

Metodi dell' Astrofisica Spaziale

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Con contributi di

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G. Romeo (Istituto Nazionale di Geofisica)

Avvisi per il calendario delle lezioni fino al 15 Dicembre

- Il prossimo Giovedì 8/10 non ci sarà lezione.
- Le prime due lezioni della D.ssa Falvella saranno tenute il 13/10 e il 15/10.
- Le altre lezioni della D.ssa Falvella si terranno nei giorni: 1, 3, 10 e 15 Dicembre 2015. (L'8 Dicembre è festa).
- è prevista in Gennaio, dopo la fine del corso, una giornata di visita ad una delle strutture di ASI (Agenzia Spaziale Italiana)

Corso "Metodi dell' Astrofisica Spaziale"

6 CFU - Laurea Specialistica in Astronomia e Astrofisica -

Primo semestre aula 8 edificio Fermi martedì 14-16 e giovedì 16-18

lezione		argomento	tenuta da
1		Introduzione - Definizione dello Spazio. Cosa c'è nello spazio. Importanza dello Spazio e suoi usi. Spazio e Astrofisica. L'atmosfera terrestre ed il suo disturbo alle osservazioni astrofisiche. Vantaggi dello spazio nelle diverse bande dello spettro elettromagnetico	S. Masi
2		Come si va nello spazio. Fisica dei Vettori Spaziali Suborbitali: Palloni Stratosferici, Quota di volo. Vettori orbitali: Problema energetico. Propulsione a Razzo, Motori, Singolo stadio e multistadio, Razzi per missioni Suborbitali, Orbitali e Planetari	S. Masi
3		Moto Orbitale - Teoria Kepleriana	S. Masi
4		Moto Orbitale - Perturbazioni	S. Masi
5		Moto Orbitale - Tipi di orbite utilizzate da satelliti terrestri; trasferimento di orbita; viaggi interplanetari.	S. Masi
6		Facilities per osservare dallo spazio - palloni: descrizione, siti, programmi a lungo e breve termine. Razzi: descrizione - Stazione spaziale: descrizione, piano di utilizzo, film. - satelliti: descrizione, piani per i prossimi anni	M.C. Falvella
7		Trasporto spaziale - propulsione e lancio, controllo assetto, determinazione e controllo orbita, sistema alimentazione, controllo termico, struttura, sistema di comunicazione, gestione di comandi e dati a bordo	M.C. Falvella
8		Payload e sensori - Utenza spaziale, caratteristiche principali di un payload per uso spaziale, sensori per astrofisica, esempi: SAX, Planck, EUSO	M.C. Falvella

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9		Progettare una missione spaziale tenendo conto dell' ambiente - design per lavorare nel vuoto tenendo conto di heat transfer, outgassing, UV degradation, ambiente neutro (sputtering, ossigeno atomico, forze di drag), plasma, radiazioni, debris e micrometeoriti+D15	M.C. Falvella
10		Criogenia Spaziale: Necessita' criogeniche in generale e in astrofisica; raffreddamento radiativo; raffreddamento con liquidi criogenici; raffreddamento attivo; temperature sotto 1 K.	S. Masi
11		Criogenia Spaziale: Disegno di criostati per lo spazio. Il porous plug. Struts & Straps, Sistemi di sospensione e rilascio. Un esempio concreto: il sistema criogenico della missione Planck.	S. Masi
12		Sistemi di Controllo d' assetto: sensori di assetto: assoluti e relativi; magnetometri, sensori d' orizzonte, sensori solari, sensori stellari, giroscopi	S. Masi
13		Sistemi di Controllo d' assetto: attuatori: ruote d' inerzia, thrusters, ...	S. Masi
14		Sistemi di Controllo d' assetto: metodologie di controllo	G. Romeo
15		Costruzione e management di un progetto - fasi A,B,C,D,E	M.C. Falvella

Cos'è lo “Spazio”

- Solo 10^{-30} del volume dell' universo è riempito da stelle e pianeti.
- Il resto della materia “barionica” è sparsa nell' universo a densità estremamente basse:
 - Pochi atomi per m^3 tra le galassie
 - Un atomo per cm^3 nelle braccia a spirale della nostra Galassia
 - Alcuni atomi per cm^3 nello spazio interplanetario.
- In queste condizioni gli atomi collidono tra loro molto raramente – mentre in condizioni terrestri lo fanno miliardi di volte al secondo. Dove si verificano queste condizioni si può parlare di “Spazio”.
- All' aumentare della quota l' atmosfera terrestre si diluisce gradualmente fino ad integrarsi nel mezzo interplanetario, ad altezze di circa un centinaio di km.

Cos'è lo “Spazio”

- L' uso dello spazio è una delle conquiste della tecnologia moderna.
- è utile per motivi diversi :
 - Osservazione/monitoraggio della Terra dall' alto (scientifico, civile e militare).
 - Relay di segnali tra stazioni non in vista (Telecommunications) – Trasmissione di segnali su vaste aree del globo (Broadcast) -
 - Esplorazione (del Sistema Solare per ora)
 - Studio di fenomeni fisici e chimici (e loro sfruttamento) nel vuoto e/o in “assenza” di gravità
 - Osservazione dell' universo (astrofisica/cosmologia) senza i disturbi prodotti dall' atmosfera terrestre.
- Il settore spaziale dà lavoro a milioni di persone nel mondo, impiegate in industrie e istituti scientifici.

Osservazione della Terra

- Daremo solo alcuni esempi interessanti estratti da un campo vastissimo e attivissimo.
- Da decenni la terra viene osservata continuamente da satelliti per studiarne l'atmosfera. Le foto satellitari sono un ingrediente essenziale per la previsione delle condizioni meteo su grande scala.



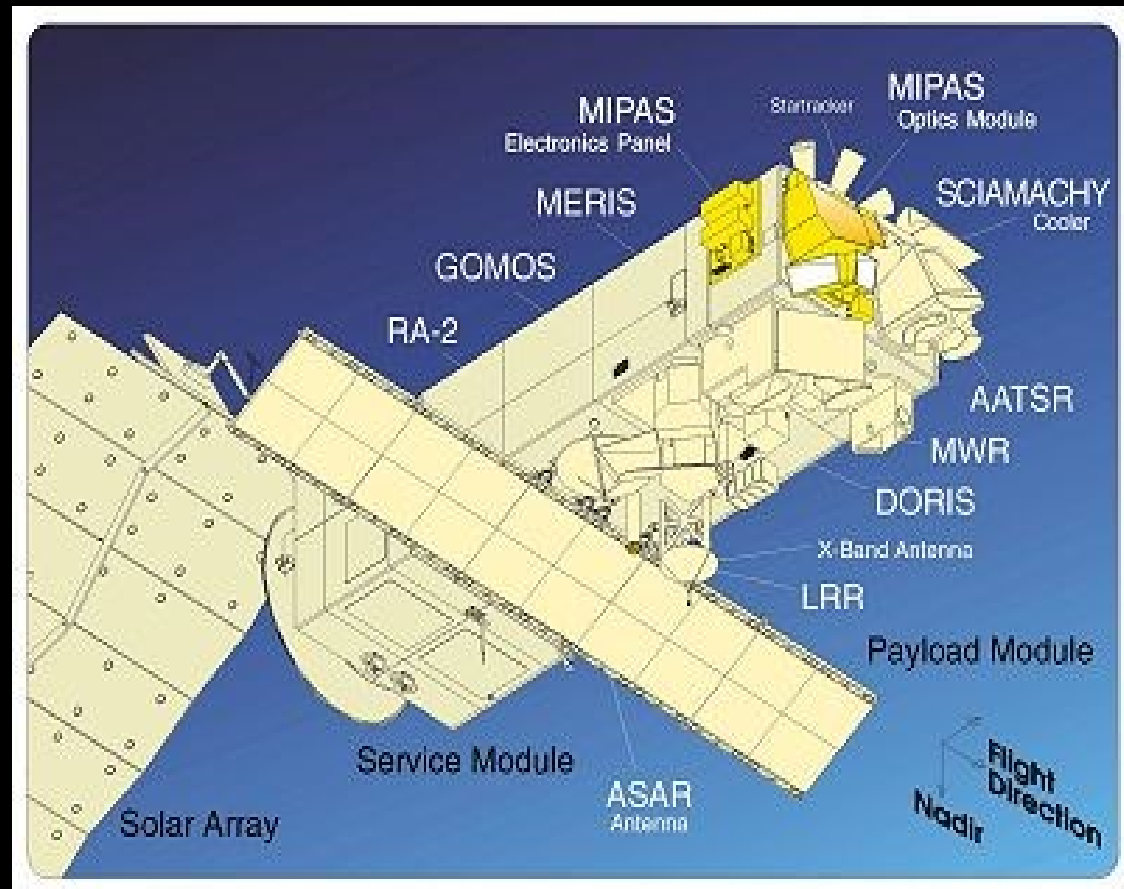
ENVISAT

- L'ultimo satellite ESA (European Space Agency) dedicato allo studio dell'ambiente terrestre.
- Grande (8 m) e pesante (5700 kg) ha richiesto il lanciatore Ariane più potente per essere introdotto nell'orbita eliosincrona a 800 km.



ENVISAT

- Launched in 2002, ENVISAT is a truly advanced Earth Observation satellite with a unique combination of sensors that vastly improve the range and accuracy of scientific measurements of the atmosphere, oceans, land surface and ice.
- The payload includes different instruments like Synthetic Aperture Radars, Altimeters, Imaging Spectrometers for Earth observation, Atmospheric Spectrometers, Infrared Spectrometers, Ozone monitors, ...
- See envisat.esa.int for details.



Huge Satellite Envisat is Dead in Space

(SPACE.com)

Date: 09 May 2012 Time: 10:48

- The European Space Agency declared the death of its massive Earth-observing satellite Envisat today (May 9) after a month of mysterious silence from the school bus-size spacecraft.
- Envisat is the world's largest Earth-watching satellite for civilian use, with ESA officials touting its 10th anniversary in space earlier this year. The \$2.9 billion satellite was originally designed to snap high-resolution photos of Earth for five years, but managed to last 10 years during its successful mission.
- Huge Satellite Poses 150-Year Threat of Space Debris (credit ESA)
- In 2010, space debris experts said that the satellite's immense size will make Envisat a major space junk risk for up to 150 years.
- ESA launched the Envisat mission in 2001 to study the Earth from space in extreme detail. The satellite carries 10 sensors to study Earth's oceans, land, ice caps and atmosphere and has been a vital resource for about 2,500 scientific studies of our home planet.
- End of the Road for Envisat --→SENTINEL

Sentinel (5 missions within the Copernicus program)

http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Overview4

- **Update: 13 September 2013** ESA's first Sentinel satellite dedicated to Europe's Copernicus environmental monitoring programme is nearing completion in readiness for launch. The series of Sentinels and this ambitious programme were much in focus at the Living Planet Symposium this week.
- The Sentinel-1 mission is a constellation of two satellites, the first of which is planned to be launched next spring.
- **Update: September 2014:**
- **The first Sentinel-1 satellite was launched on a Soyuz rocket from Europès Spaceport in French Guiana on 3 April 2014.**
- The flight acceptance review was in January 2014, confirming that the satellite was ready to be launched as planned.
- Sentinel-1 sister satellite launch will follow about 18 months later.
- Now scheduled for 2016!

Sentinel-1



Vedere a questa pagina web per le updates e per delle belle elaborazioni delle immagini fornite dal radar in più di un anno di operazione dal lancio. Adesso i satelliti previsti sono 7!

http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-1

- **Launch:** 3 April 2014
- **Launcher:** Soyuz rocket
- **Launch site:** Kourou, French Guiana
- **Orbit:** Polar, Sun-synchronous at an altitude of 693 km
- **Revisit time:** Six days from two-satellite constellation
- **Life:** Minimum of seven years
- **Satellite:** 2.8 m long, 2.5 m wide, 4 m high with 2×10 m-long solar arrays and a 12 m-long radar antenna
- **Mass:** 2300 kg (including 130 kg fuel)
- **Instrument:** C-band synthetic aperture radar (SAR) at 5.405 GHz

Main applications: Monitoring sea ice, oil spills, marine winds & waves, land-use change

, land deformation among others, and to respond to emergencies such as floods and earthquakes

Mission: Developed, operated and managed by various ESA establishments

Funding: ESA Member States and the European Union

Prime contractors: Thales Alenia Space, Italy for the satellite; Airbus

Defence and Space,

Germany for the SAR instrument

Data access: sentinel.esa.int

ENVISAT - MERIS

- Observation of Etna eruption by MERIS (medium resolution infrared spectrometer) 27-May-2004.
- Ashes and sulphur-dioxide have been identified and monitored in the outgas plume extending south over the Lybian sea.
- Dust particles absorb sunlight heating the atmosphere and cooling the earth.
- Sulphuric-acid aerosols produced by sulphur dioxide will stay in the atmosphere for years.
- Both were monitored by ENVISAT.



