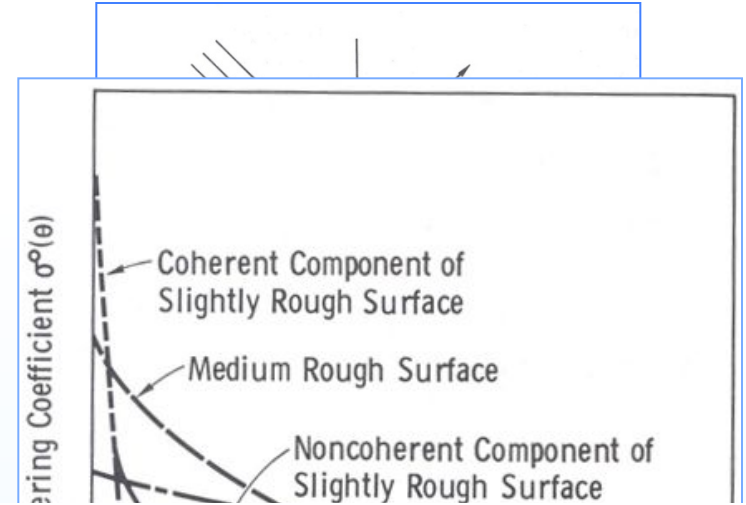
Immagini radar ad alta risoluzione dell'ambiente terrestre in qualsiasi condizione ambientale e di illuminazione



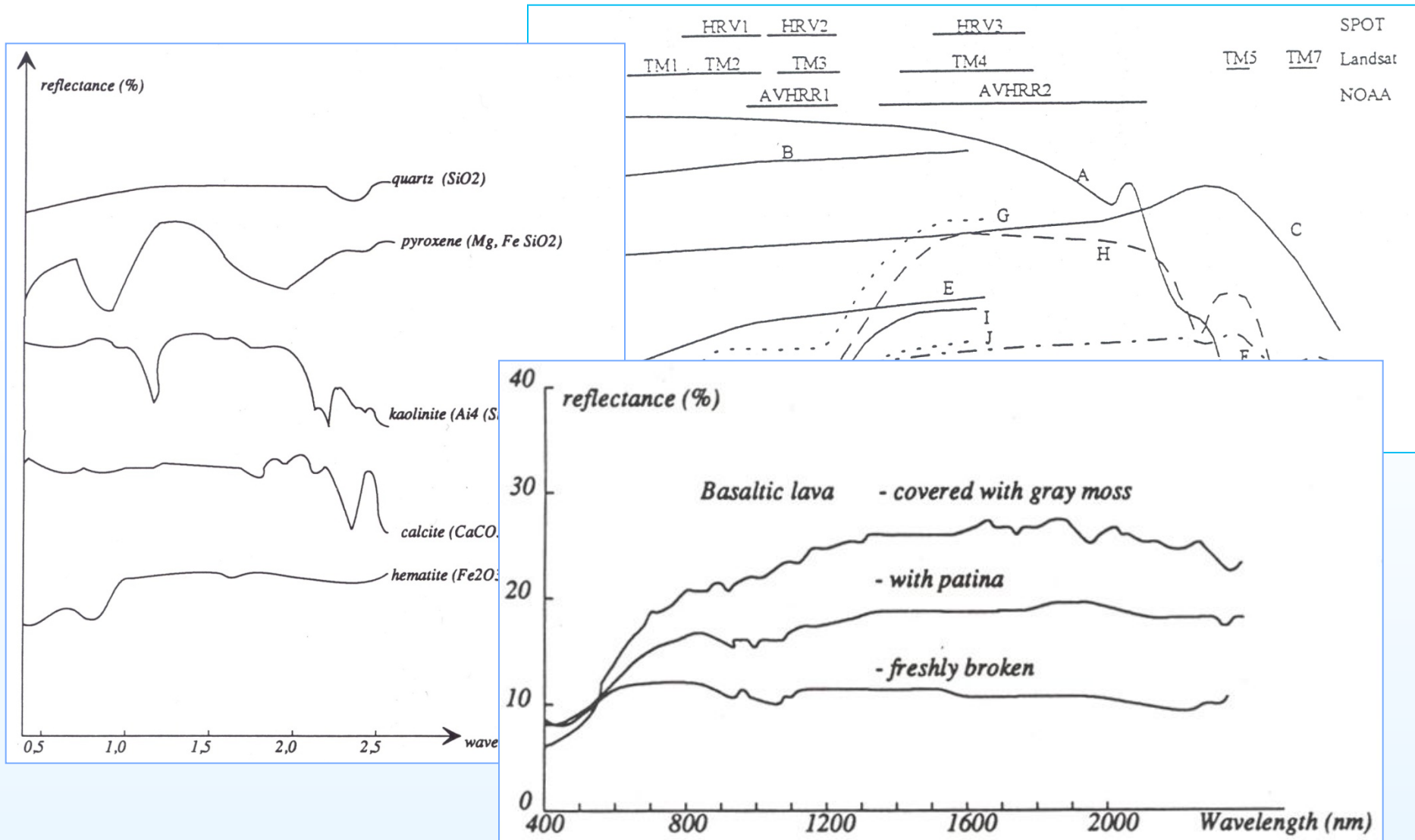
Imaging Radar: light reflectance, back-scattering



Surface rugosity is the second primary driver in radar signature



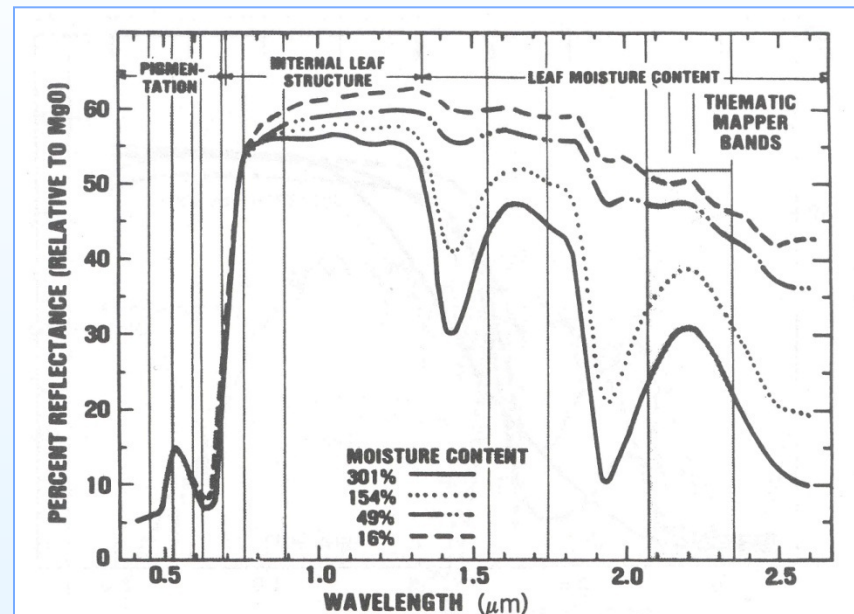
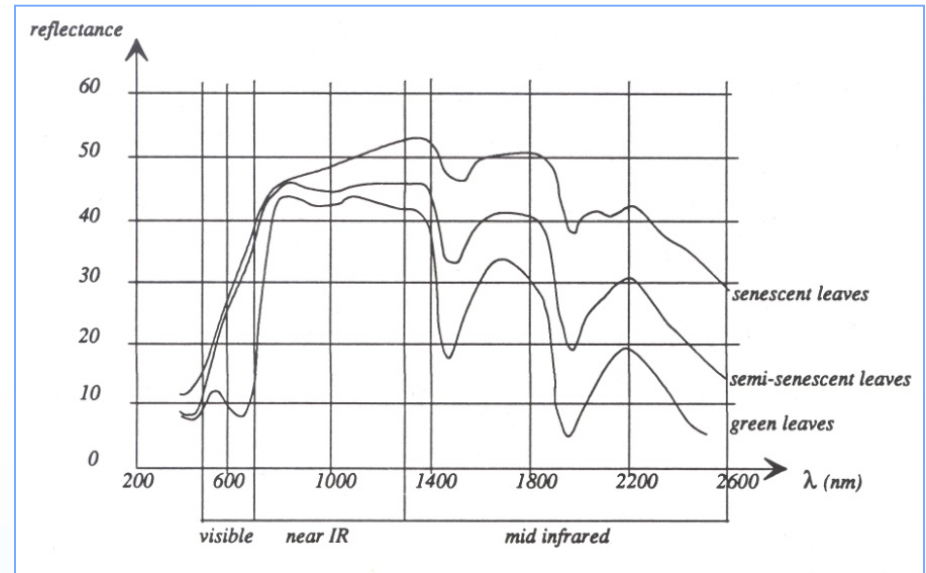
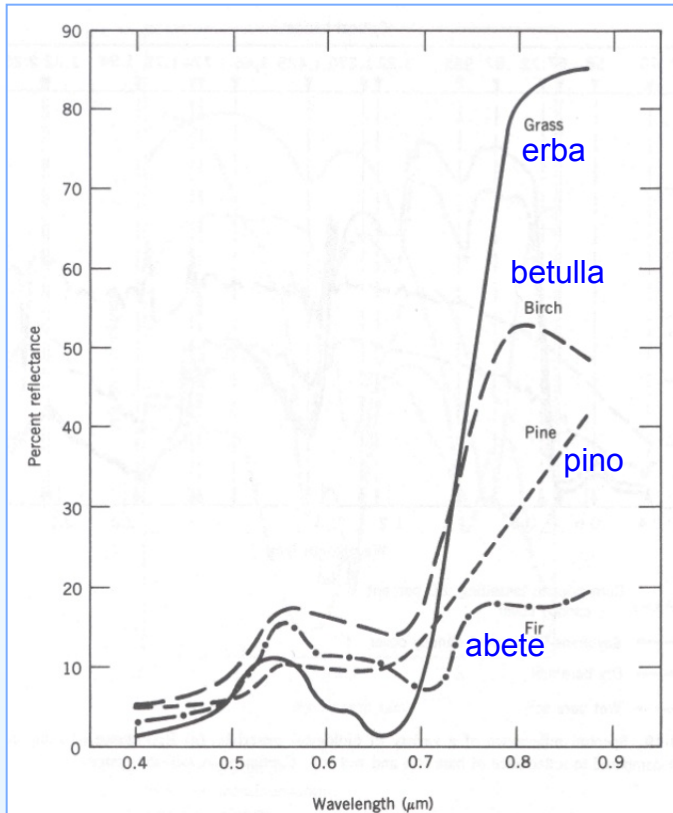
Geologia: struttura del suolo