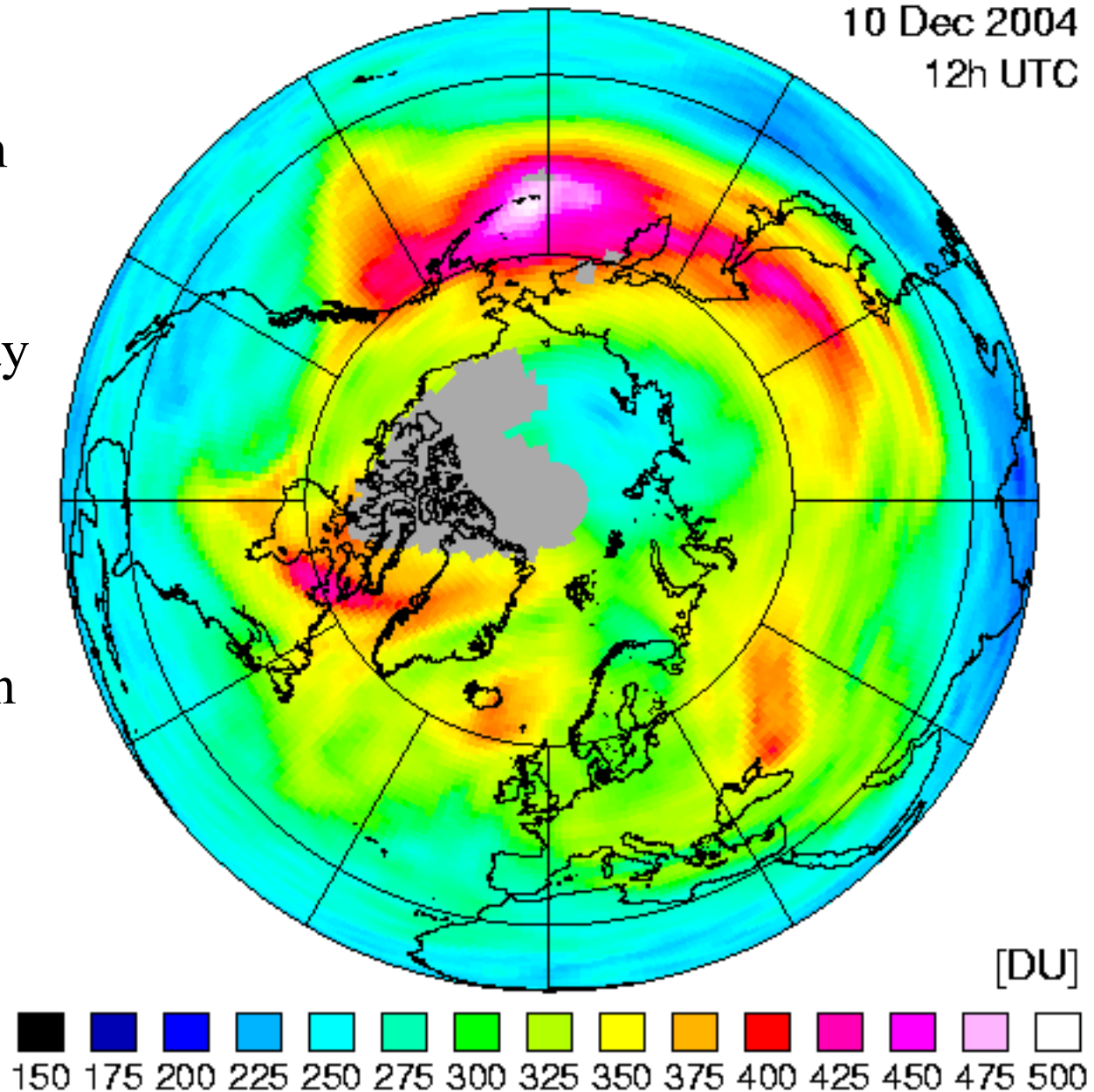
KNMI / ESA

SCIA assimilated total ozone

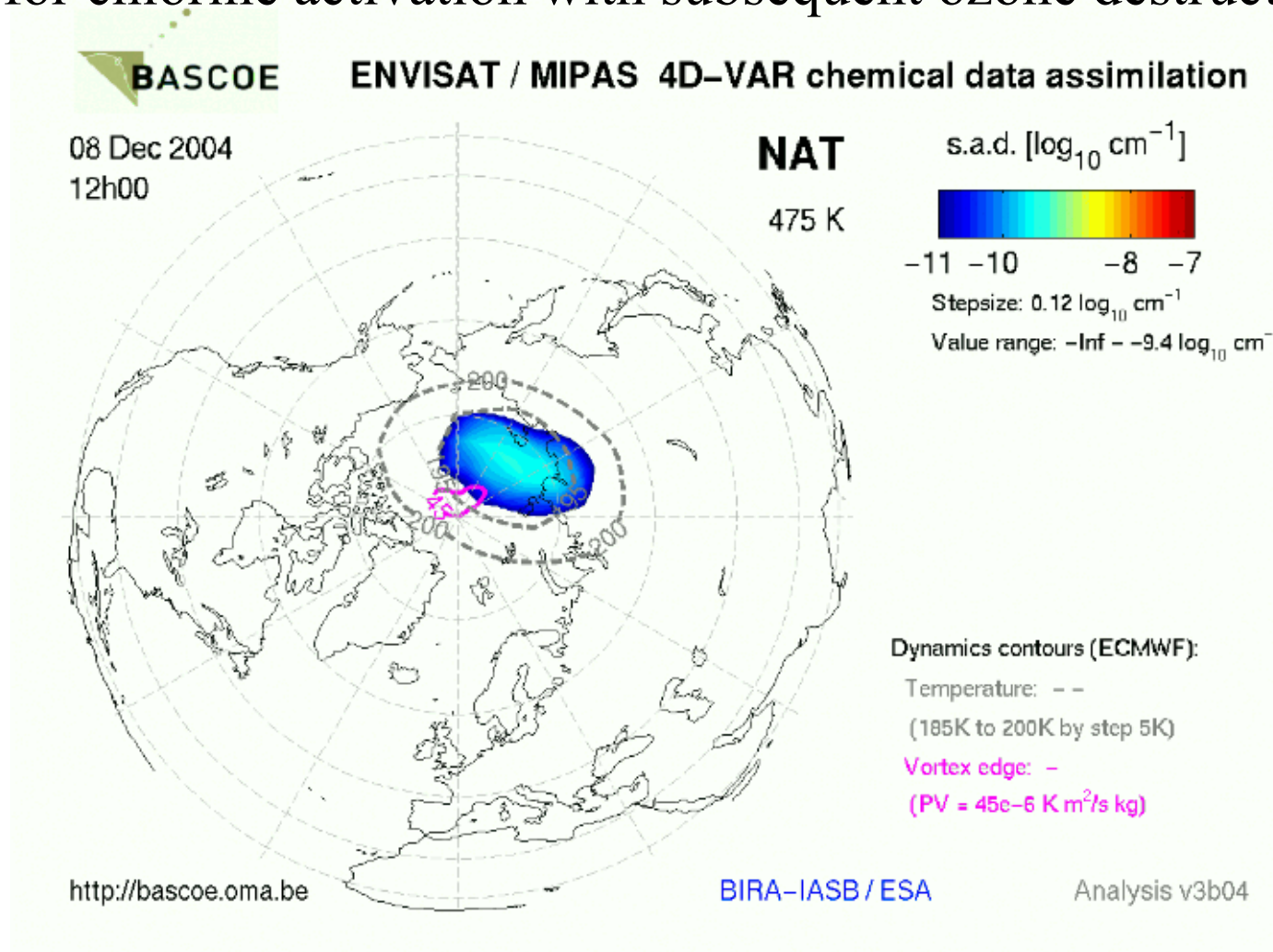
10 Dec 2004

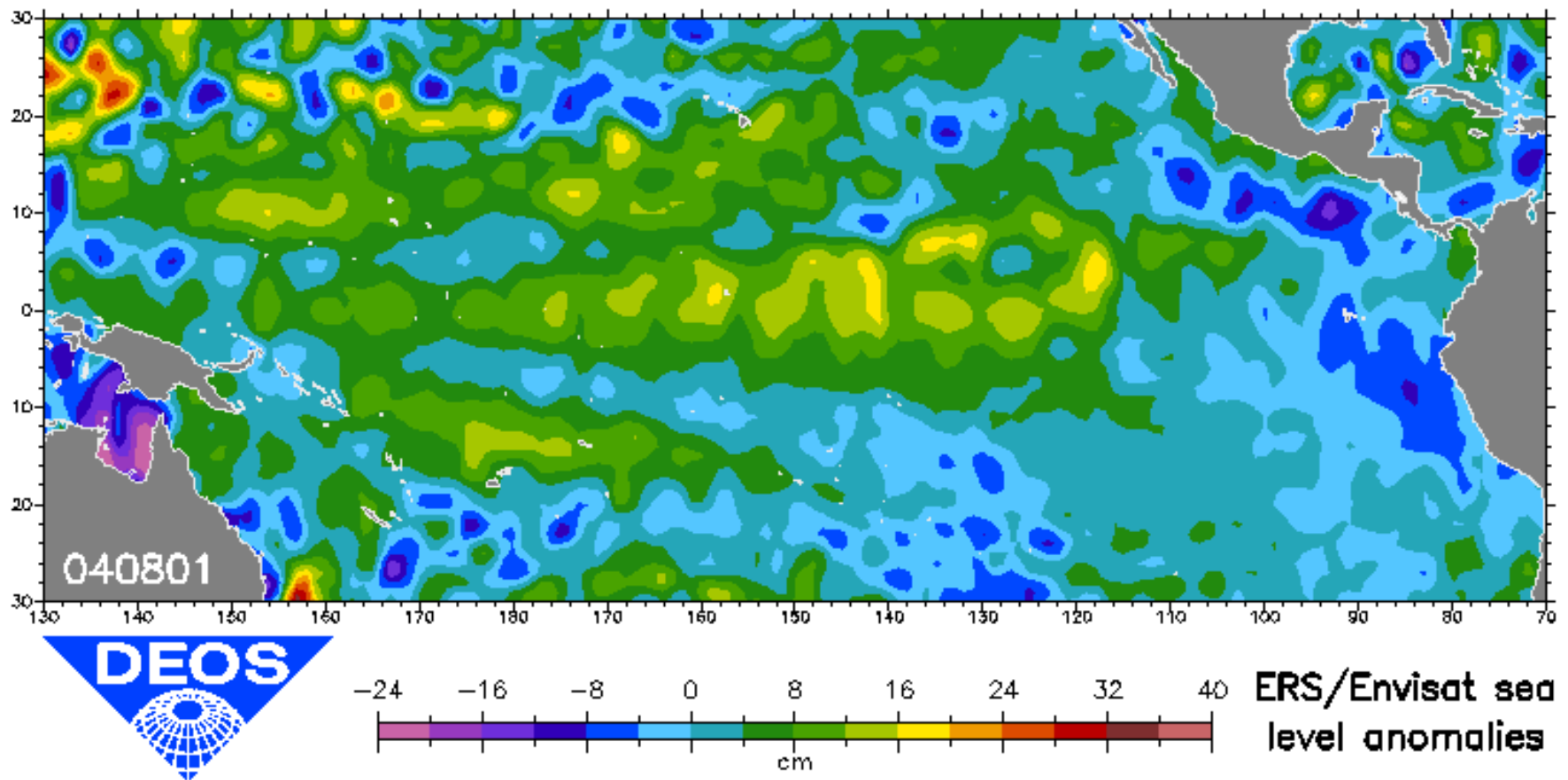
12h UTC

The image shows the near-real-time variation of the Assimilated Ozone Field over the North Pole on a two-day basis. Measurements derive from ENVISAT SCIAMACHY and are processed at TEMIS (Tropospheric Emission Monitoring Internet Service).



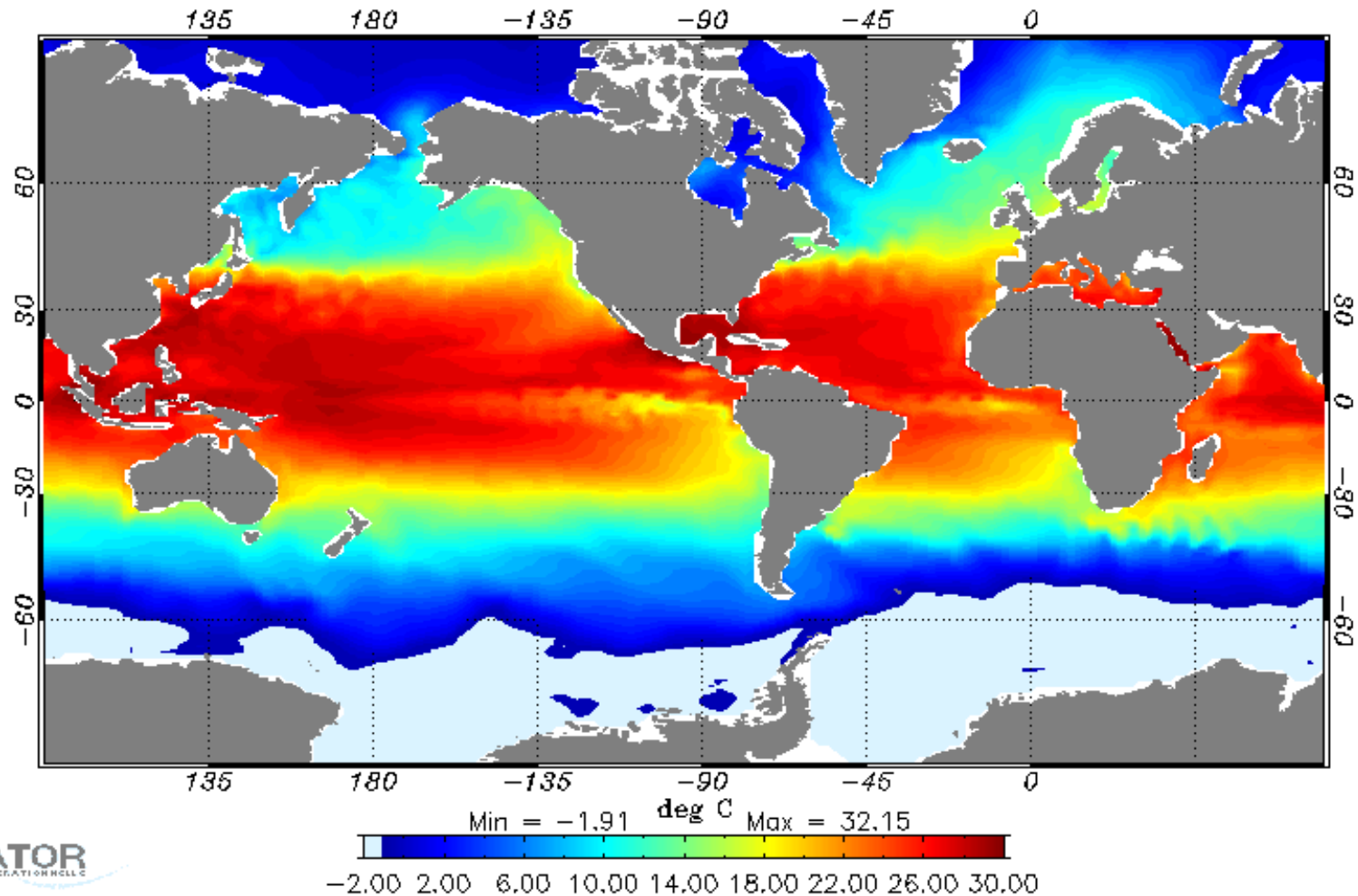
- Daily variation of the Nitric Acid Trihydrate (NAT, water and nitric acid at a molar ratio of 3:1) over the Arctic. Observed with the IR spectrometer MIPAS onboard of ENVISAT.
- The presence of NAT (nitric acid trihydrate) particles enhances the potential for chlorine activation with subsequent ozone destruction.



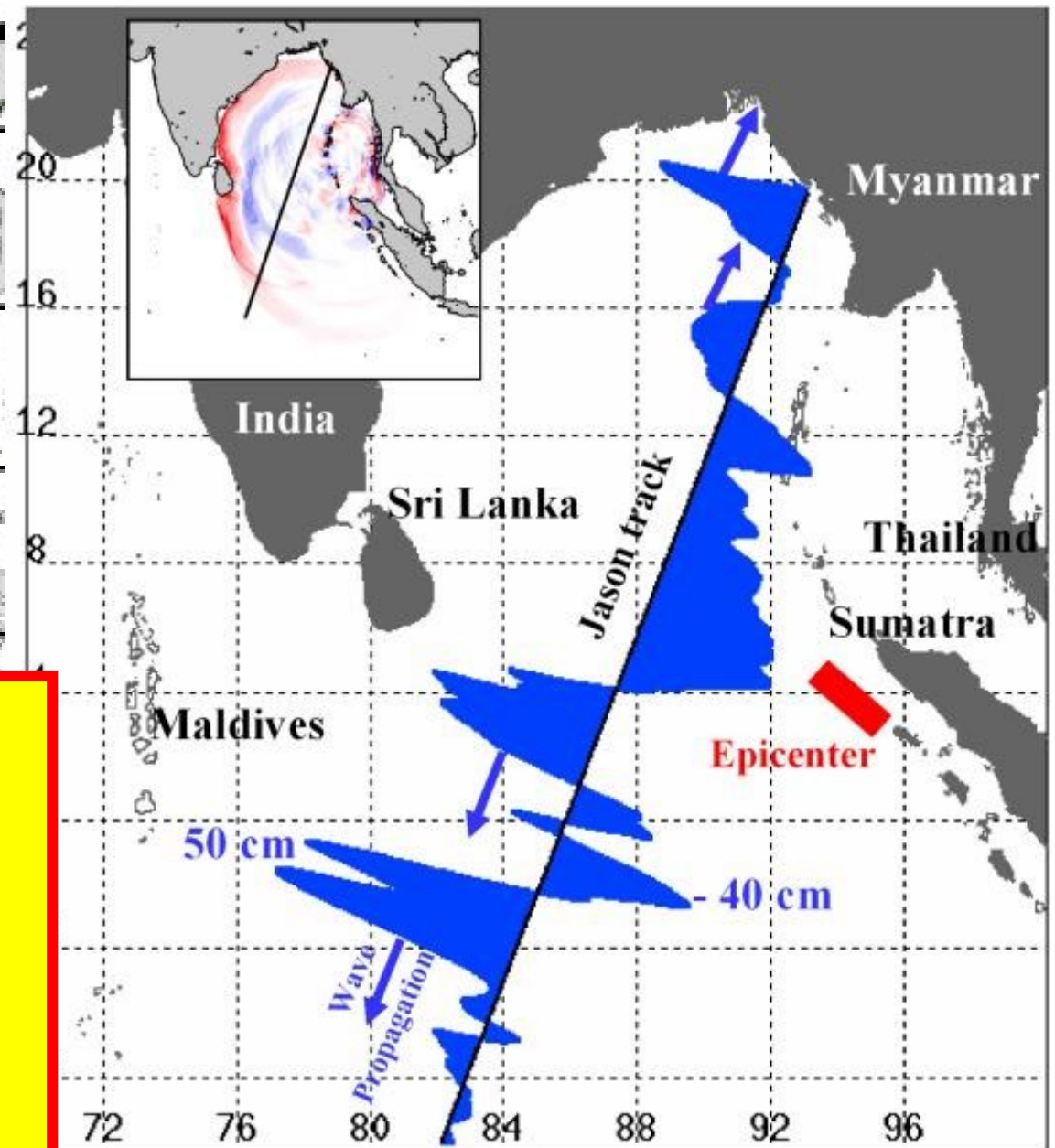
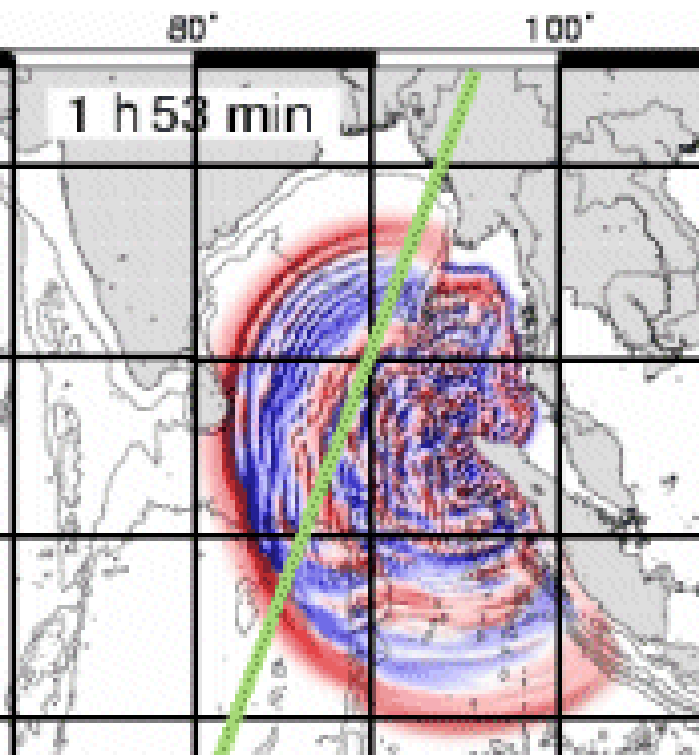


Real-near-time variation of the sea level anomalies over the Equatorial Pacific Ocean. Measured by the Radar altimeter onboard of ENVISAT. El Niño induces a relatively high sea level along the west coast of Central America accompanied by a radical switch of the regional climate with heavy rainfall. The most recent snapshot shows that the sea level has returned to its normal level.

initialised temperature : T on 11-08-2004 near 0 m



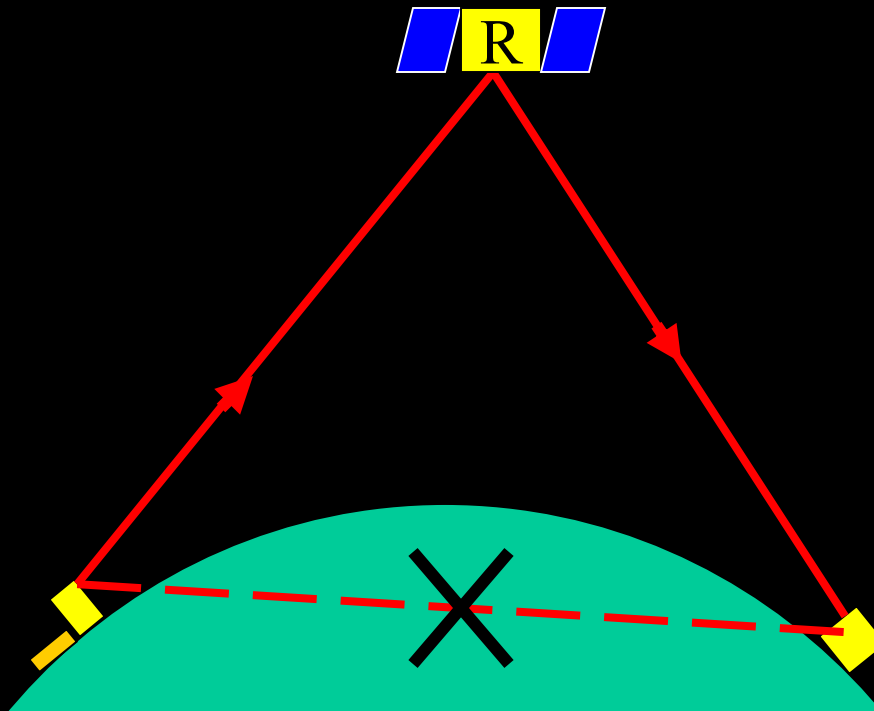
Global variation of sea temperature over a 4-month time period. The maps are created on a weekly basis and are made from altimetry data which are then converted to show increase in temperature, salinity and speed.



Altimetry
observations of the
Tsunami of Dec.26,
2005 by the
CNES/NASA
oceanography
satellites Jason and
Topex/Poseidon

Telecomunicazioni

- Due punti della Terra che non sono in linea di vista, possono scambiarsi informazioni tramite uno o più “relays” in grado di ricevere e ritrasmettere i segnali (transponder):



- Esistono particolari orbite dette geostazionarie che permettono ai satelliti di rimanere fermi rispetto alla superficie terrestre. Pur rimandando alla 3^a lezione lo studio generale delle orbite...

Satelliti Geostazionari

- Un satellite può rimanere su un' orbita circolare intorno alla Terra quando l' accelerazione centrifuga compensa esattamente la forza di gravità:

$$-\frac{GMm}{R^2} + m\frac{v^2}{R} = 0 \rightarrow -\frac{GM}{R^2} + \frac{\omega^2 R^2}{R} = 0$$
$$R = \sqrt[3]{\frac{GMT^2}{4\pi^2}}$$

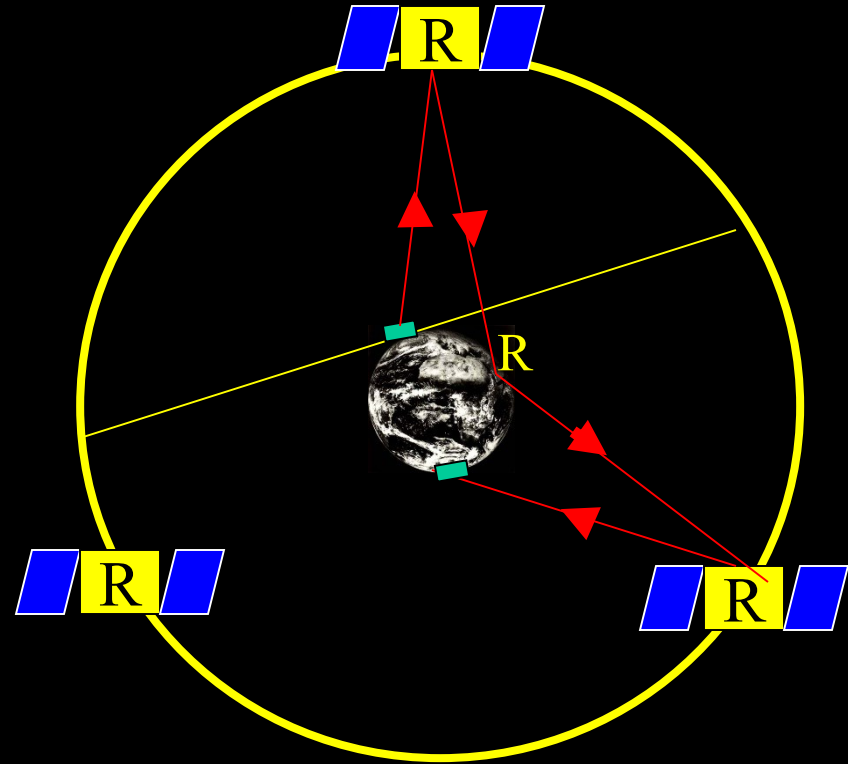


- Se si pone l' orbita nel piano equatoriale, e si impone che il periodo sia di un giorno, il satellite ruoterà in modo sincrono alla superficie terrestre, rimanendo fermo rispetto ad essa. Risulta:

$$R_{geost} = \sqrt[3]{\frac{GMT^2}{4\pi^2}} \cong \sqrt[3]{\frac{6.68 \times 10^{-11} \cdot 5.98 \times 10^{24} \cdot 86400^2}{4\pi^2}} m = 42300 km$$
$$h_{geost} = R - R_{terra} \cong 35900 km$$

Communication constellations

- The concept of the communications satellite was first proposed by Arthur C. Clarke, based on Herman Potocnik's previous work from 1929.
- In 1945 Clarke published an article titled "Extra-terrestrial Relays" in the magazine Wireless World.
- The article described the fundamentals behind the deployment artificial satellites in geostationary orbits for the purpose of relaying radio signals.
- Thus Arthur C. Clarke is often quoted as the inventor of the communications satellite.



Using a minimum of 3 geostationary satellites, all points of the Earth can see at least one satellite over the horizon. So all points can be connected.

Communication constellations

- The first geosynchronous communications satellite was Syncom 2, launched on July 26, 1963. However, Syncom 2 was positioned in an inclined orbit so special tracking equipment was needed to see it.
- The first geosynchronous communications satellite that could be seen from a fixed satellite antenna (over North America) was Anik 1, a Canadian satellite launched in 1973.
- A low Earth orbiting (LEO) satellite is a satellite with a low orbit with an orbital period much shorter than a day.

$$R = \sqrt[3]{\frac{GMT^2}{4\pi^2}} \quad ; \quad R = 400km + R_{earth} \quad \rightarrow \quad T = 2\pi\sqrt{\frac{R^3}{GM}} \approx 5500s$$

- As these satellites can only be seen from any given part of the Earth for a short time as it passes over, large numbers of these satellites are needed to ensure coverage. A group of satellites working in concert is known as a satellite constellation.
- Nowadays several telephony constellations are active : INTELSAT, TELESTAR, IRIDIUM, etc.

Broadcast and localization satellites

- A direct broadcast satellite is a special high-powered communications satellite that transmits to small DBS satellite dishes. Direct broadcast satellites always operate in the upper portion of the Ku-Band (11-14 GHz).
- Examples of satellite constellations are the **GPS** and the **Iridium** and **Globalstar** satellite telephony services.

Fundamental Physics / Chemistry

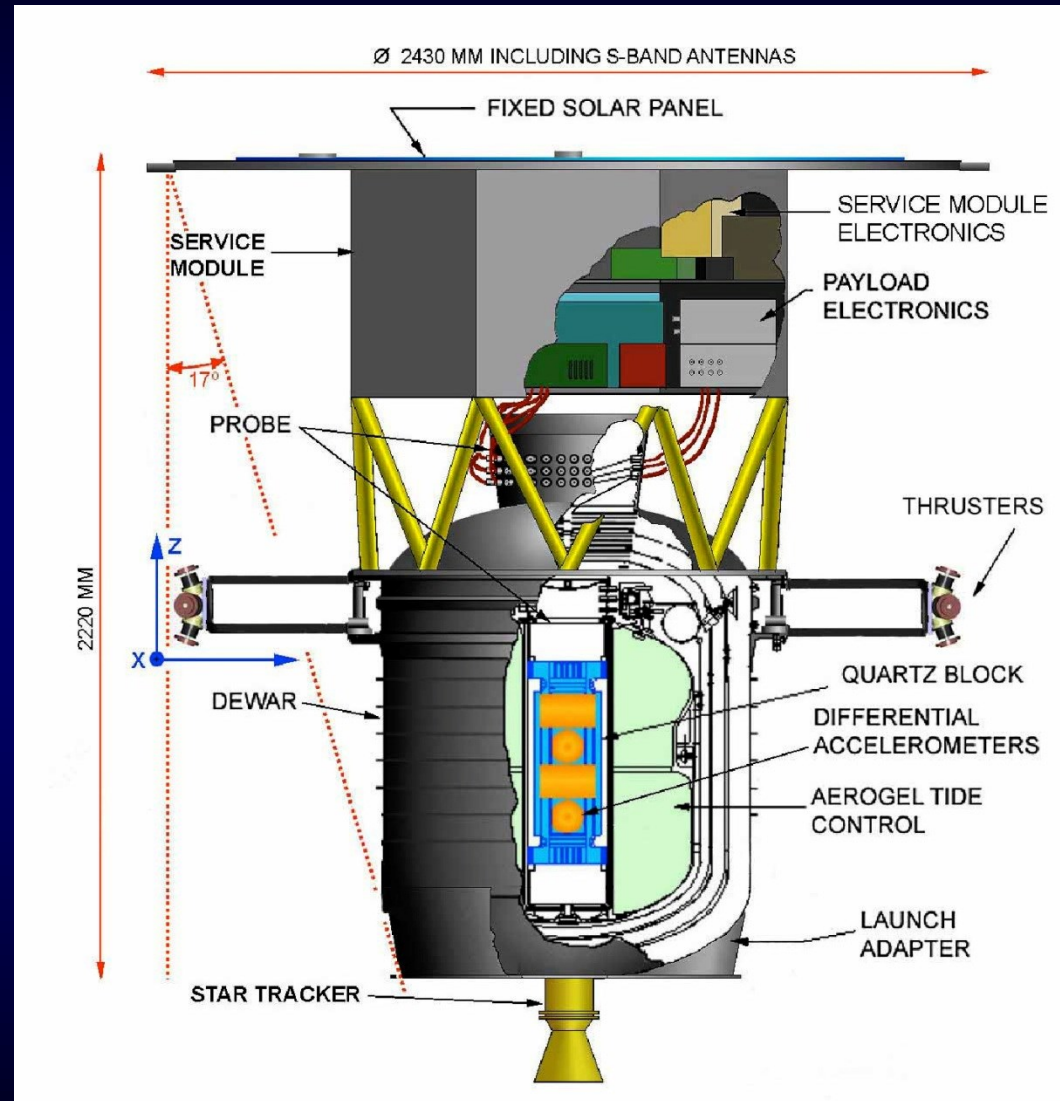
- Microgravity conditions – the ones experienced in a “free fall” satellite or space station orbiting the Earth – are invaluable for studying fundamental physics phenomena normally hidden by the effect of gravity.
- This is especially true for certain phases of **materials processing**.
- Mixers must operate almost constantly to keep ingredients uniformly blended;
- Molten items produced by some methods must be cooled quickly, or spun like the molten glass at the county fair, to prevent distortion of their external shape;
- Some products that depend on a well-ordered internal arrangement, such as electronic components, are not as perfectly ordered as they could be because of gravity's effects.
- Gravity is the driving force behind convection currents between hot and cold regions. These currents mask other events that scientists wish to study and can lower the quality of the final product by causing it to be improperly mixed.

Fundamental Physics / Chemistry

- Fluid mechanics is the study of the behavior of fluids in response to applied forces. The force of gravity on Earth plays an important role in fluid behavior.
- On Earth, it is difficult to study subtle effects because the force required to overcome gravity is so strong that it overwhelms them.
- For example, Acoustical levitation, the use of sound waves to hold uncontained fluid specimens in position, is difficult on Earth because high-intensity sound waves tend to cause the fluid to deform and become unstable.
- In space, weak sound waves can be used to position and manipulate weightless specimens. This method is being investigated because sound waves can be used in "containerless processing," a method for processing materials while they are suspended without touching anything; contact with containers sometimes causes imperfections in processed materials.

Fundamental Physics / Chemistry

- STEP is a NASA/ESA satellite proposed to test the Equivalence Principle by measuring the free-fall of different materials in complete absence of perturbations.



Per saperne di più...

<http://arxiv.org/pdf/1401.4784v1.pdf>

- STEP has nearly completed its technology development phase and is now in position to compete for a flight mission new start. Phase A study grass-roots costing, independently verified using the Aerospace Small Satellite Cost Mode I and the JPL Parametric Mission Cost Model, confirm that STEP is a SMeX (Small Explorer) class mission. Opportunities to re-compete STEP within the NASA explorer program will be enhanced following the recommendation of the NRC Decadal Survey Report, New Worlds New Horizons to augment the NASA Explorer program.
- The Satellite Test of the Equivalence Principle (STEP) will advance experimental limits on violations of Einstein's Equivalence Principle from their present sensitivity of 2 parts in 10^{13} to 1 part in 10^{18} through multiple comparison of the motions of four pairs of test masses of different compositions in a drag-free earth-orbiting satellite. We describe the experiment, its current status, and its potential implications for fundamental physics. Equivalence is at the heart of general relativity, our governing theory of gravity, and violations are expected in most attempts to unify this theory with the other fundamental interactions of physics, as well as in many theoretical explanations for the phenomenon of dark energy in cosmology. Detection of such a violation would be equivalent to the discovery of a new force of nature. A null result would be almost as profound, pushing upper limits on any coupling between standard-model fields and the new light degrees of freedom generically predicted by these theories down to unnaturally small levels.

Fundamental Physics : GW

- LISA is a NASA/ESA Gravitational Waves Interferometer on a satellite constellation, built to detect very long wavelength gravitational waves.

Launch in 2025 ?

- Test this year with LISA pathfinder.
- <http://lisa.jpl.nasa.gov>



LISA will detect GWs produced by binary stars in our galaxy, and by massive black-holes in distant galaxies.

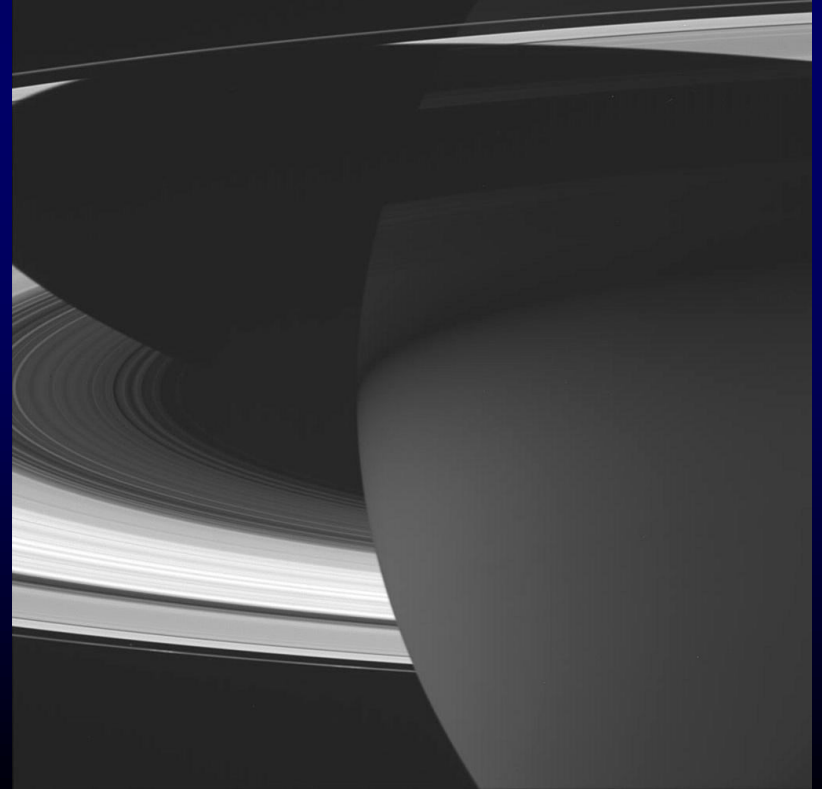
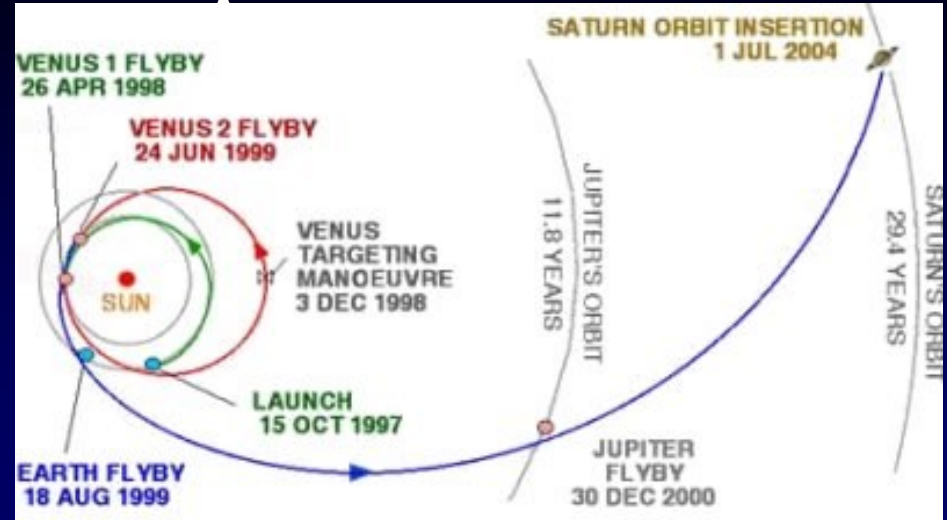
Solar System Exploration

- Another example is the Cassini-Huygens mission (ASI, ESA, Japan, NASA) devoted to Saturn.
- The Cassini orbiter has been orbiting Saturn and its moons for four years, and the Huygens probe was diving into the murky atmosphere of Titan and landed on its surface.
- Huygens has been the first probe to land on a world in the outer Solar System - on the surface of Titan, Saturn's largest moon.



Solar System Exploration

- How did the giant planet develop?
- What causes its lightning bolts, massive storms and whistlers?
- How does its magnetosphere interact with the rings and the moons?
- What is the secret of its perfectly aligned magnetic field? Saturn's magnetic field and the planet appear to rotate about the same axis. This alignment is unique among all known planets .



Cassini Instruments

- **Cassini Plasma Spectrometer** (CAPS) explores plasma (highly ionised gas) within and near Saturn's magnetic field.
- **Cosmic Dust Analyser** (CDA) studies ice and dust grains in and near the Saturn system.
- **Composite Infrared Spectrometer** (CIRS) measures infrared energy from the surfaces, atmospheres and rings of Saturn and its moons to study their temperature and compositions.
- **Ion and Neutral Mass Spectrometer** (INMS) examines neutral and charged particles near Titan, Saturn and moons to learn more about their extended atmospheres and ionospheres.
- **Imaging Science Subsystem** (ISS) takes pictures in visible, near-ultraviolet and near-infrared light.