Biologia: vegetazione

Vegetation spectral signatures vary with

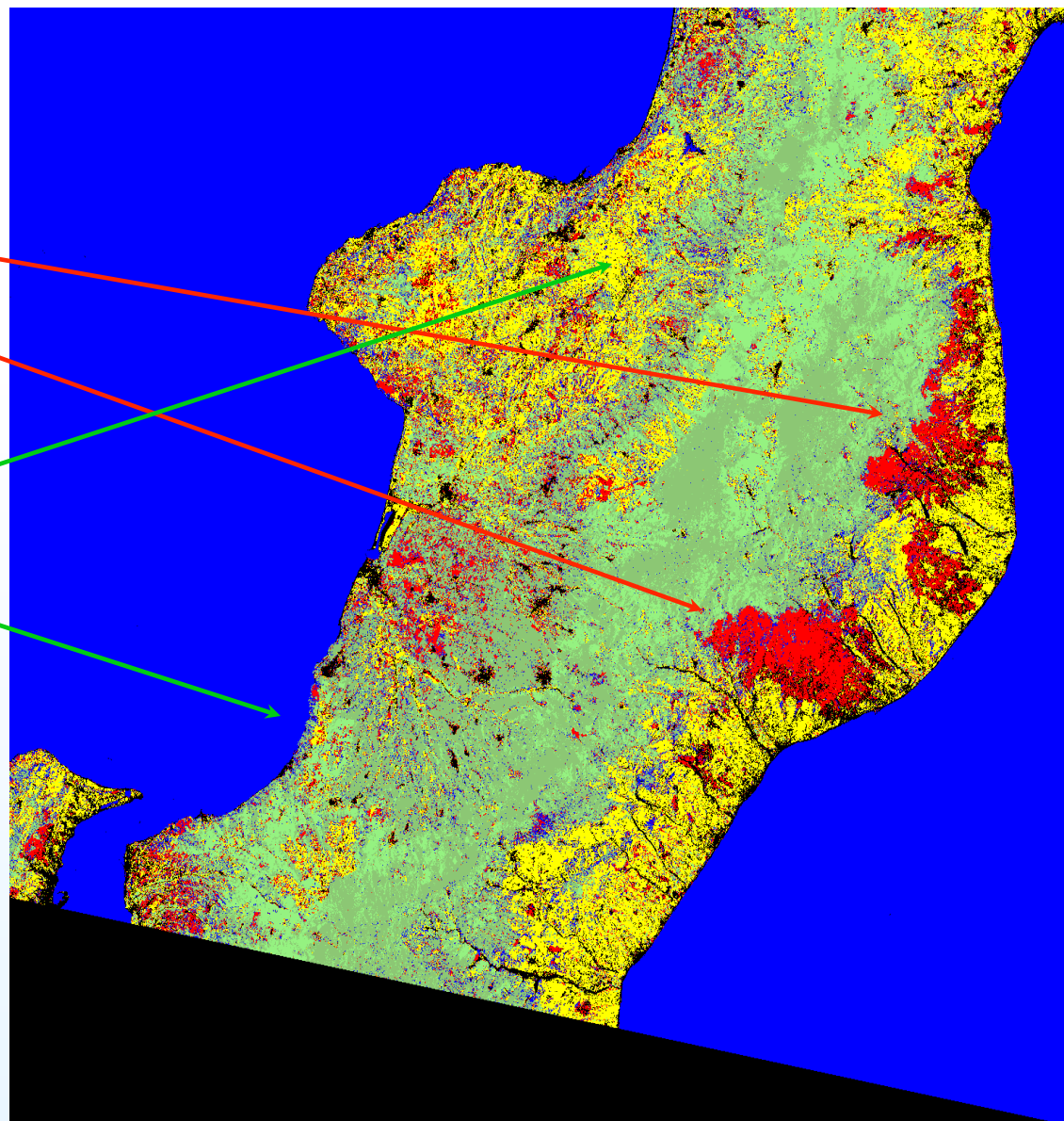
- leaf state
- canopy species
- leaf moisture content
- phenological stage