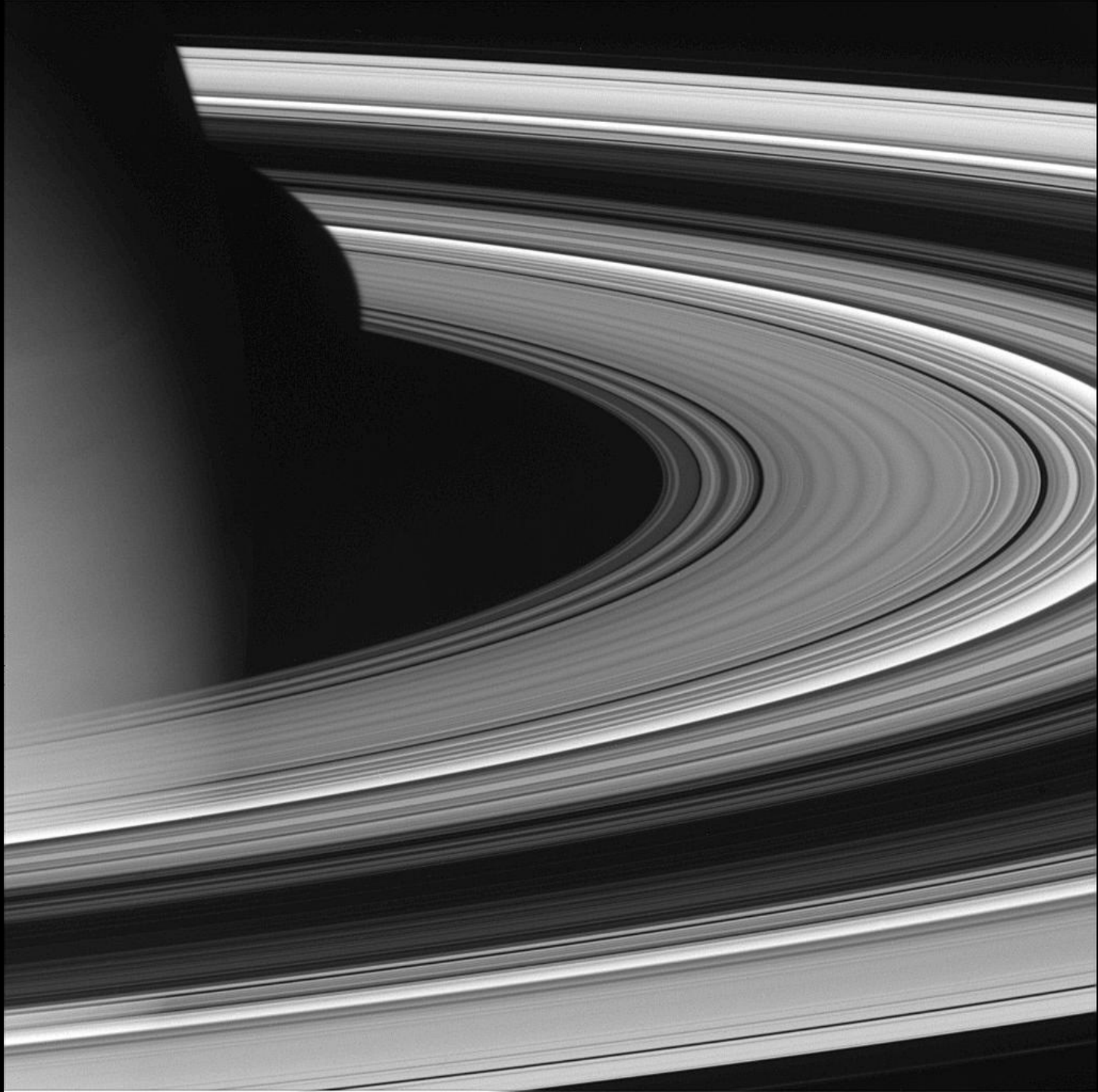
Cassini Instruments

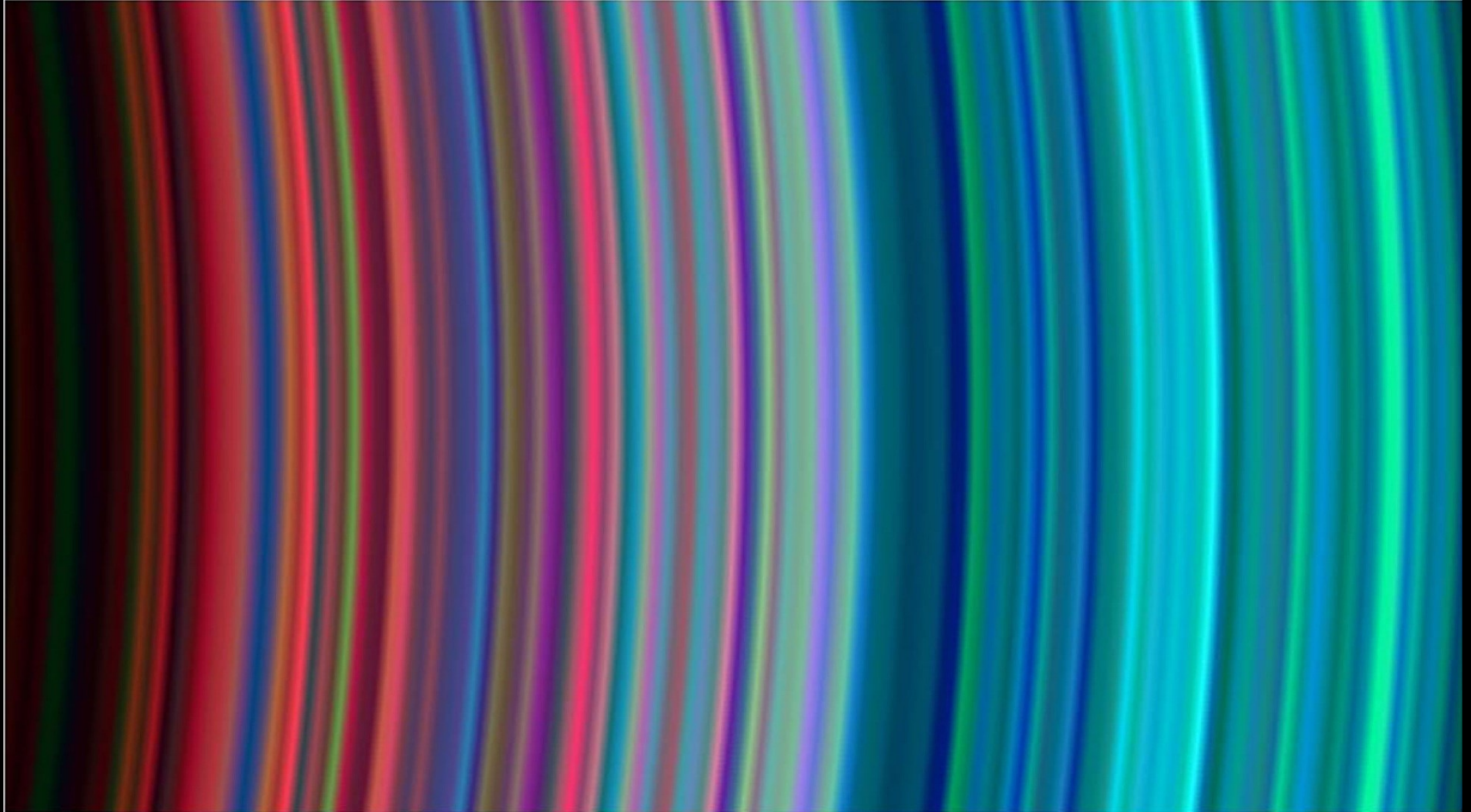
- **Dual-Technique Magnetometer** (MAG) studies Saturn's magnetic field and its interactions with the solar wind, the rings and the moons of Saturn.
- **Magnetospheric Imaging Instrument** (MIMI) images Saturn's magnetosphere and measures interactions between the magnetosphere and the solar wind, a flow of ionised gases streaming out from the Sun.
- **Cassini Radar** (RADAR) maps surface of Titan using radar imager to pierce veil of haze. Also used to measure heights of surface features.
- **Radio and Plasma Wave Spectrometer** (RPWS) investigates plasma waves (generated by ionised gases flowing out from the Sun or orbiting Saturn), natural emissions of radio energy and dust.

Cassini Instruments

- **Radio Science Subsystem** (RSS) searches for gravitational waves in the Universe; studies the atmosphere, rings and gravity fields of Saturn and its moons by measuring telltale changes in radio waves sent from the spacecraft.
- **Ultraviolet Imaging Spectrograph** (UVIS) measures ultraviolet energy from atmospheres and rings to study their structure, chemistry and composition.
- **Visible and Infrared Mapping Spectrometer** (VIMS) identifies the chemical compositions of the surfaces, atmospheres and rings of Saturn and its moons by measuring colours of visible light and infrared energy emitted or reflected.

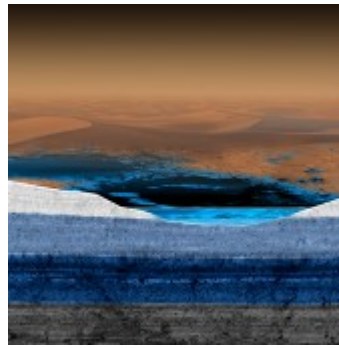
Image taken in visible light with the Cassini spacecraft wide angle camera on 29 October 2004, at a distance of about 940000 kilometres from Saturn. The image scale is 52 kilometres per pixel.



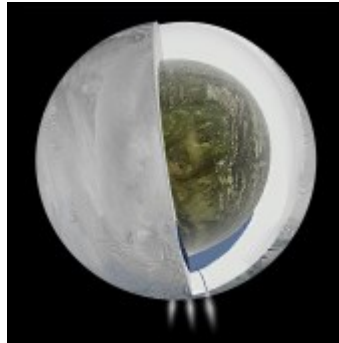


The C and B rings in ultraviolet. This image shows the outer C and inner B rings, with the inner B ring beginning about halfway across the image. The general pattern is from 'dirty' red particles to the denser ice shown in turquoise as the ringlets spread outward.

<http://sci.esa.int/cassini-huyges/>



Titan's subsurface reservoirs modify methane rainfall 01 September 2014 The international Cassini mission has revealed hundreds of hydrocarbon lakes and seas spread across the icy surface of Saturn's moon Titan, mostly in its polar regions. While most of the liquid in the lakes is thought to be replenished by rainfall from clouds in the moon's atmosphere, the cycling of liquid throughout Titan's crust and atmosphere is still not well understood.



Icy moon Enceladus has underground sea.03 April 2014 Saturn's icy moon Enceladus has an underground sea of liquid water, according to the international Cassini spacecraft.

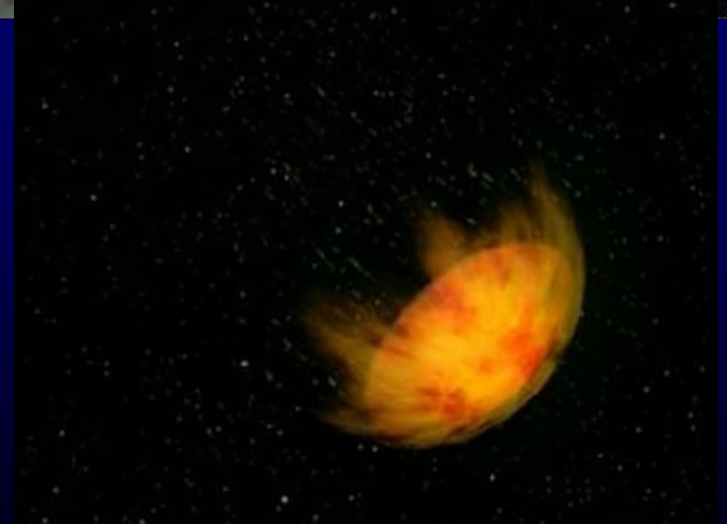
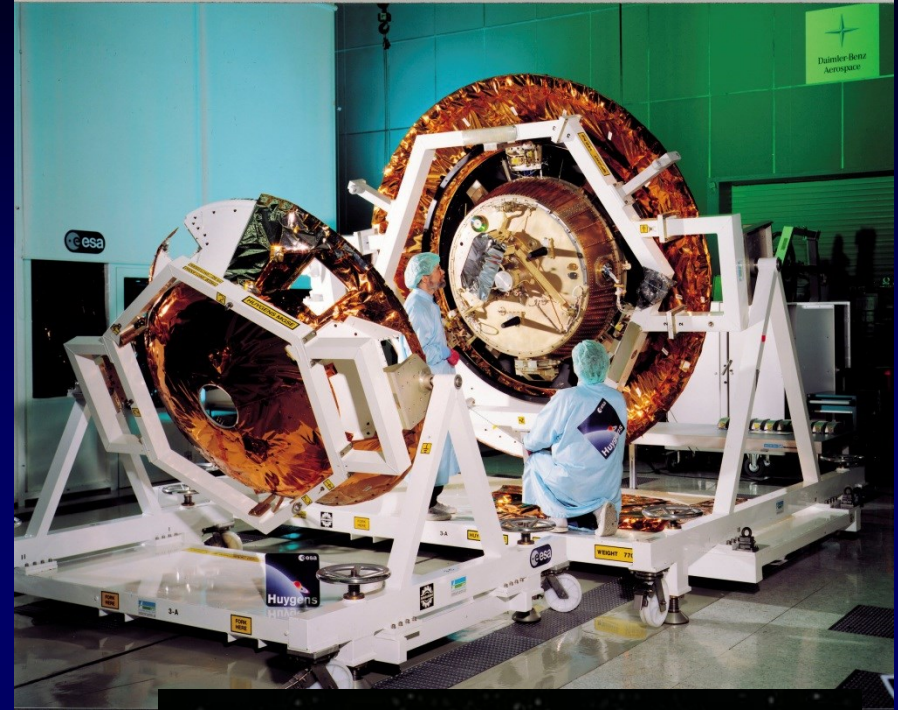
Probable evidence on Phoebe of an ice-rich body overlain with a thin layer of dark material. The sharply-defined crater at above centre exhibits two or more layers of alternating bright and dark material.

The layering might occur during the crater formation, when ejecta thrown out from the crater buries the pre-existing surface that was itself covered by a relatively thin, dark deposit over an icy mantle.



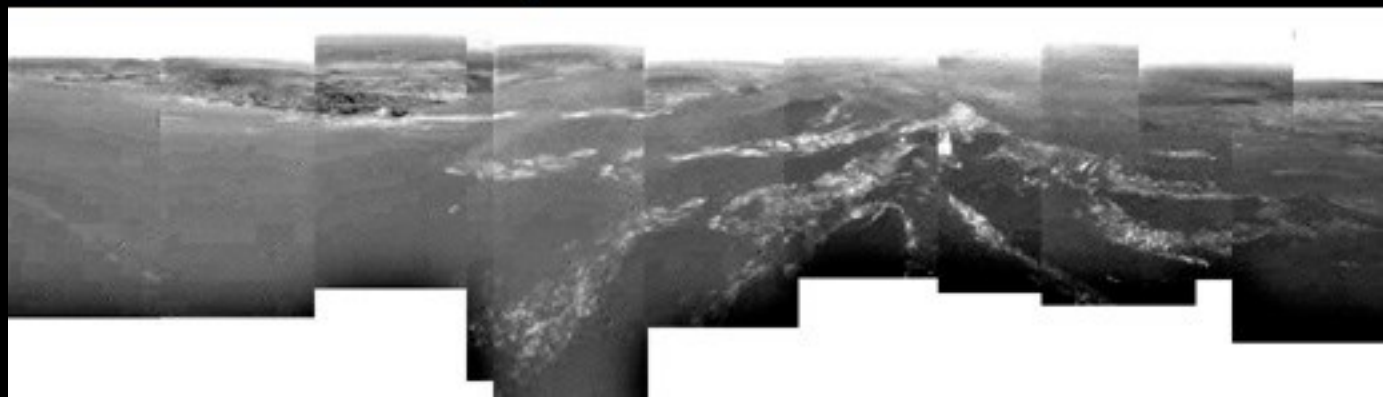
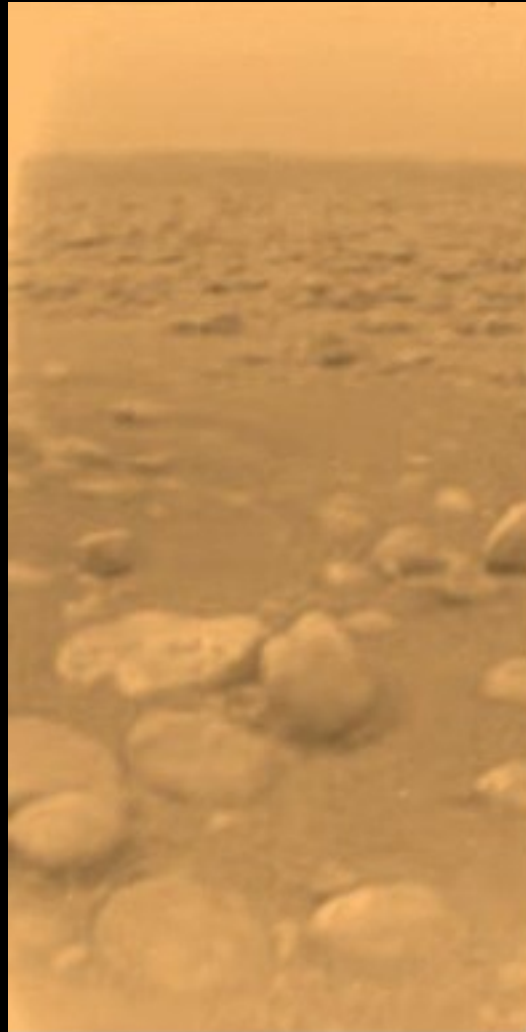
Huygens Probe

- Titan is one of the most mysterious objects in our Solar System. It is the second largest moon and the only one with a thick atmosphere, resembling that of a very young Earth.
- Preserved in the deep freeze of Titan's atmosphere are chemical, carbon-rich compounds thought to be similar to those of Earth's primeval soup.
- The in situ results from Huygens, combined with Cassini's global observations from repeated flybys of Titan, provided vital information towards the great mystery of how life began on Earth.



14/01/2005
Huygens
probe lands
on Titan





Huygens Instruments

- **Aerosol Collector and Pyrolyser** (ACP) will collect aerosols that will be analysed by the Gas chromatograph and Mass Spectrometer experiment. It is equipped with a deployable sampling device that will be operated twice during the descent. The first sample will be taken from the top of the atmosphere down to an altitude of about 40 km. The second sample will be collected in the cloud layer, between altitudes of about 23 km and 17 km. At the end of each collection period, the filter is retracted into a pyrolysis furnace where the material from the captured aerosols is analysed, first at ambient temperature (about 0°C), then while heated to 250 °C and then to 600 °C in order to conduct a multi-step pyrolysis.
- **Descent Imager and Spectral Radiometer** (DISR) is an optical remote sensing instrument. It includes a set of upward and downward looking photometers, visible and infrared spectrometers, a solar aureole sensor, a side-looking imager, and two down-looking imagers - one providing medium resolution and the other high resolution. Works in the 0.3 to 1.7 μm range.

Huygens Instruments

- **Doppler Wind Experiment** (DWE) is designed to determine the direction and strength of Titan's zonal winds. A height profile of wind velocity will be derived from the residual Doppler shift of Huygens radio relay signal as received by Cassini. This will be corrected for all known probe and orbiter motions and signal propagation effects. Wind-induced motion of the probe will be measured with a precision better than 1 ms^{-1} starting when the parachute deploys at an altitude of about 165 km and continuing down to the surface.
- **Gas Chromatograph and Mass Spectrometer** (GCMS) is designed to measure the chemical composition of Titan's atmosphere from 170 km to the surface and determine the isotope ratios of the major gaseous constituents. It will also analyse gas samples from the ACP experiment and will investigate the composition of several candidate surface materials.

Huygens Instruments

- **Huygens Atmospheric Structure Instrument** (HASI) is a multi-sensor instrument that will measure the physical and electrical properties of Titan's atmosphere. Its sensors suite consists of a 3-axis accelerometer, a temperature sensor, a multi-range pressure sensor, a microphone and a electric field sensor array. HASI will also process the reflected signal of the radar altimeter.
- **Surface Science Package** (SSP) is a suite of sensors for determining the physical properties of the surface at the landing site and for providing information on the composition of the surface material. The instrument includes a force transducer for measuring the impact deceleration and sensors to measure the refraction index, temperature, thermal conductivity, heat capacity, speed of sound and dielectric constant of the surface material. The instrument suite includes an acoustic sounder for sounding the bottom layer of the atmosphere and the physical properties of the surface prior to landing. If the Probe lands in a liquid, the sounder will be used to probe the liquid depth. A tilt sensor is included to indicate the Probe's attitude after landing.

Il lander della missione Rosetta, che ha dato e sta dando molti risultati:
<http://blogs.esa.int/rosetta/>

Oltre ai risultati, che avrete sentito alla TV, e letto sui quotidiani Nazionali
C'è anche la storia di questa missione, il suo lungo viaggio, e il
Lavoro di molti scienziati in questi lunghi anni .

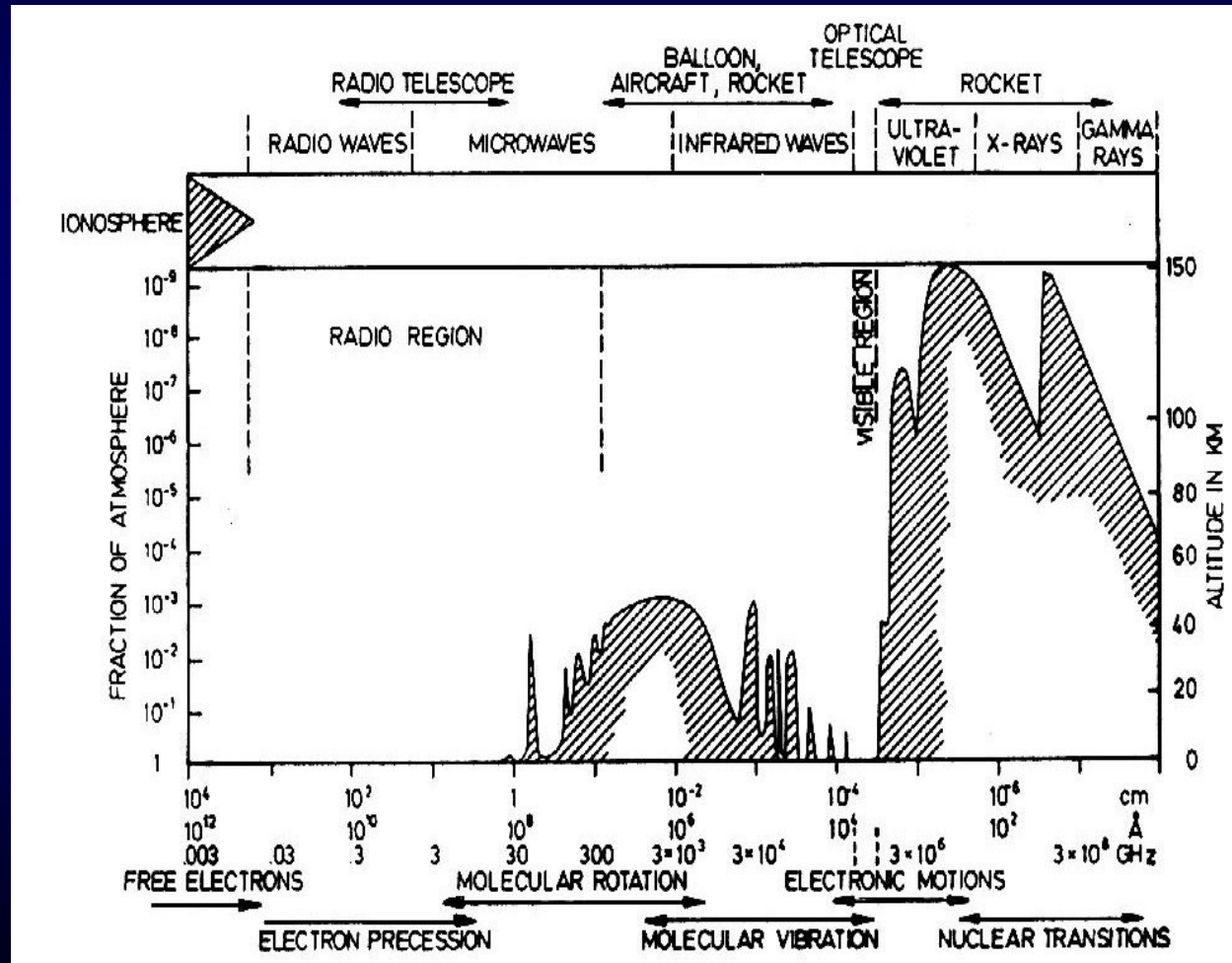
Adesso una delle scienziate che hanno permesso la realizzazione ed il
Successo di questa missione, Angioletta Coradini, ha avuto dedicata
Una porzione della cometa, (**67P Churyumov-Gerasimenko**)
come risulta dal sito web di ASI (www.asi.it)

.....Lo Science Working Team di Rosetta ha dedicato un'area della cometa alla scienziata
già PI dello strumento VIRTIS scomparsa nel 2011

“**A. Coradini Gate**” . A lei si deve lo sviluppo di gran parte della strumentazione per l'esplorazione
del Sistema Solare, che l'**Agenzia Spaziale Italiana** ha realizzato negli ultimi vent'anni
per le più importanti missioni **ESA** e **NASA** dedicate all'Esplorazione dell'Universo.....

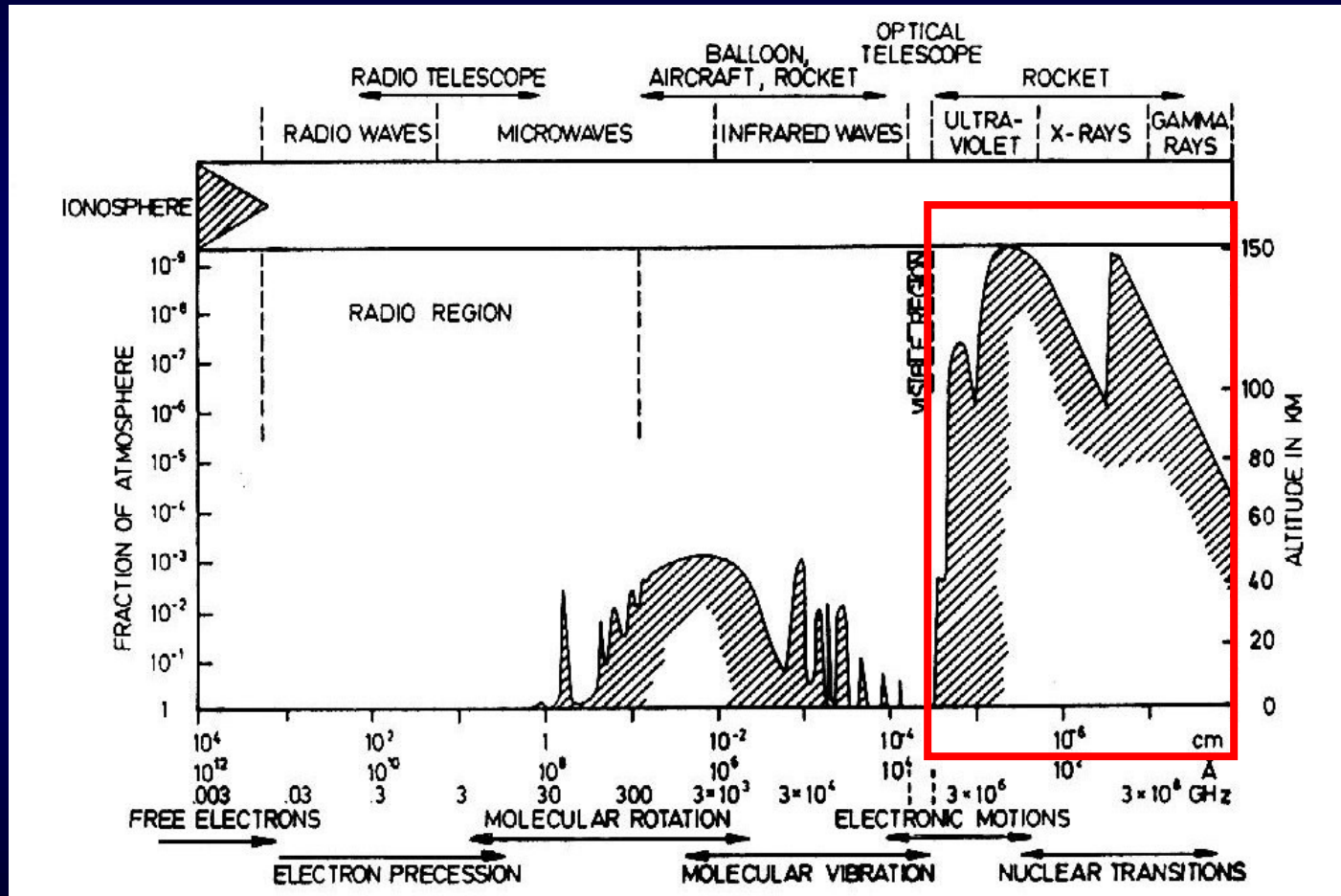
Observation of the Universe

- In this case, space is needed to **avoid the effects of the Earth atmosphere**: opacity (extinction), emission, fluctuations of opacity, fluctuations of emission.
- These have different weights at different wavelengths.
- In this plot we plot vs wavelength the altitude needed to have less than half of the extraterrestrial photons absorbed by the atmosphere.



Observation of the Universe

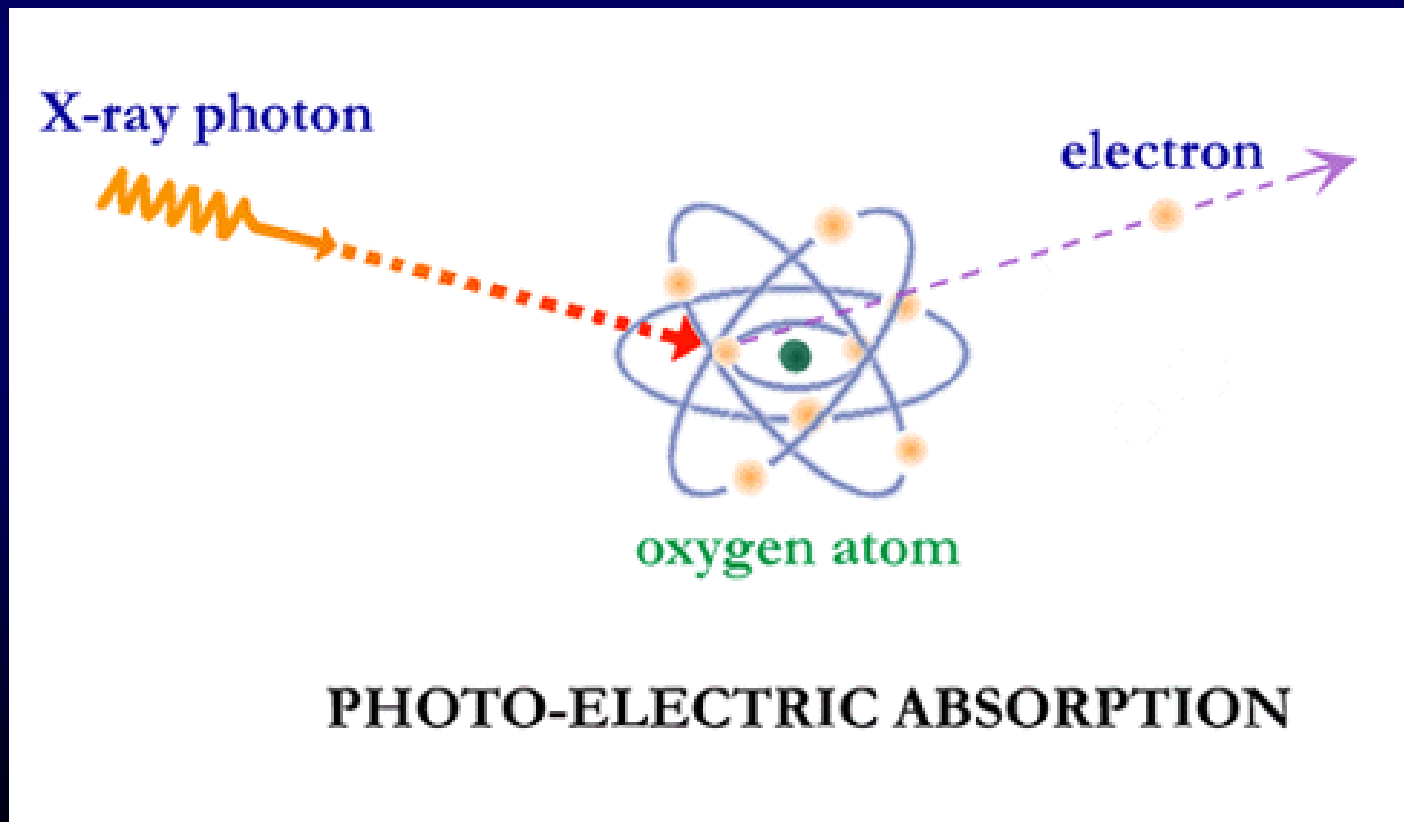
- In the **UV, X-rays and Gamma-rays** ranges, the atmosphere is simply **opaque**, because electronic and nuclear transitions of the atoms efficiently absorb photons with $>eV$ energy.



- High energy astronomy did not even start until space carriers became available.

X-ray astronomy

- The problem is photoelectric absorption of X-ray photons by atoms in the O_2 or N_2 molecules of the air.
- An X-ray photon passing through the atmosphere will encounter as many atoms as it would in passing through a 5 meter (16 ft) thick wall of concrete!