Ambiente: Controllo Incendi

incendi

zone calde



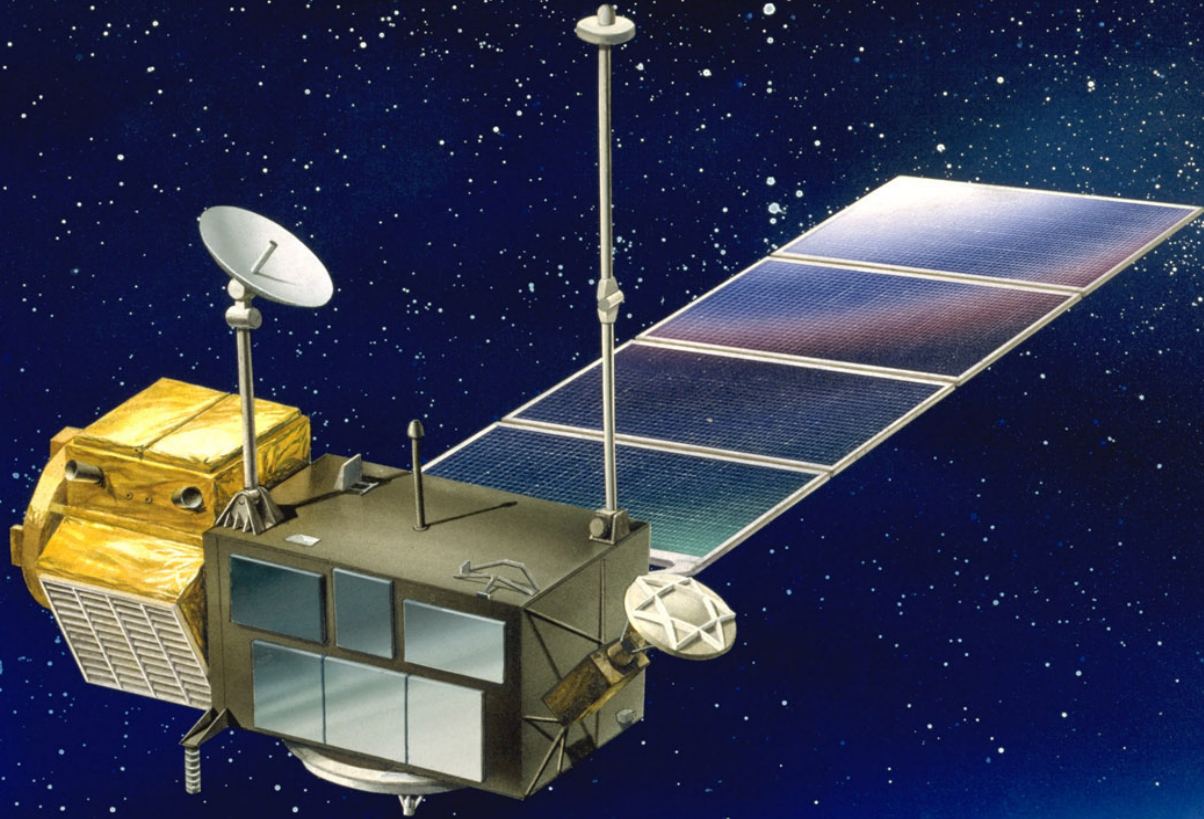
Osservazioni Della Terra

S P O T
I M A G E



Trieste, 30 settembre 2019

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 instrument offering a high

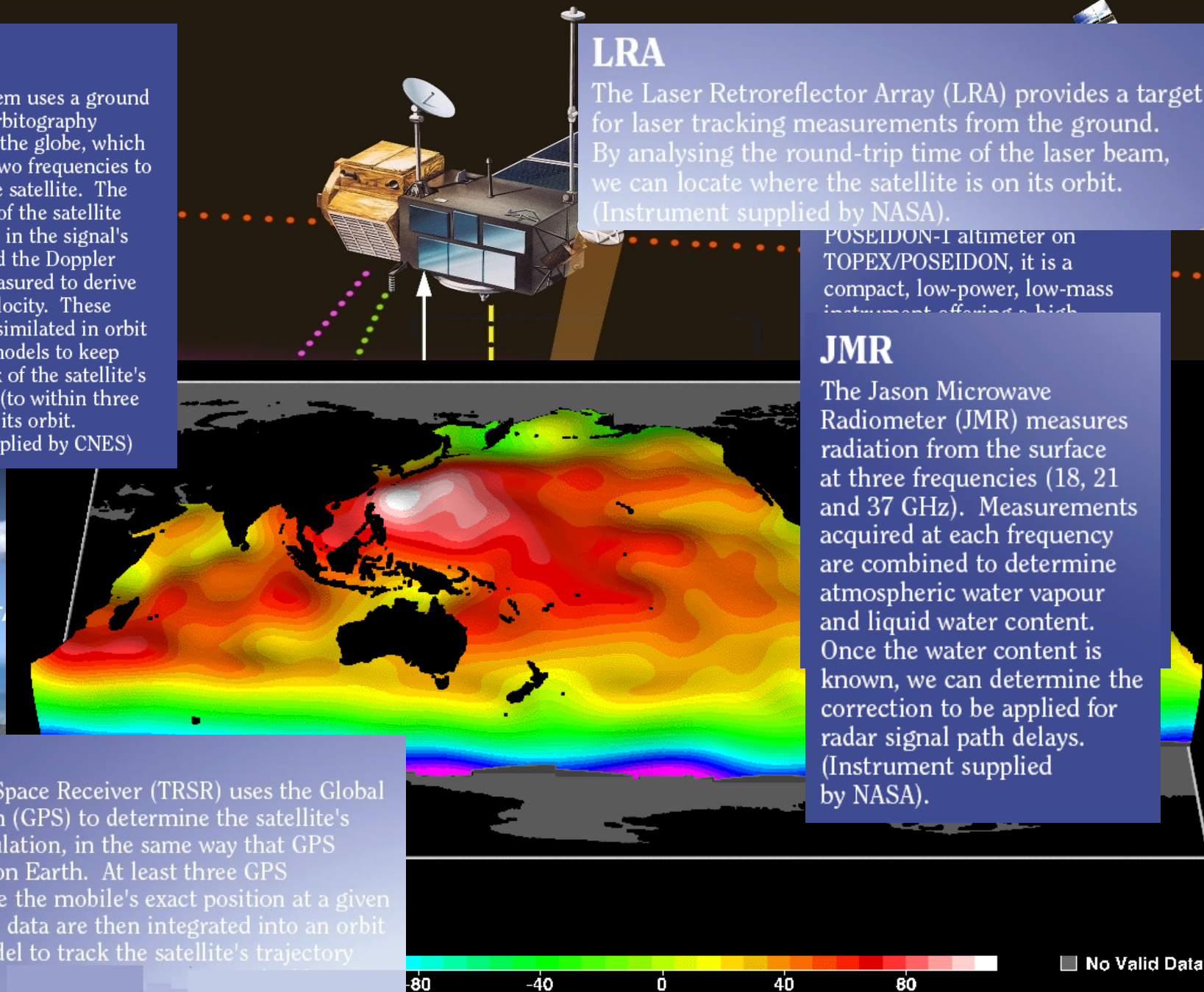
JMR

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.

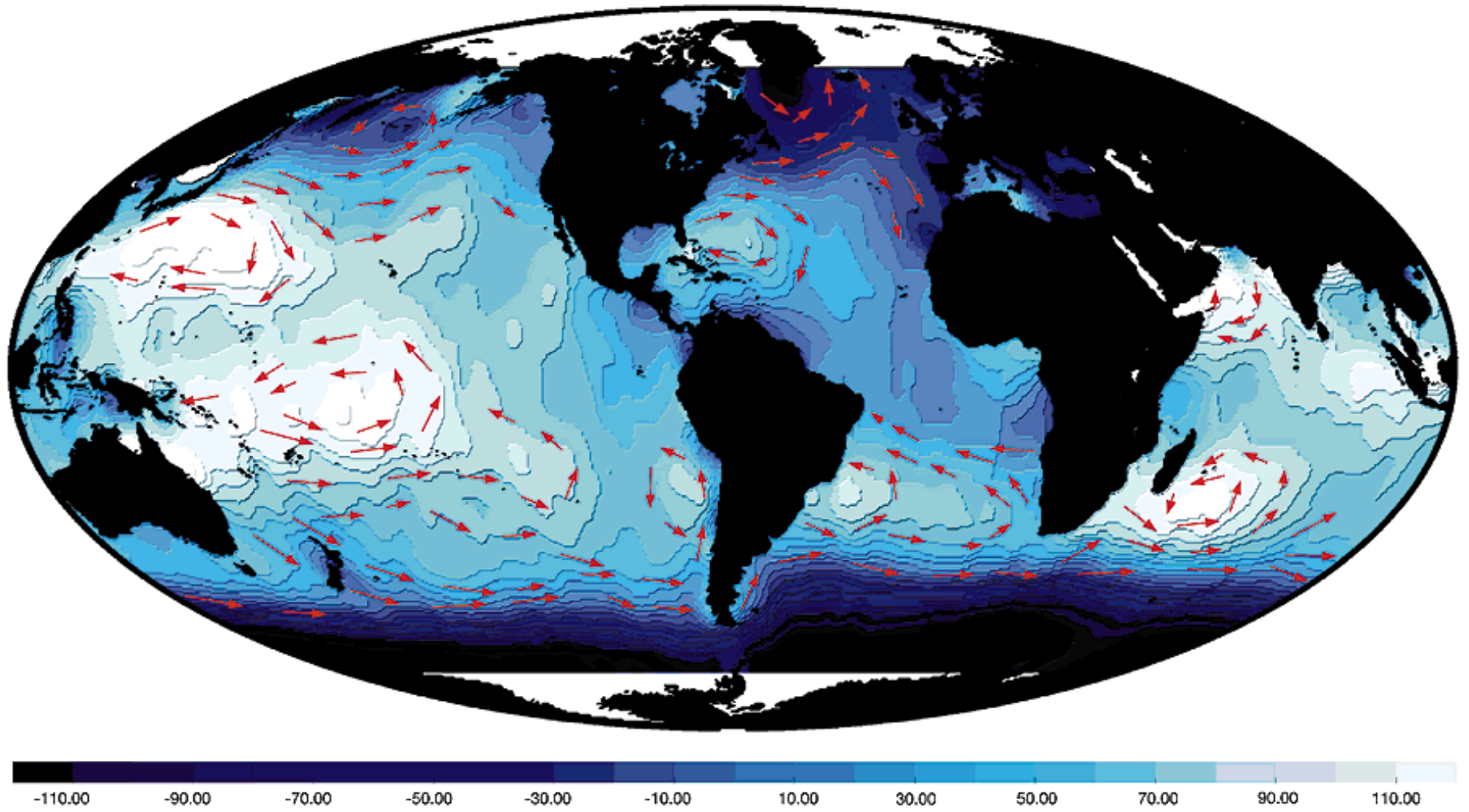


Ocean Dynamic Topography (cm)