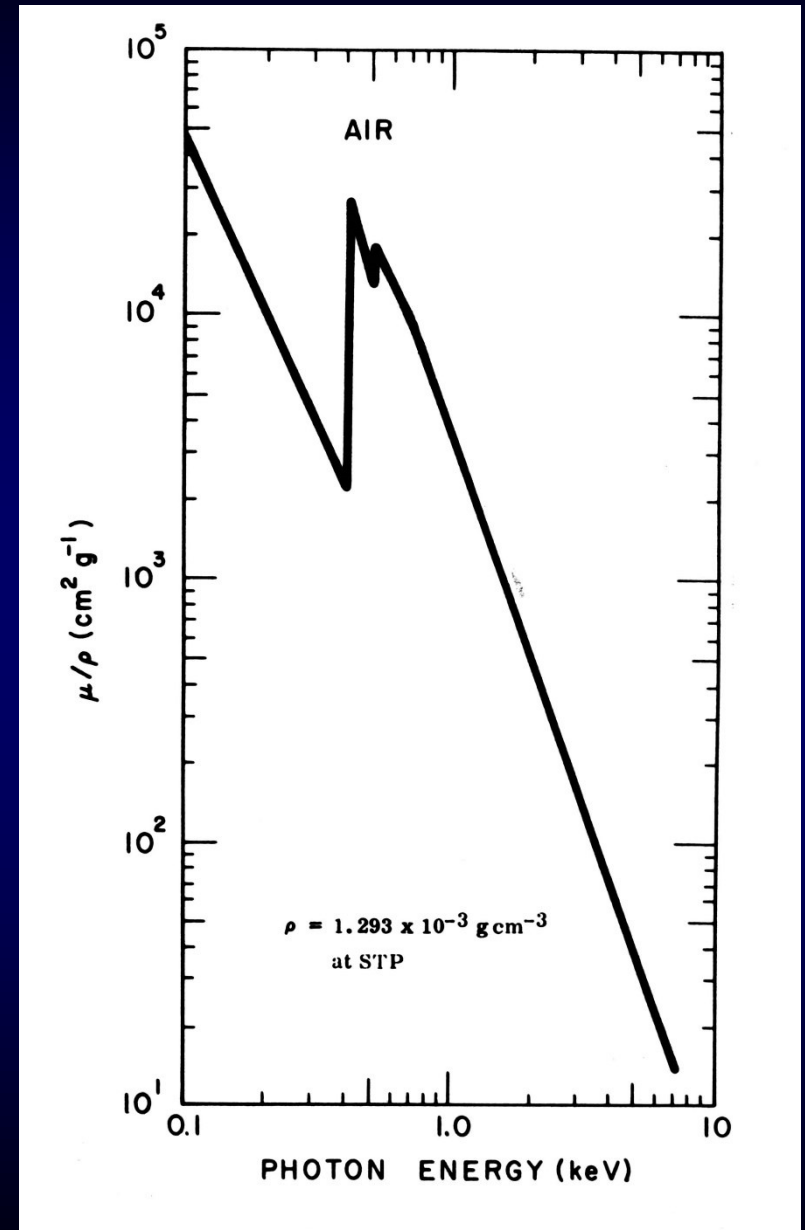


X-ray astronomy

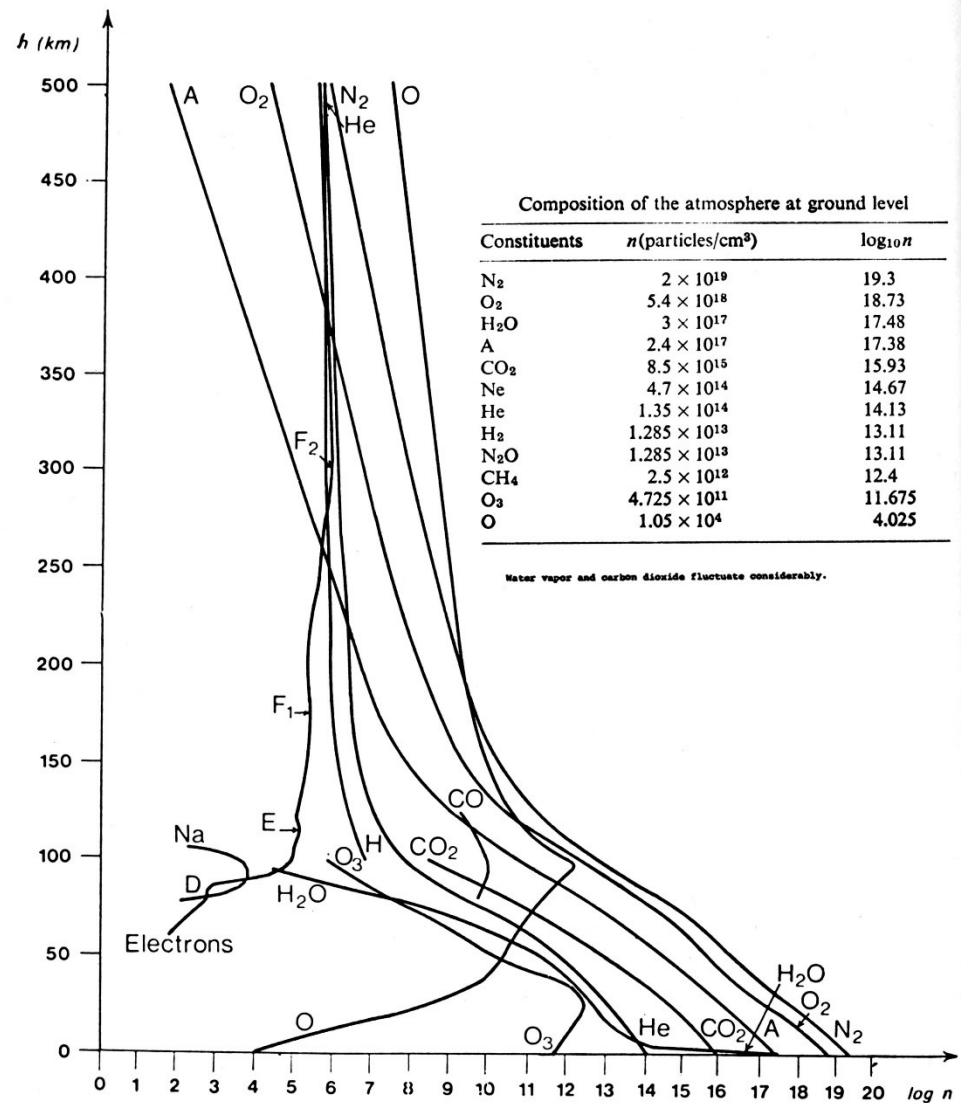
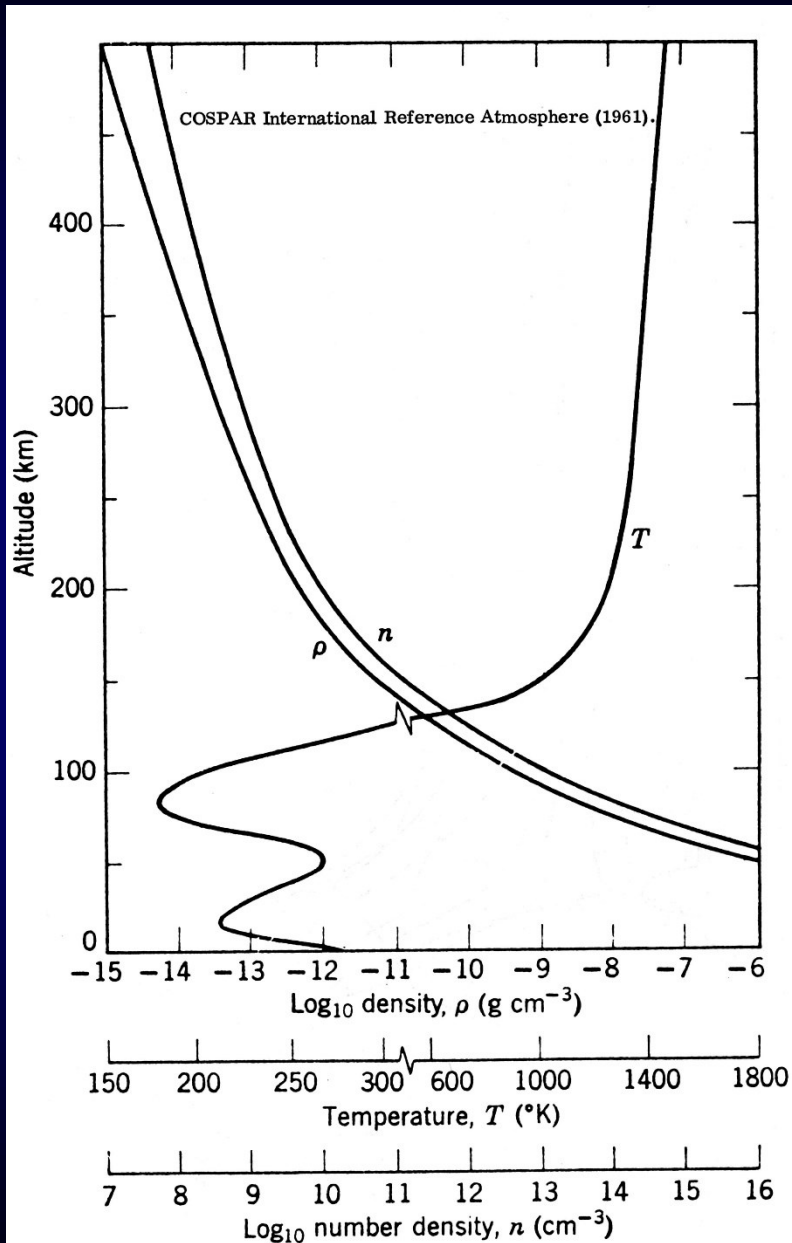
- Sezione d' urto per assorbimento fotoelettrico:
- Lo scalino è dovuto alla shell K di elettroni.
- La probabilità di interazione è

$$P = \tau = \int_h^{\infty} n \sigma d\ell \stackrel{\text{def}}{=} \int_h^{\infty} \mu d\ell$$

- Aumentando la quota h , la densità delle molecole diminuisce di molti ordini di grandezza, e la probabilità di assorbimento diminuisce di conseguenza.



X-ray astronomy



Variation with altitude of the various constituents of the atmosphere. The horizontal scale is the logarithm of the particle density n in particles per cm³.

(adapted from Pecker, J., "Space Observatories", D. Reidel Publishing Company, Dordrecht, 1970)

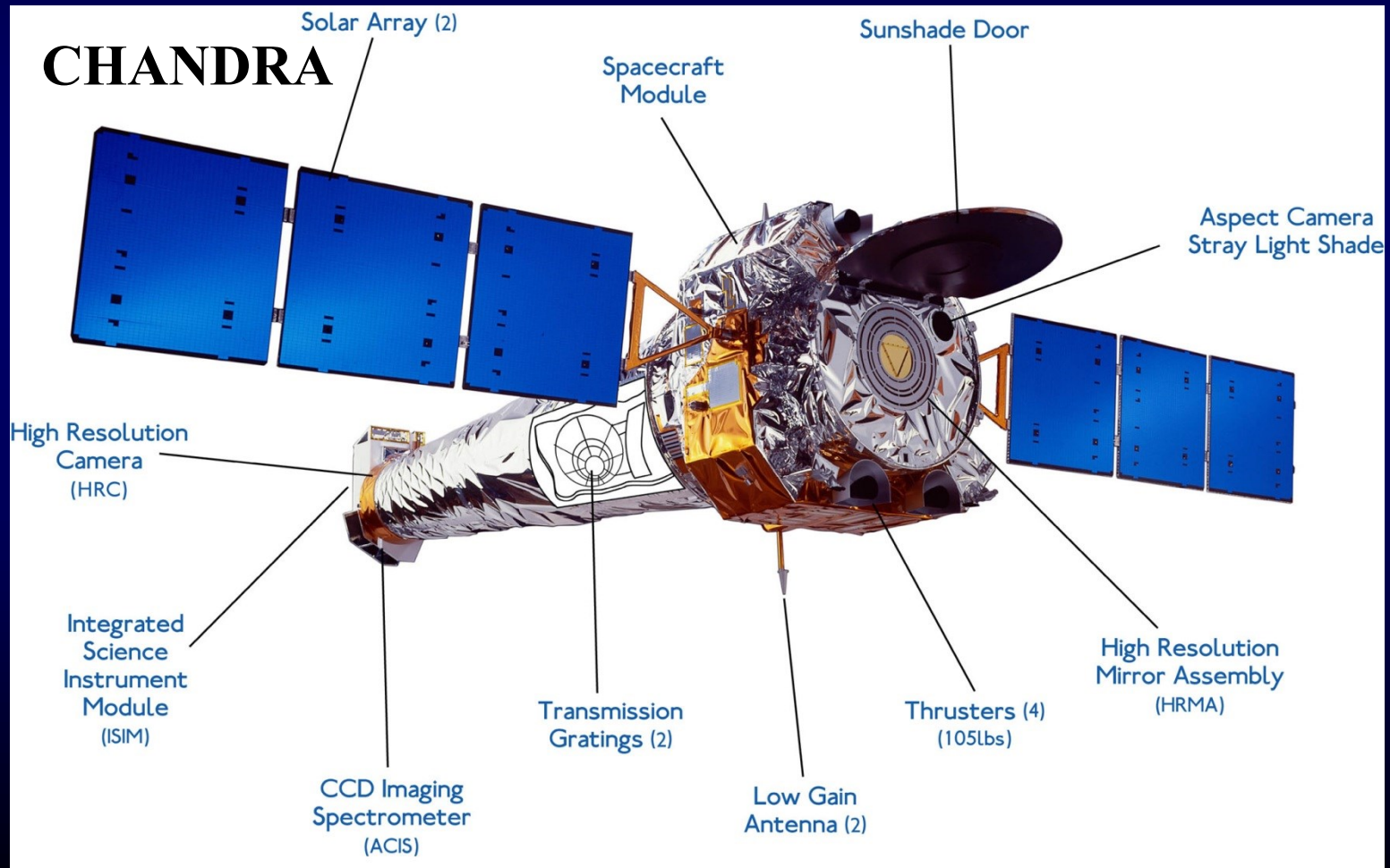
X-Ray astronomy

- X-ray astronomy has been carried out from balloons and sounding rockets in the early days; then with satellite telescopes.
- The long list of satellites devoted to X-ray astronomy is a demonstration of the need of space for these observations:
- Uhuru (1970), Skylab (1970), Einstein (1978), Rosat (1990), ASCA (1993), RXTE (1995), BeppoSAX (1996), XMM (1999), Chandra (1999)...

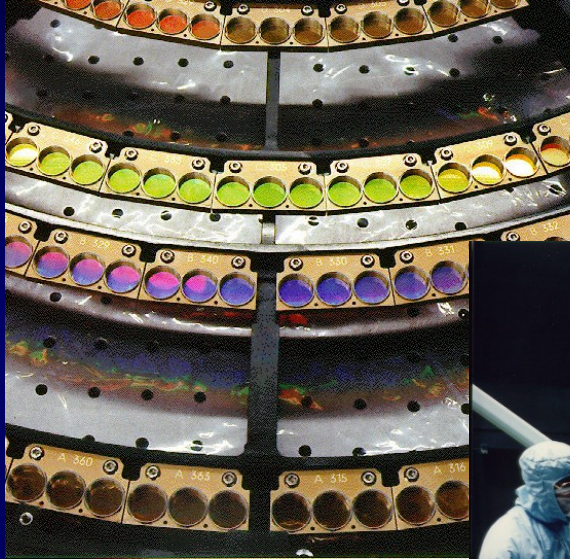


X-Ray astronomy

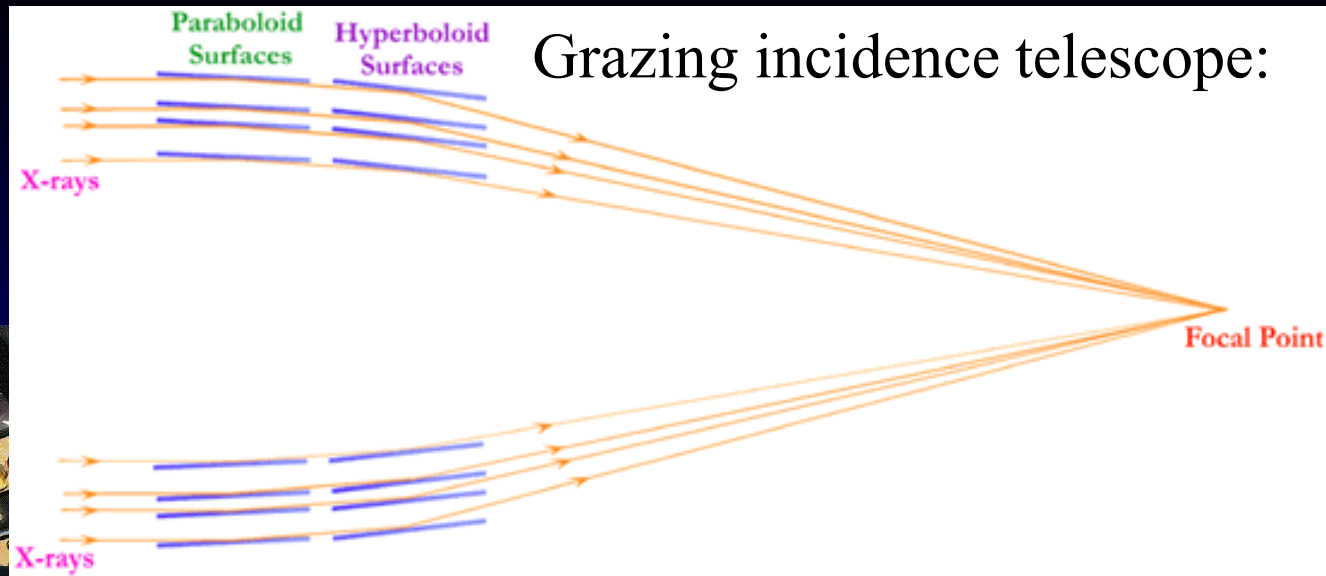
- The great X-ray telescopes today are XMM-Newton (ESA:<http://xmm.esac.esa.int/>) and Chandra (NASA:http://www.nasa.gov/mission_pages/chandra/main/index.html).
- Both are incredibly large and complex machines.



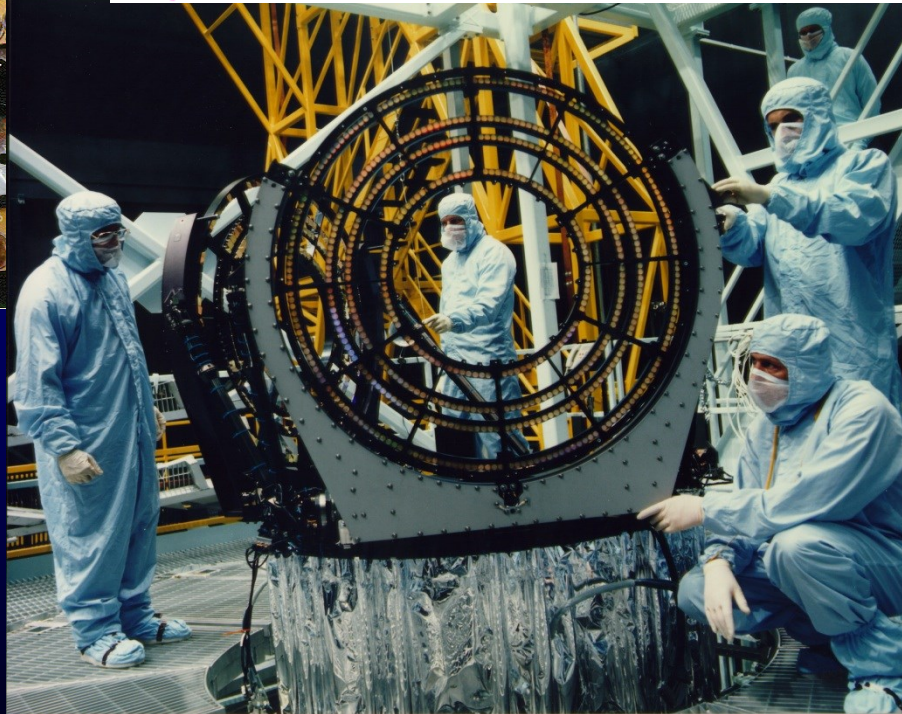
Chandra



Diffraction
Gratings



Grazing incidence telescope:



Thrusters

X-Ray astronomy: Chandra

- Mosaic of Galactic plane observations by the ACIS instrument



Optical-IR Astronomy

- Optical-IR extinction by the atmosphere depends on three principal components, each with different wavelength dependence and scale-height:
 - Rayleigh scattering by molecules
 - Extinction by Aerosol particles (fine dust, water droplets, pollution)
 - Molecular absorption in discrete lines and bands, mainly by Ozone O_3 , oxygen, water vapour.

Optical-IR Astronomy

- Rayleigh scattering by molecules (Hayes & Latham, Ap.J., 197, 593, 1975; Penndorf, JOSA, 47, 176, 1976)

$$A_R(\lambda, h)[mag / airmass] = 9.50 \times 10^{-3} \frac{1}{\lambda(\mu m)^4} \left[\frac{n(\lambda)}{n(1\mu m)} \right]^2 e^{-h(km)/7.996}$$

- Extinction by Aerosol particles (Tug et al., A&A, 61, 679, 1974)

$$A_A(\lambda, h)[mag / airmass] = A_o \lambda^{-0.8} e^{-h(km)/1.5}$$

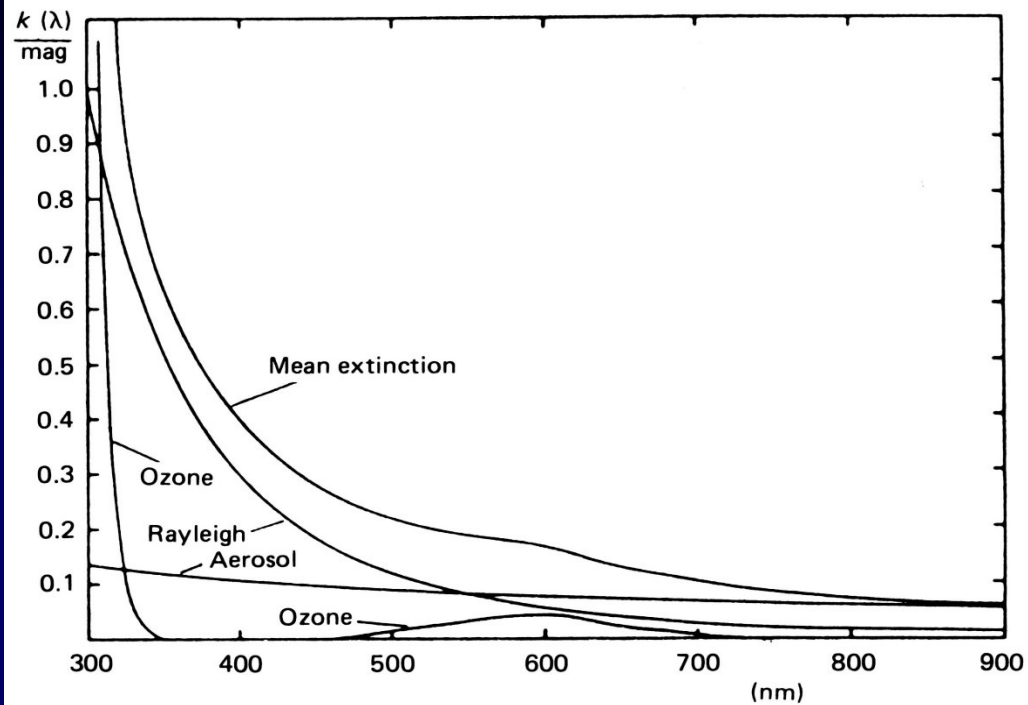
- Molecular absorption in discrete lines and bands, mainly by Ozone O_3 (Hayes & Latham), oxygen, water vapour.