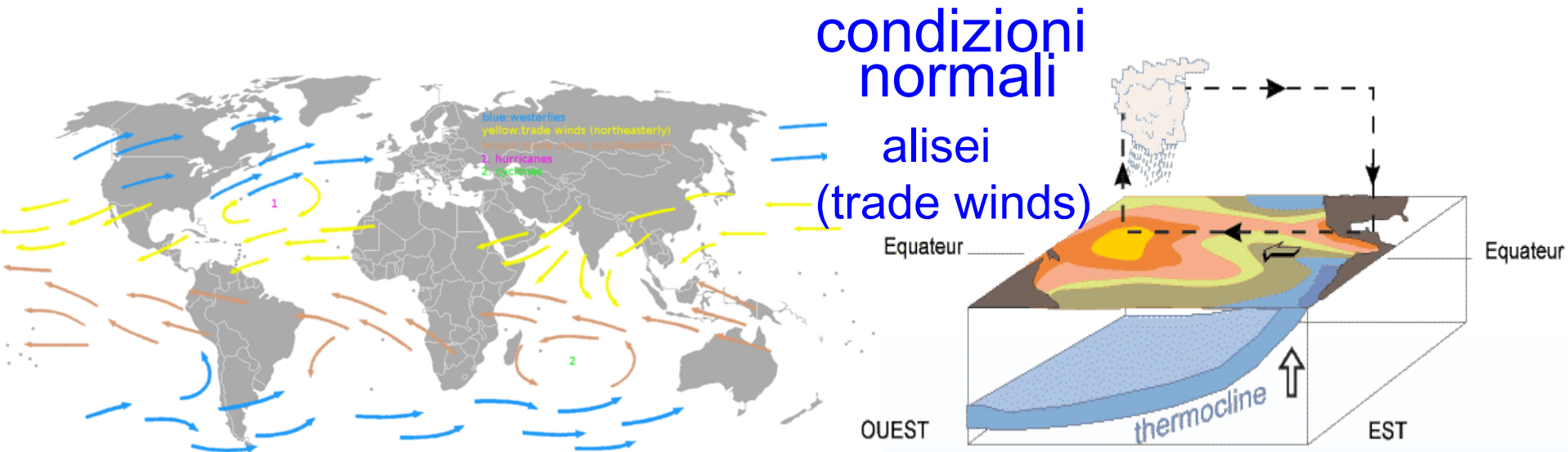
Oct 3-12, 1992

■ No Valid Data

Dinamica degli Oceani

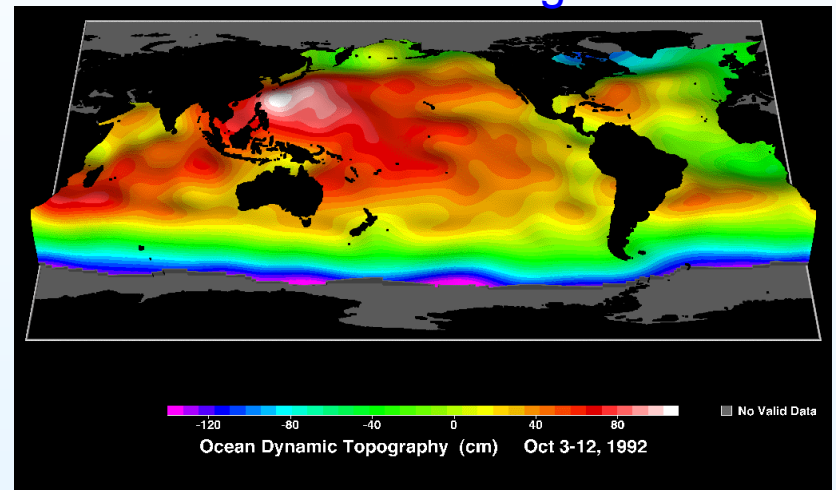
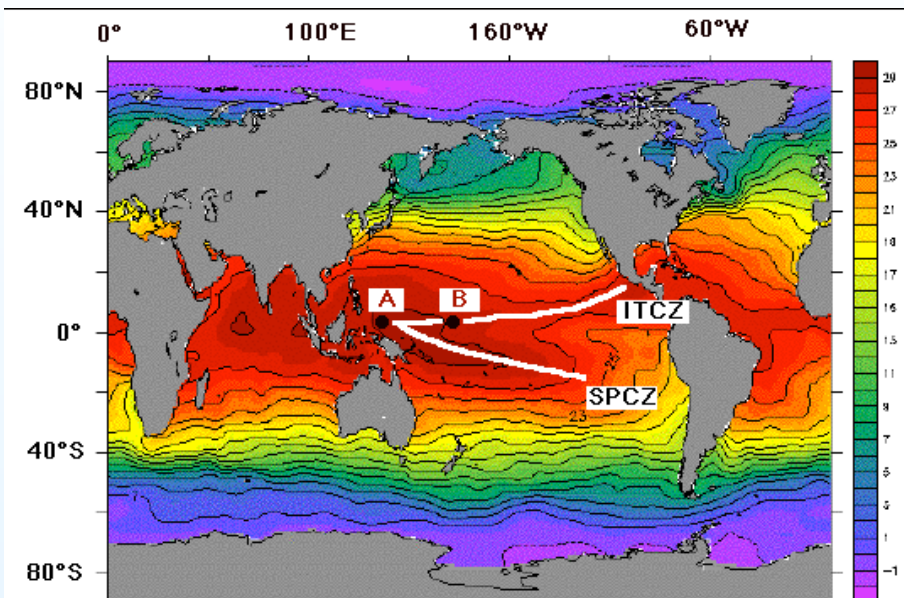


El Niño / La Niña

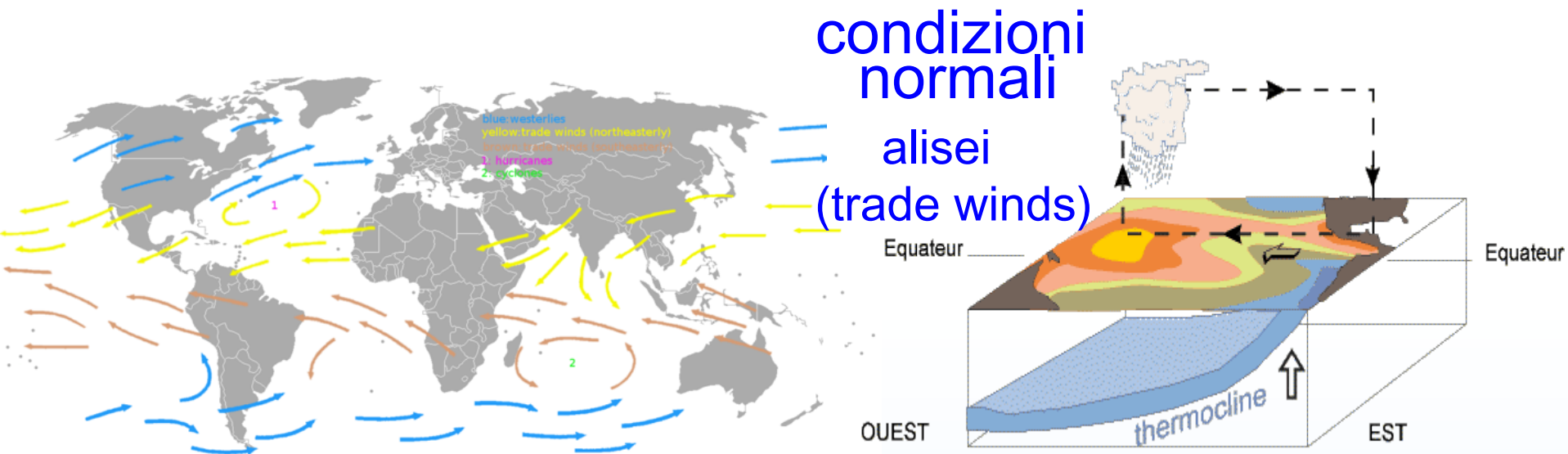


ITCZ – InterTropical Convergence Zone

SPCZ – South Pacific Convergence Zone



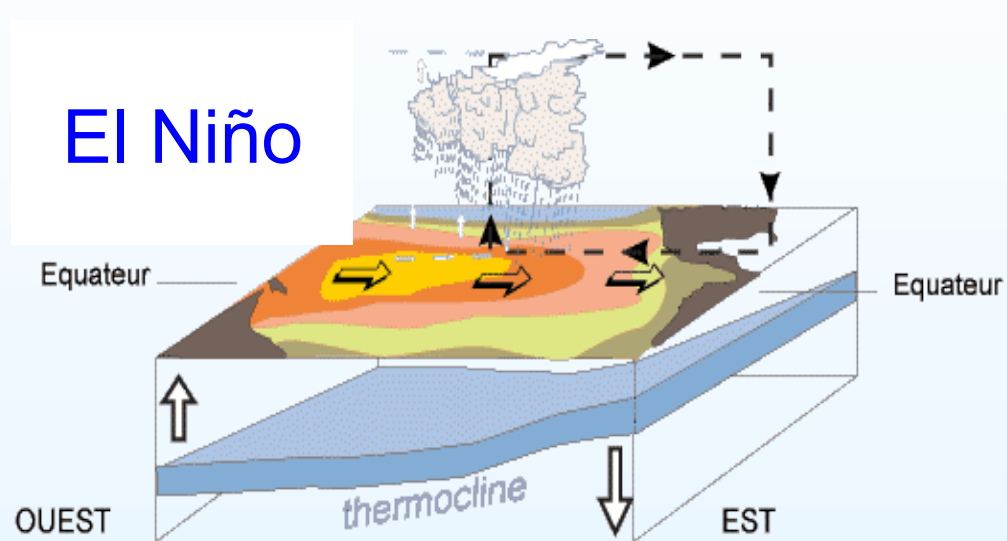
El Niño / La Niña



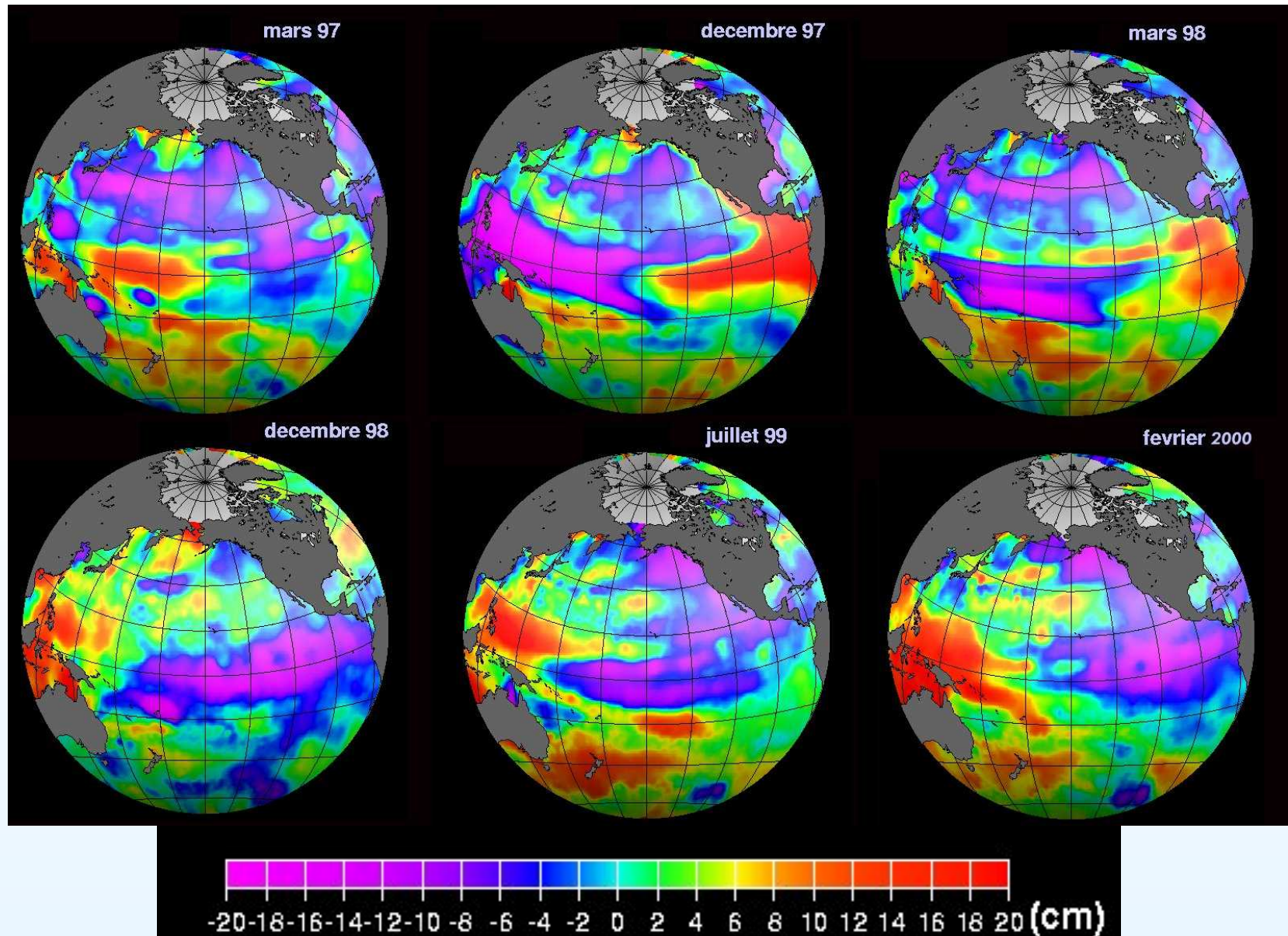
Fine primavera/inizio estate:
monsoni (Indian Ocean
monsoons) NE → SW

ENSO:

El Niño Southern
Oscillations

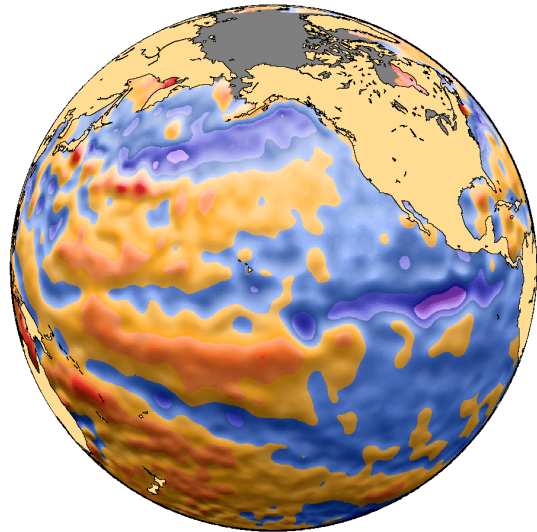


El Niño / La Niña



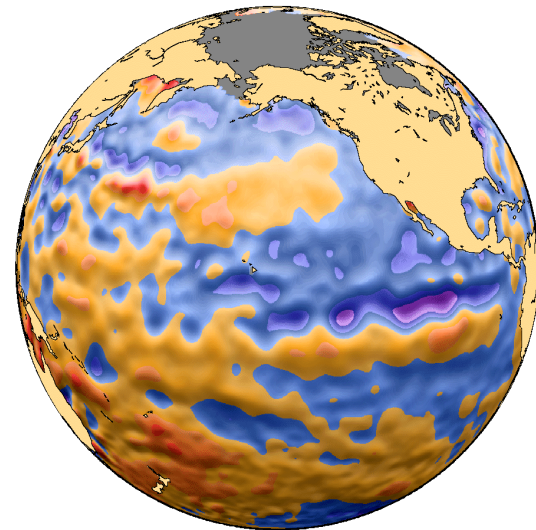
Esempio del 2002

situation au
2 janvier 2002



© Cnes-CLS, 9 janvier 2002
-24 -16 -8 0 8 16 24 cm
Hauteur de mer par rapport à la moyenne

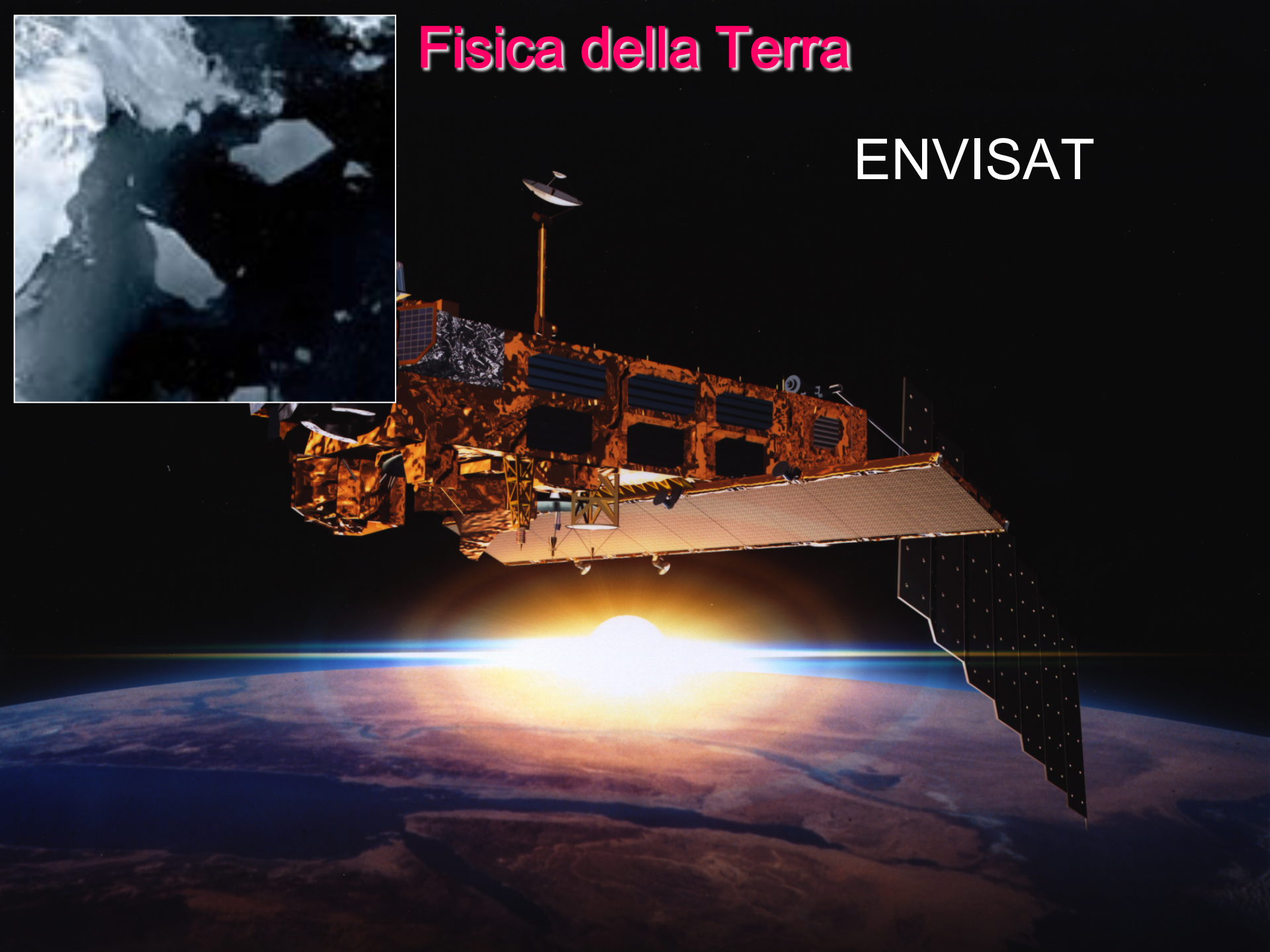
situation au
23 janvier 2002



© Cnes-CLS, 29 janvier 2002
-24 -16 -8 0 8 16 24 cm
Hauteur de mer par rapport à la moyenne