$$A_{O_3}(\lambda)[mag / airmass] = 1.1 T k(\lambda)$$

T = total O_3 column in atm cm $\approx 0.2 - 0.3$

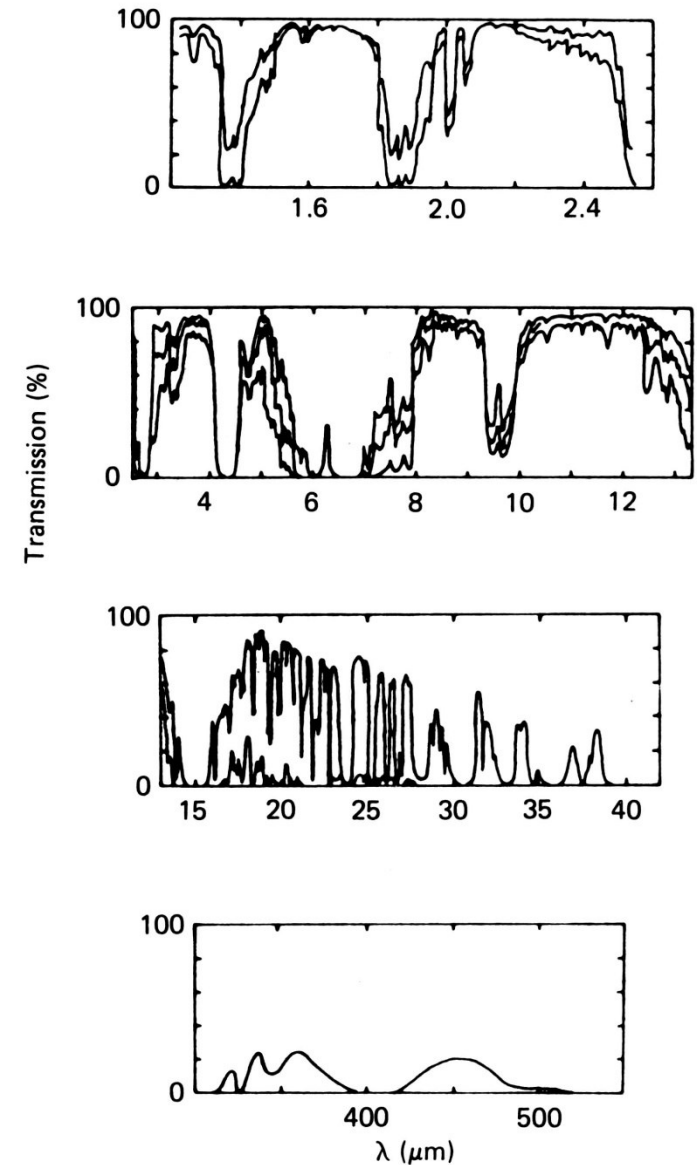
$k(\lambda)$ (absorption coefficient in cm^{-1})

Optical-IR Astronomy



Estinzione atmosferica nel visibile

Trasmissione atmosferica nell' IR



Optical-IR Astronomy

- The other big problem is atmospheric **seeing**.
- This is the effect of turbulence, producing fluctuations of the air refraction index n .
- n for air is close to 1, with a variable fraction of the order of 10^{-6} . The refractive modulus is defined as $N=(n-1)10^6$. In STP conditions (Cauchy formula)

$$N = 272.643 + \frac{1.2288}{10^{-6} \lambda^2} + \frac{0.03555}{10^{-12} \lambda^4} \quad (\lambda \text{ in nm})$$

$$N = 0.79 \frac{P(Pa)}{T(K)}$$

- So, under adiabatic conditions, T fluctuations produce

$$\Delta N = 0.79 \frac{P}{T^2} \Delta T$$

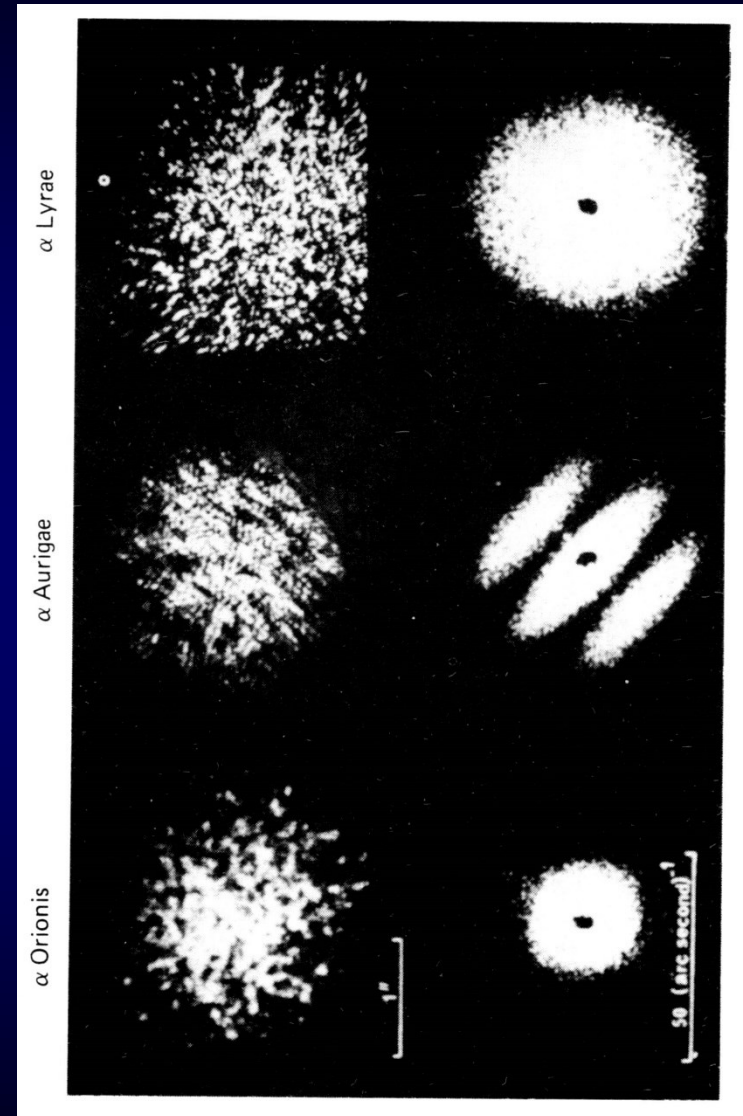
Optical-IR Astronomy

- The principal source of atmospheric turbulence is convection.
- Air heated by conduction at the Earth's surface rises into cooler air, expands, and continues to rise while the cooler air descends towards the surface.
- High winds (and jet streams) produce turbulence through wind shear.
- Energy deposited into turbulence at large scales (the so-called outer scale L_o , of the order of 100 m) cascades to smaller and smaller scales down to few mm, where heat conduction smooths any further temperature fluctuation.
- The distribution of thermally generated isotropic turbulence at different scales is described by the Kolmogorov spectrum. If k is the wavenumber

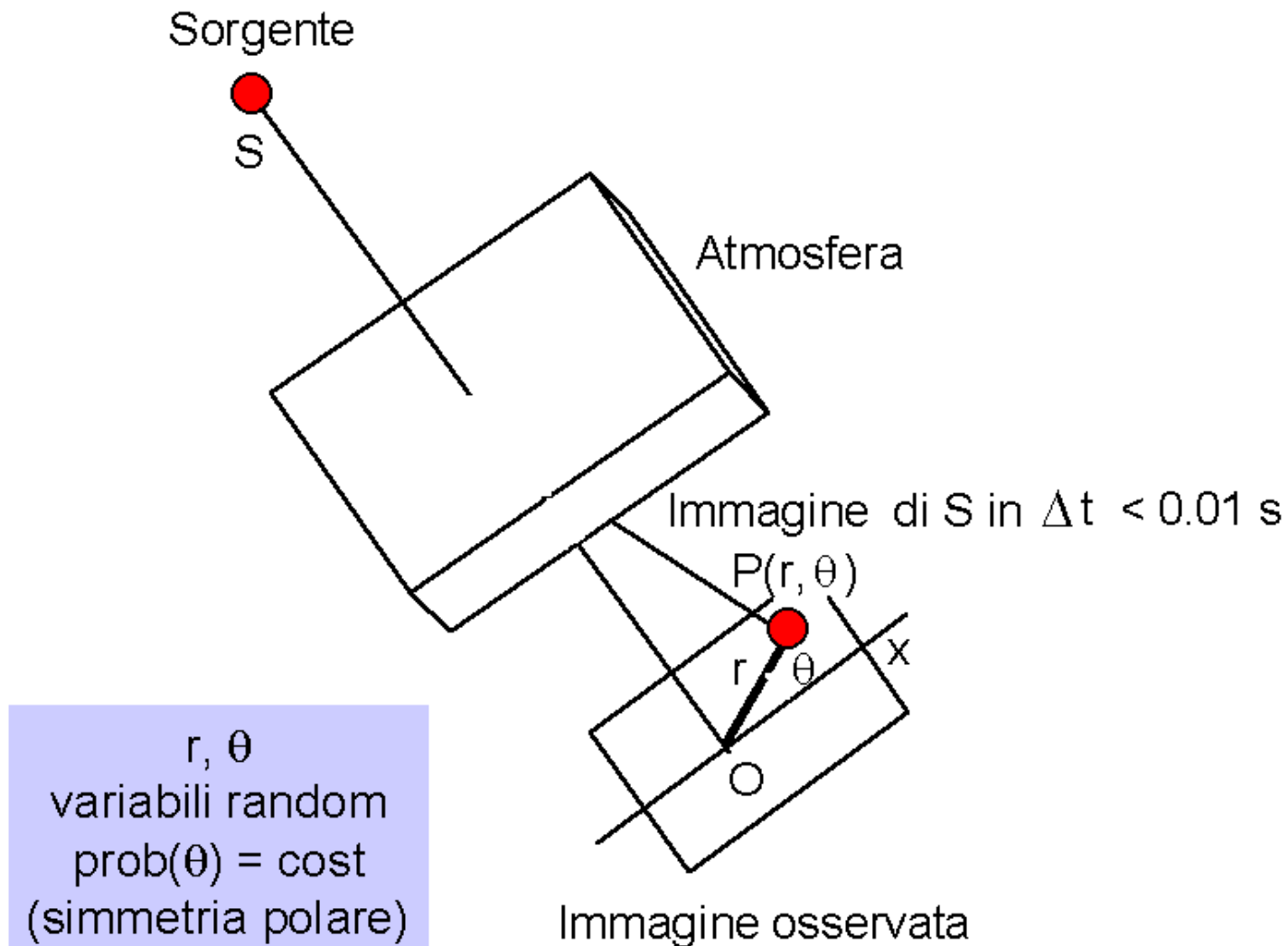
$$G(k) = A \frac{(kL_o / 2\pi)^2}{[1 + (kL_o / 2\pi)^2]^{11/6}}$$

Optical-IR Astronomy

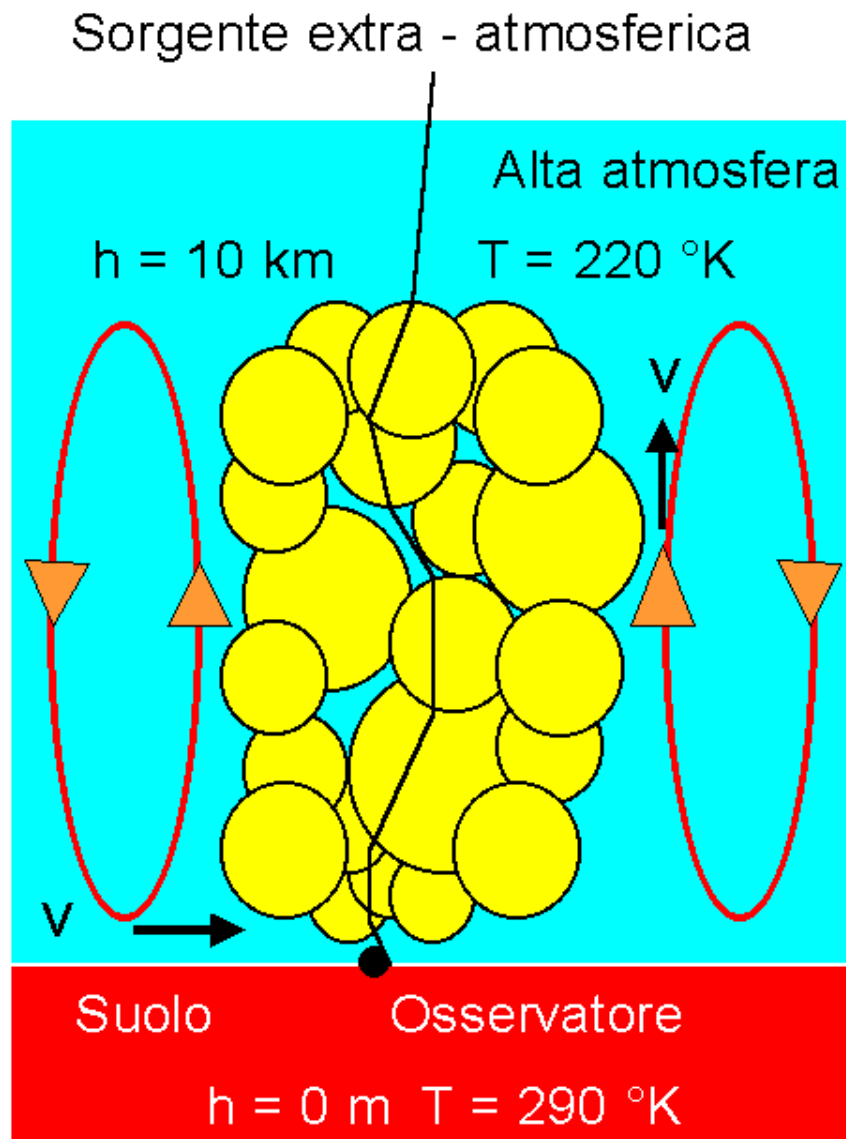
- Wavefronts arriving above the Earth's atmosphere from a star are practically plane-parallel.
- Turbulence produces temperature inhomogeneities which in turn induce small scale variations of the refractive index according to
$$\Delta N = 0.79 \frac{P}{T^2} \Delta T$$
- These variations produce corrugations in the wavefronts with amplitude up to several wavelengths. As a result the telescope optics cannot form the classical diffraction pattern (Airy disc) appropriate to a single point source.



Fluttuazioni casuali di rifrazione atmosferica. Seeing astronomico.



Turbolenza atmosferica

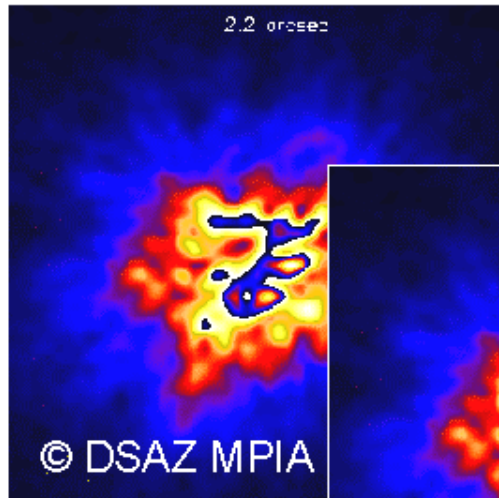


Le differenze di temperatura fra regioni diverse dell' atmosfera implicano moti convettivi di bolle d' aria a temperatura diversa da quella dell' ambiente circostante (venti verticali e orizzontali). Ciò provoca una rifrazione casuale nella propagazione dell' immagine.

Per una colonna atmosferica con $v \approx 1 \text{ m/s}$ ed $L \approx 10 \text{ m}$, $K_v \approx 1.5 \cdot 10^{-5} \text{ m}^2/\text{s}$ costanti della turbolenza, il numero di Reynold $R = v L / K_v$ risulta $R \approx 6.7 \cdot 10^5$.

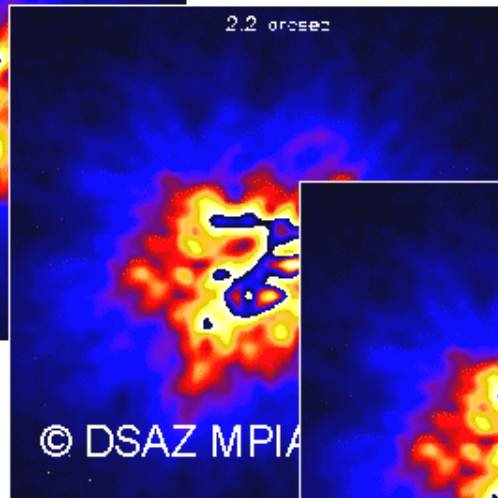
Il regime convettivo risulta quindi turbolento perché è superata la condizione critica $R \gg 1$.