Fisica della Terra

ENVISAT



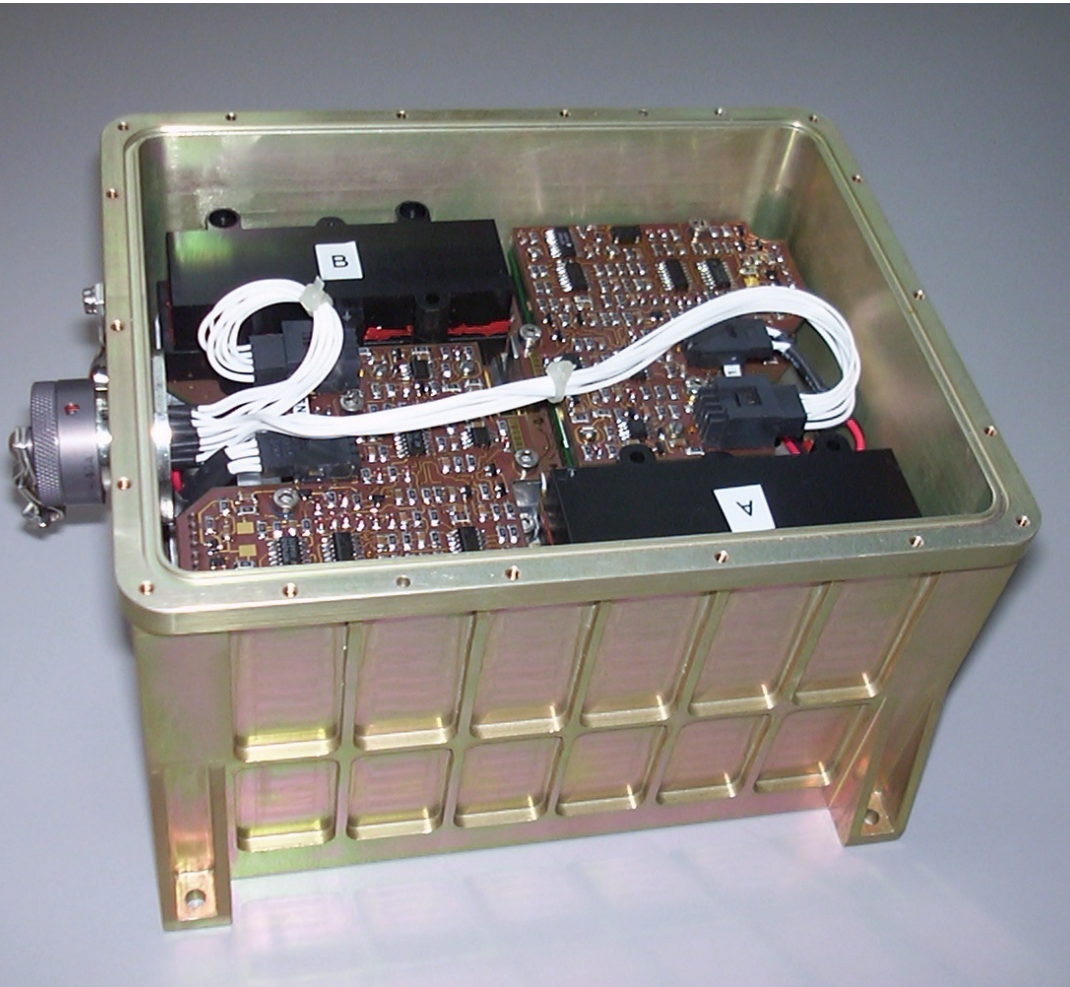
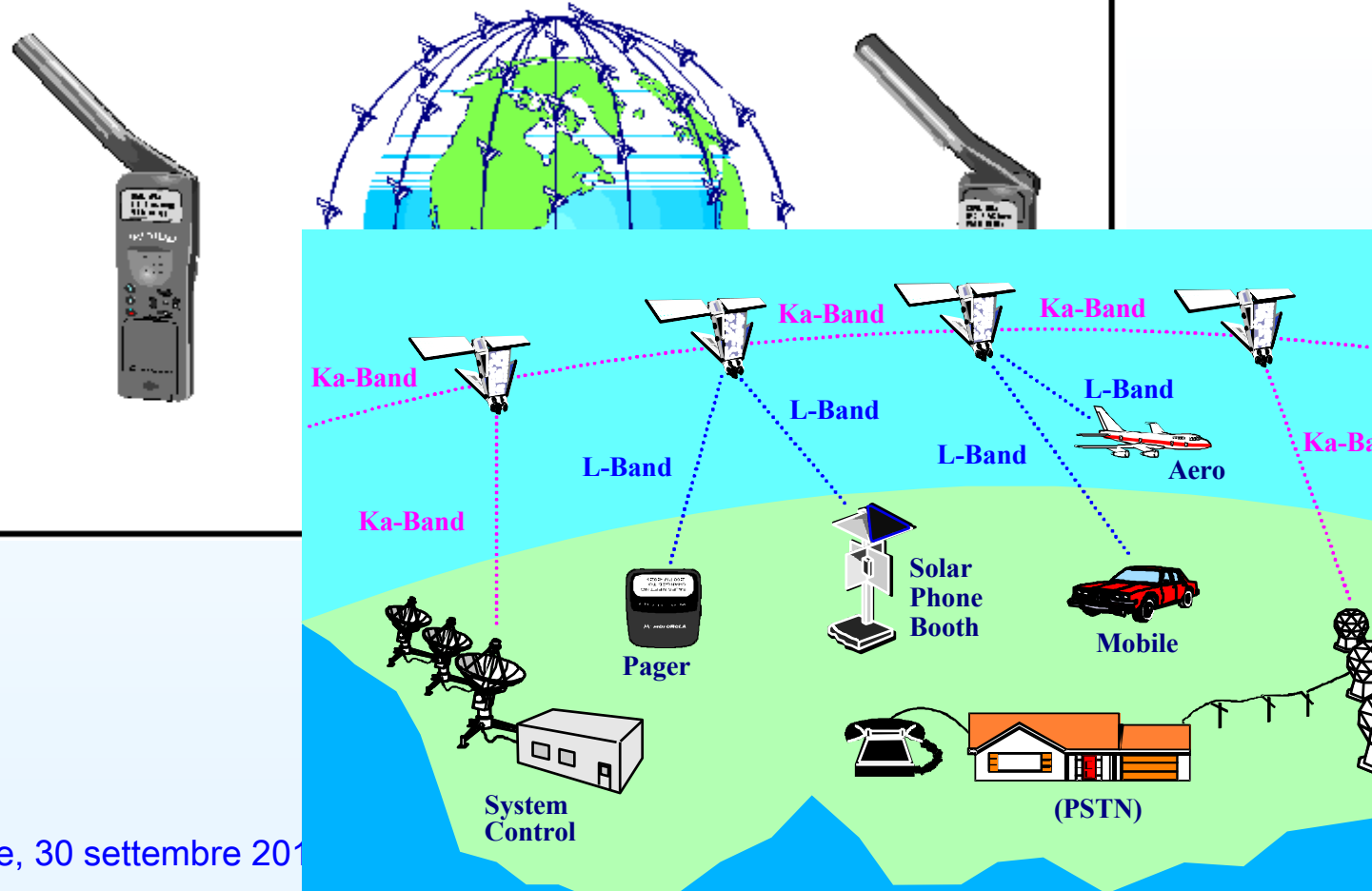


PHOTO II:
misure dedicate
per la BIOLOGIA

Programmi Commerciali: IRIDIUM

Global Personal Communications
Anyone .Anywhere .. Anytime

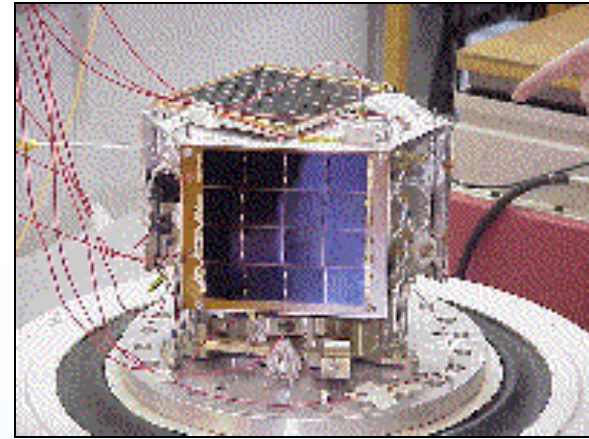


IRIDIUM®
Subscriber Unit

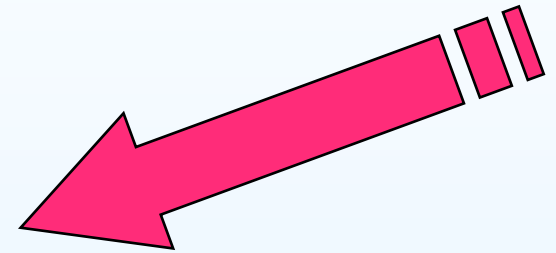
Programmi Educativi



SSTL



CUBESAT



ATMO-CUBE/CUBESAT

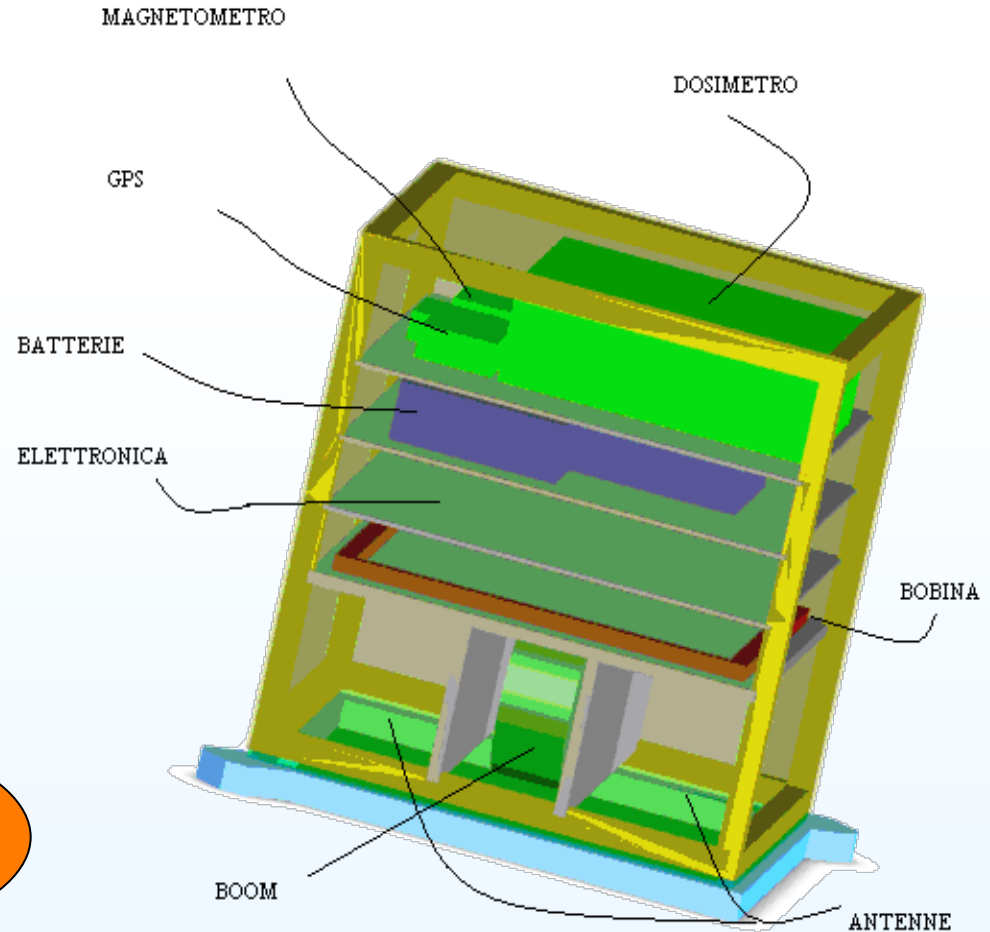
GOAL: Costruire una MAPPA precisa di

Campo Magnetico
Terrestre

Flusso di Radiazione che
incide su AtmoCube

e ...

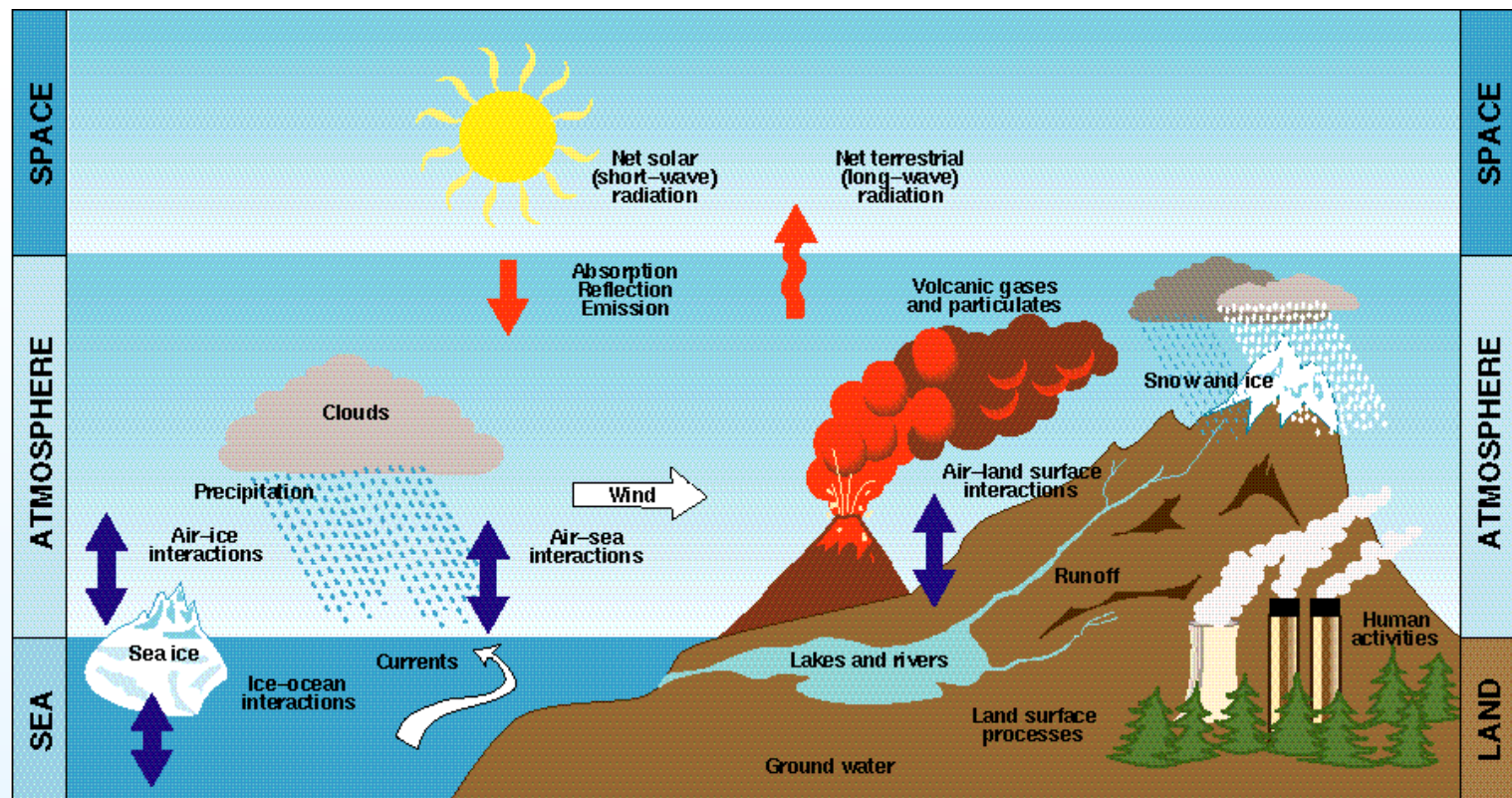
COINVOLGERE
STUDENTI !



SPACE WEATHER 1/3

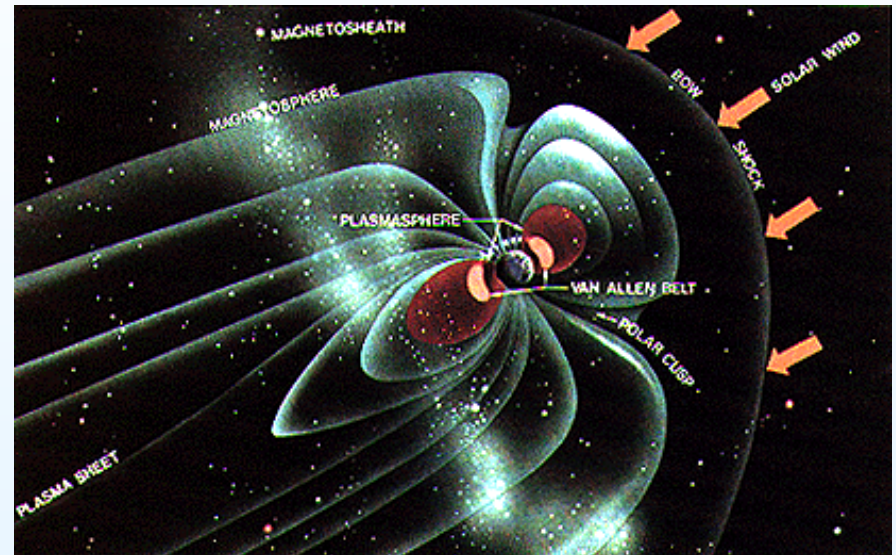
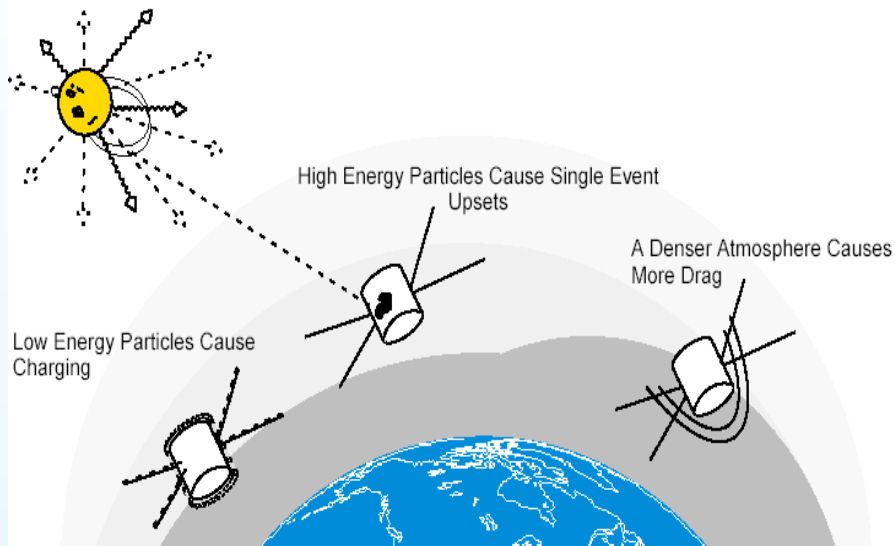
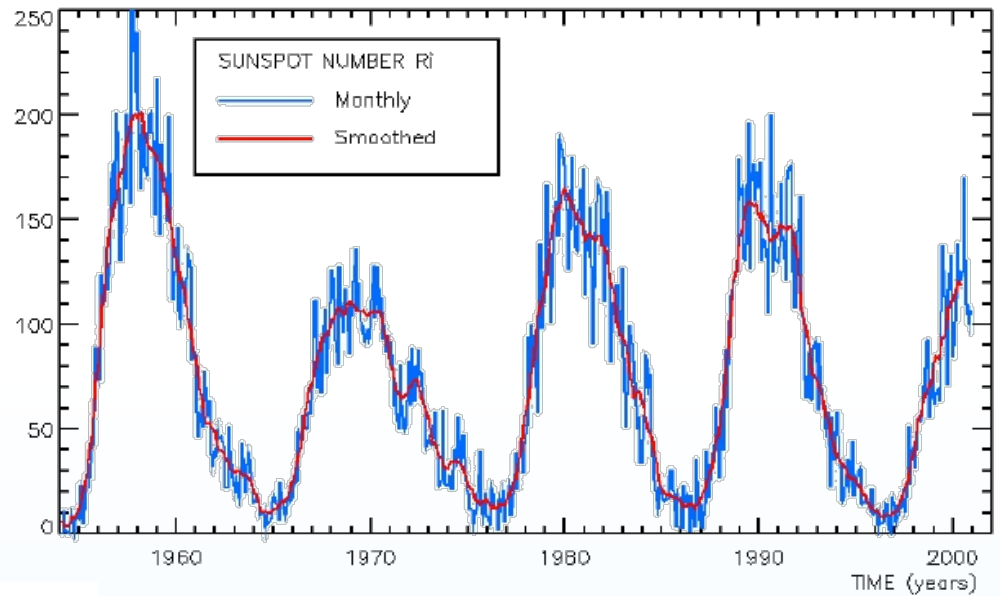
“Space Weather: condizioni sul Sole e sul vento solare, sulla magnetosfera, ionosfera, termosfera, che possono influenzare le prestazioni e l’affidabilità dei sistemi tecnologici nello spazio e a terra e possono mettere in pericolo la vita e la salute umana.”

ESA website: www.esa.int



SPACE WEATHER 2/3

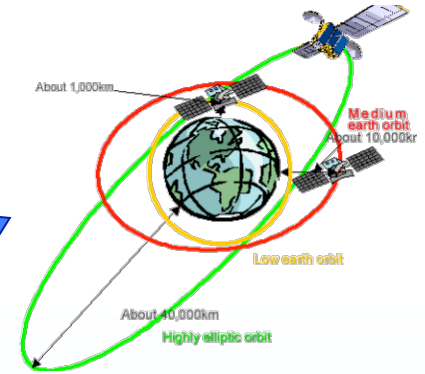
Sole: nel visibile
COSTANTE MA



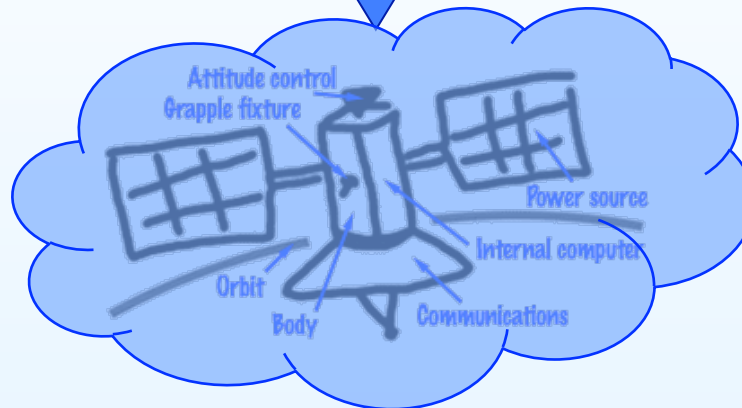
SPACE WEATHER 3/3

- **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



© Alex Bannykh * www.ClipartOf.com/73729

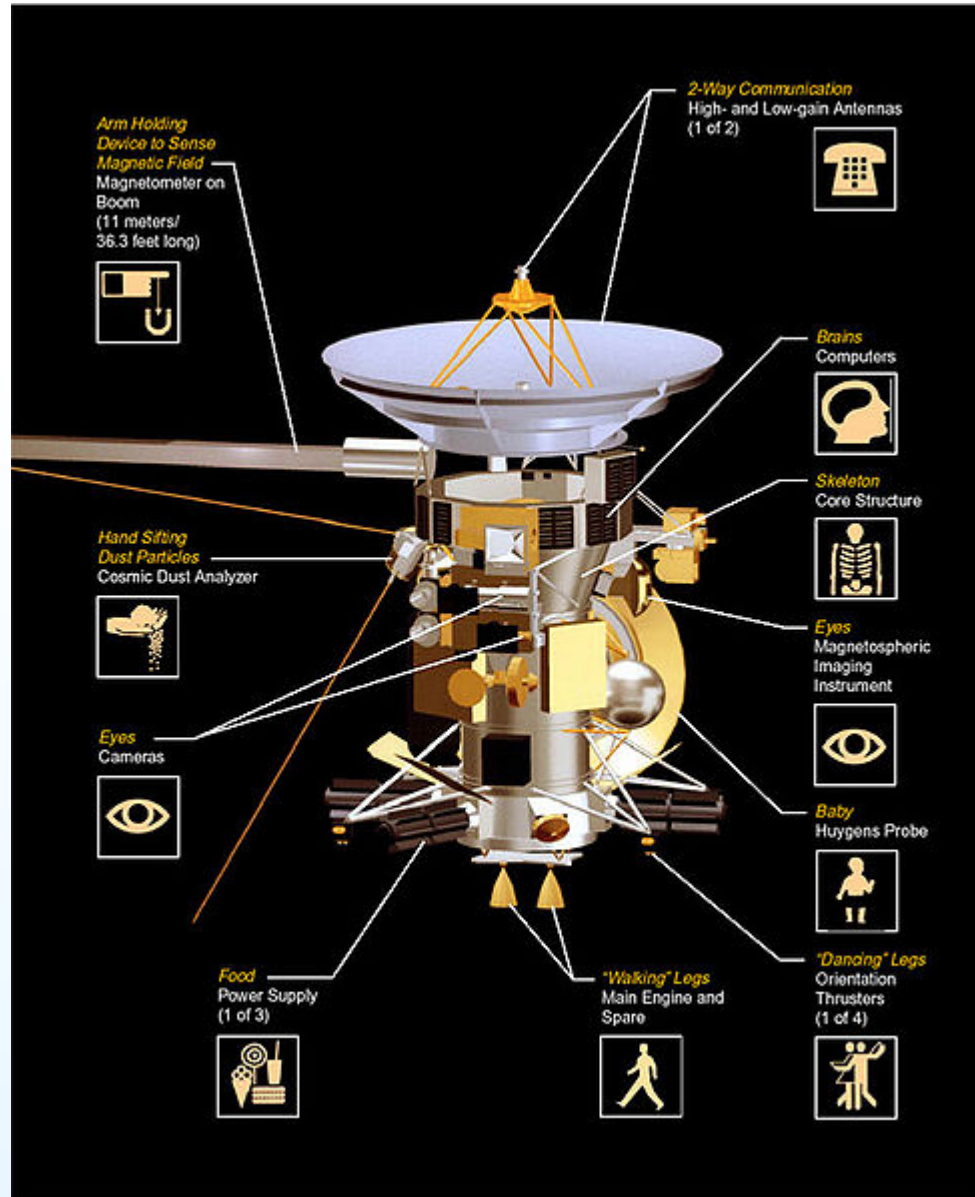


I Sistemi di un Satellite 1/3

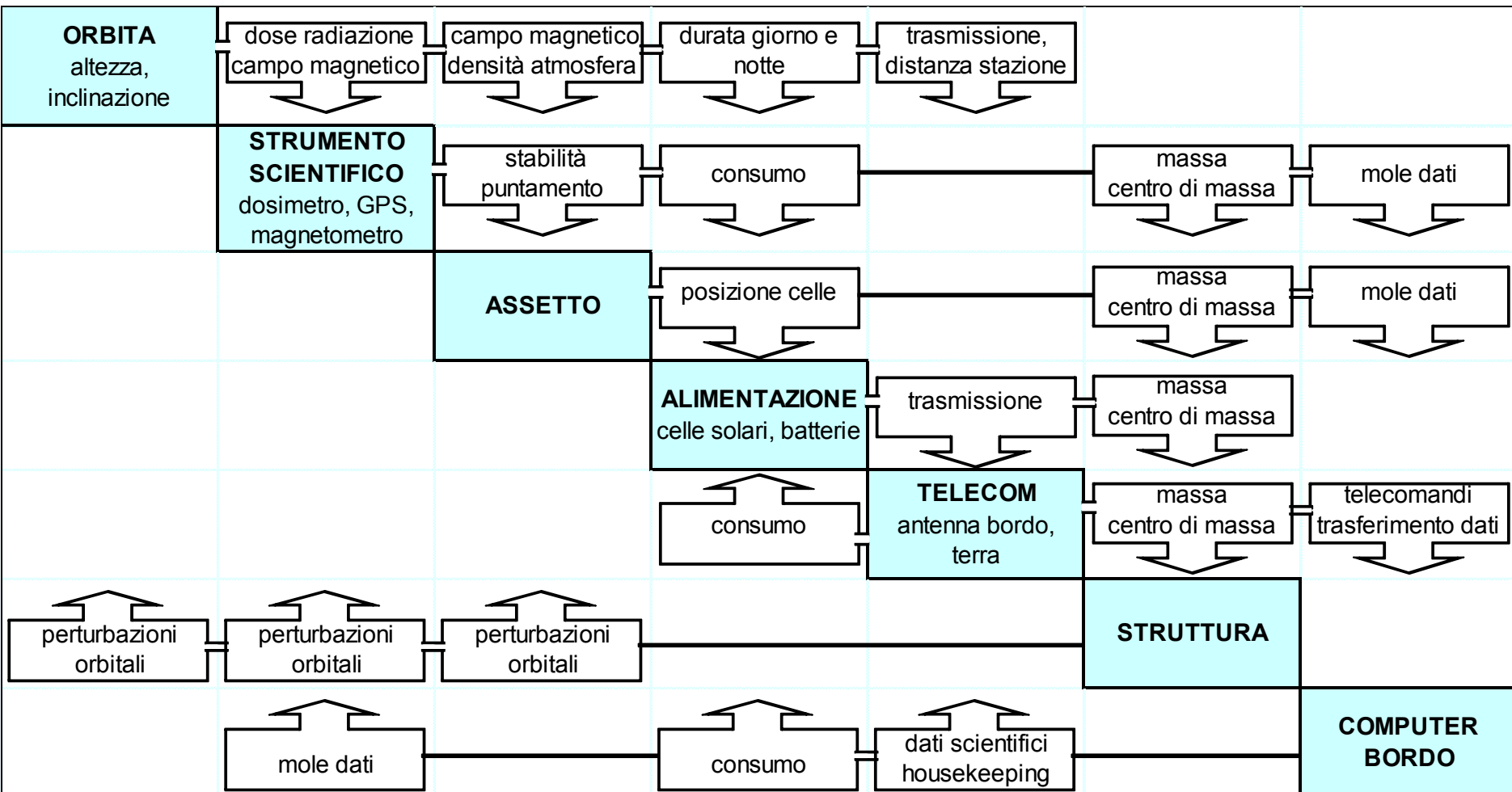


I Sistemi di un Satellite 2/3

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

Ruolo della Fisica Spaziale

Studia le **relazioni fra la Terra e l'umanità** considerando anche la Terra come un sistema di cui vanno analizzati i cambiamenti globali.

Studia la **Terra come un pianeta** anche per mezzo dello studio degli altri pianeti e con le tecniche della planetologia comparativa.

Studia il **Sole**, non solo come unica fonte di tutta la nostra energia, ma anche come una stella utilizzando l'astrofisica stellare osservativa e teorica per caratterizzare la nascita, l'evoluzione e la fine delle stelle e dei sistemi stellari.

Studia il **posto dell'uomo nel Cosmo** attraverso la comprensione della vastità dello spazio e del tempo ed attraverso lo studio dei problemi fondamentali sull'origine, l'evoluzione ed il destino dell'Universo.

Studia **l'origine ed il valore della vita** attraverso l'analisi delle molecole organiche di natura extraterrestre, incluse le molecole del mezzo interstellare, l'analisi chimico-fisica delle atmosfere di mondi come Giove e Titano, o di pianeti come Marte che una volta possono essersi trovati in condizioni adatte allo sviluppo d'organismi viventi simili a quelli terrestri, la ricerca di pianeti esterni al sistema solare, la ricerca di vita extraterrestre.

Studia le **leggi che governano le proprietà dei materiali**, d'aggregati e di macchine quando sono sottoposti alle condizioni estreme di gravità, temperatura, vuoto, flussi di particelle cariche che si trovano nello spazio.

Conclusioni

➤ TECNOLOGIA

- proprietà dei materiali
- comunicazioni

➤ RISULTATI SCIENTIFICI

- Sole e di altre stelle (astrofisica & astronomia)
- Universo (cosmologia)
- Pianeta Terra (planetologia)
- Origine della vita, dell'atmosfera, dell'ambiente...

➤ CONNESSIONE CON ALTRI CAMPI

- biologia, chimica, ingegneria ...