Seeing astronomico e speckles

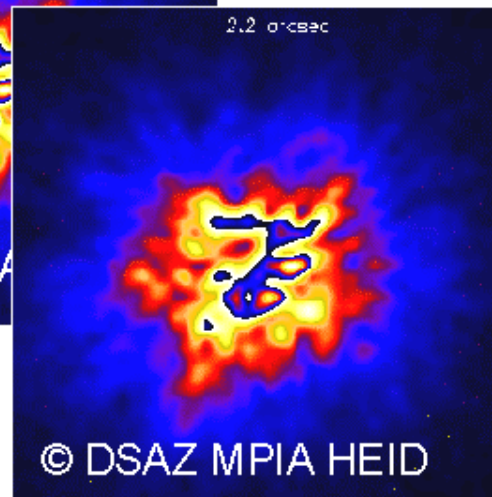


1 di N speckles

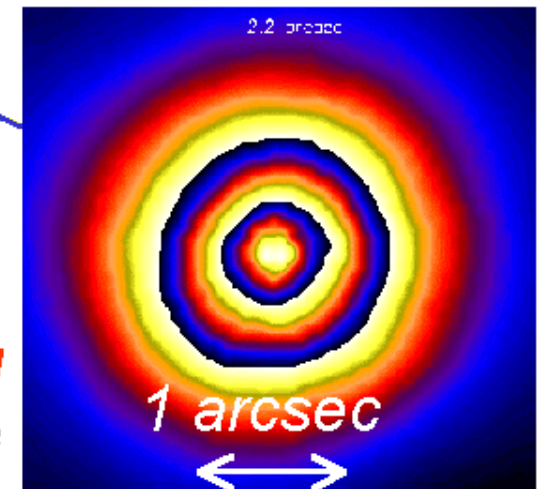
immagine di breve tempo di esposizione



k di N speckles



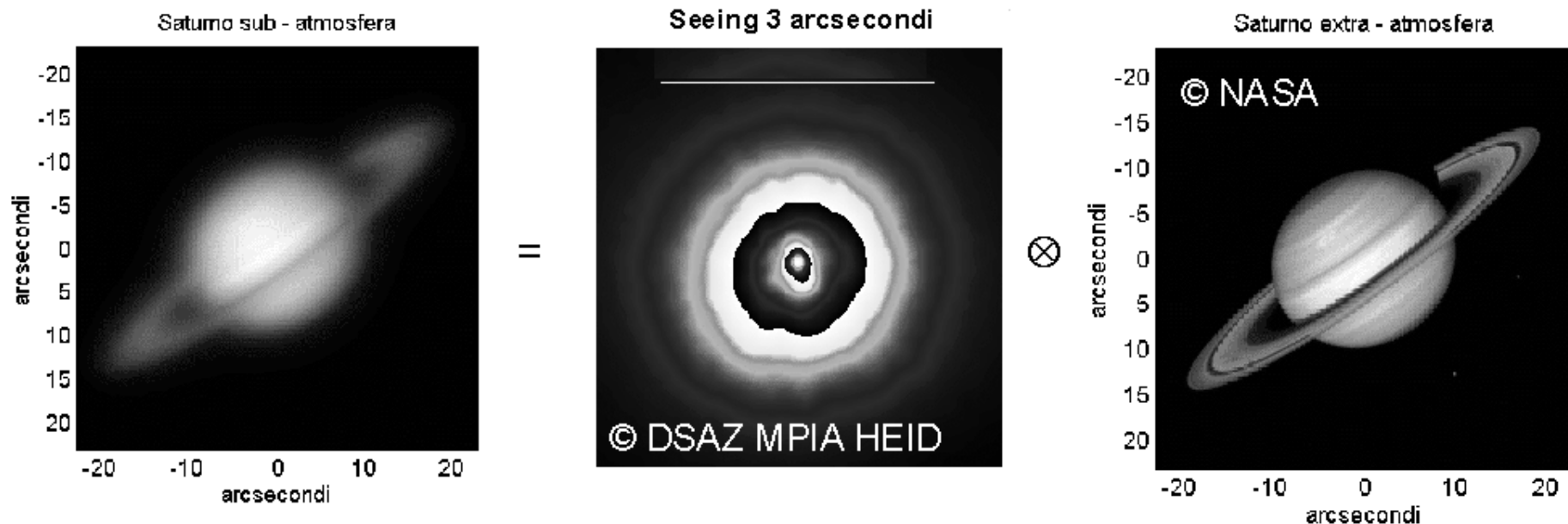
N di N speckles



seeing

immagine a lungo tempo di esposizione
somma di N immagini di breve tempo di esposizione

Convoluzione di oggetto e PSF osservativa



← degrado dovuto alla PSF →

Immagine osservata = Point Spread Function $\otimes$ Oggetto

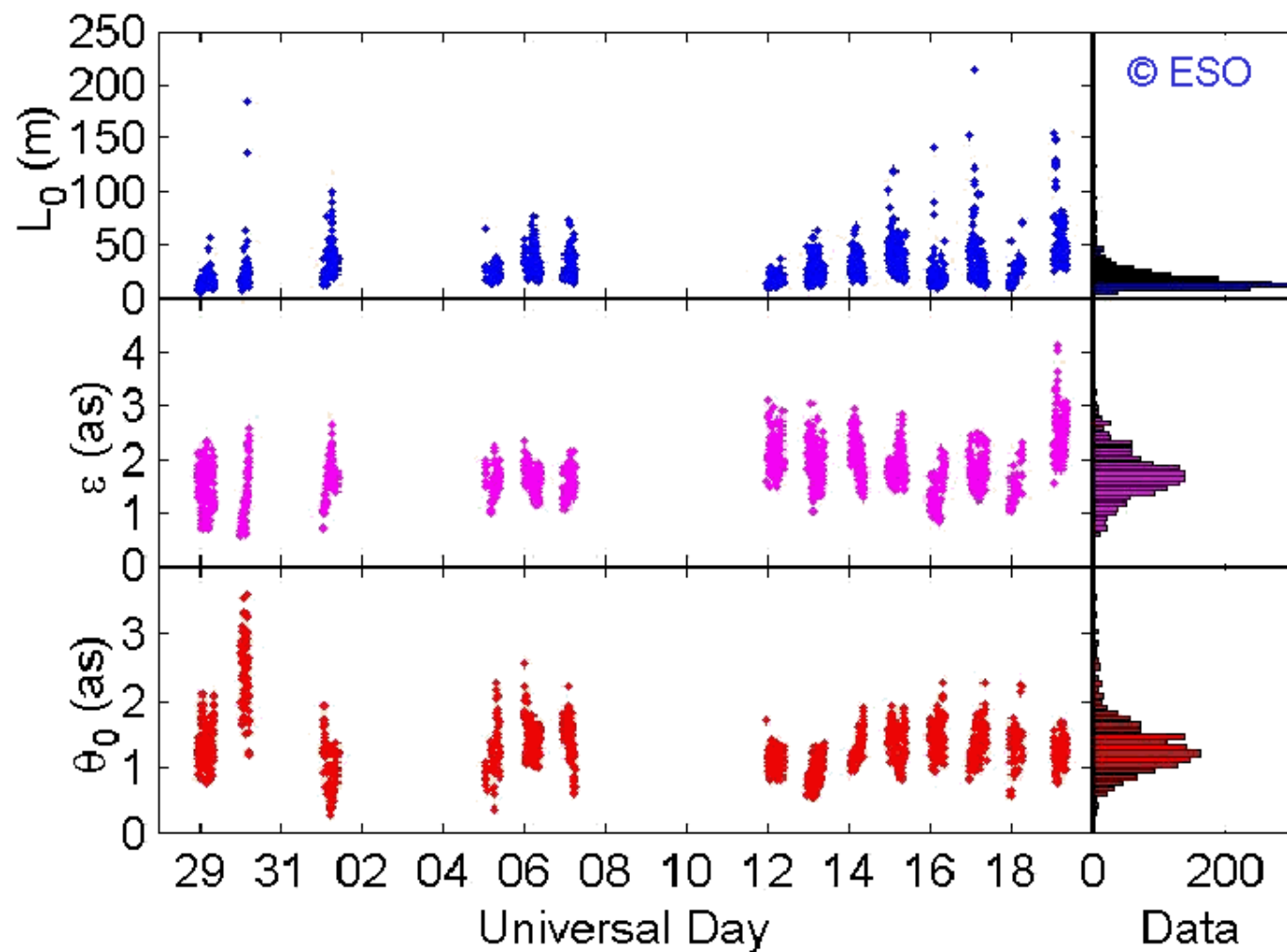
$$I(x,y) = \text{PSF}(x,y) \otimes O(x,y)$$

$$I(x,y) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \text{PSF}(u,v) O(x-u,y-v) du dv$$



Dati osservativi spaziali della turbolenza atmosferica

La Silla



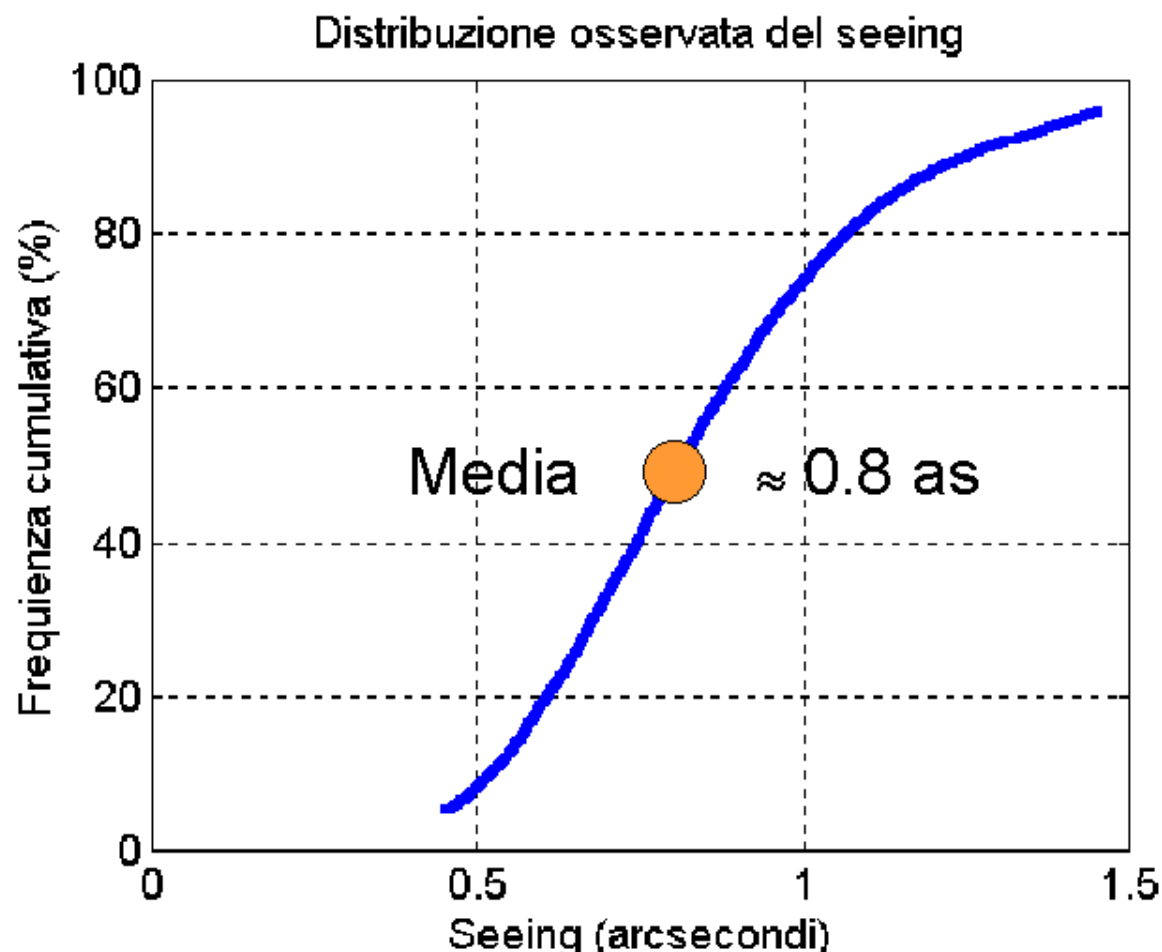
Lunghezza di
scala esterna
 L_0 (m)

Angolo
isoplanatico
(arcsecondi)

Seeing
(arcsecondi)



Dati medi mondiali di seeing astronomico osservati
con il DIMM al di sopra dello strato di inversione
termica dell' atmosfera ($h > 2000$ m)



The Hubble Space Telescope

- The brute force solution: carry the telescope at 400 km, above the atmosphere !



$$\theta \approx 1.22 \frac{\lambda}{D} \approx 1.22 \frac{0.5 \times 10^{-6} m}{2m} \approx 0.06 \text{ arcsec}$$

M51



The Whirlpool Galaxy — M51

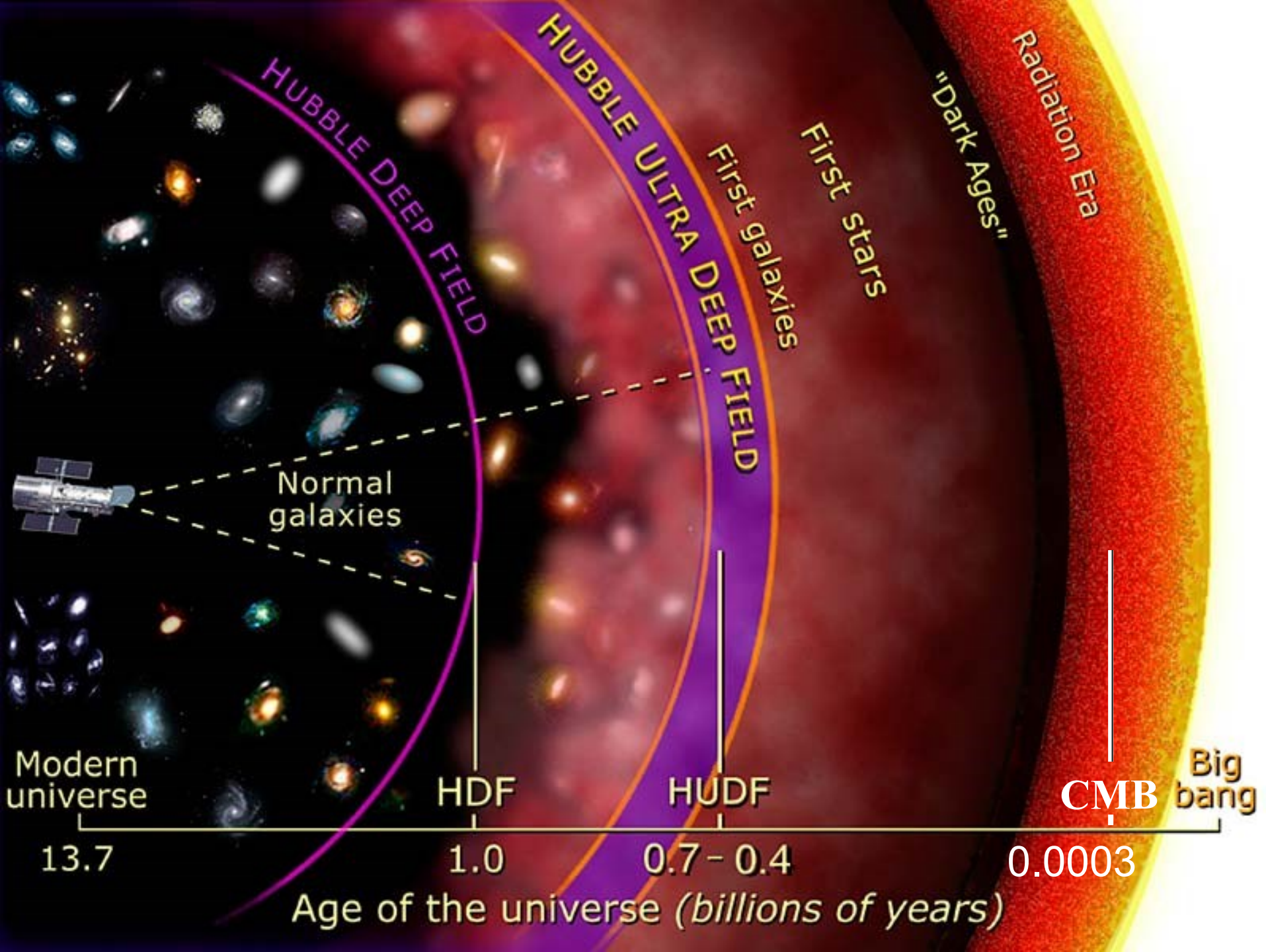


HUBBLESITE.org

V838 Mon

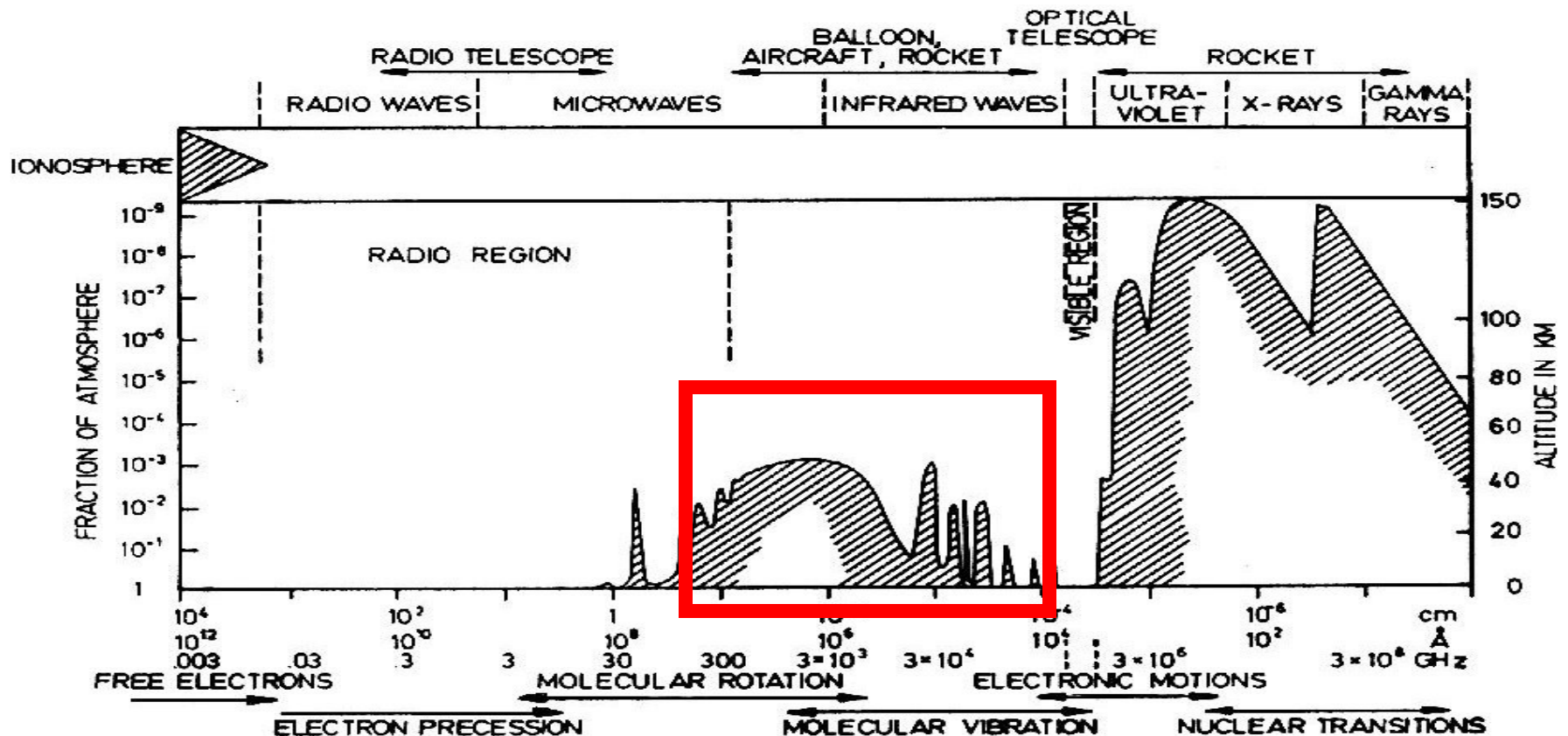






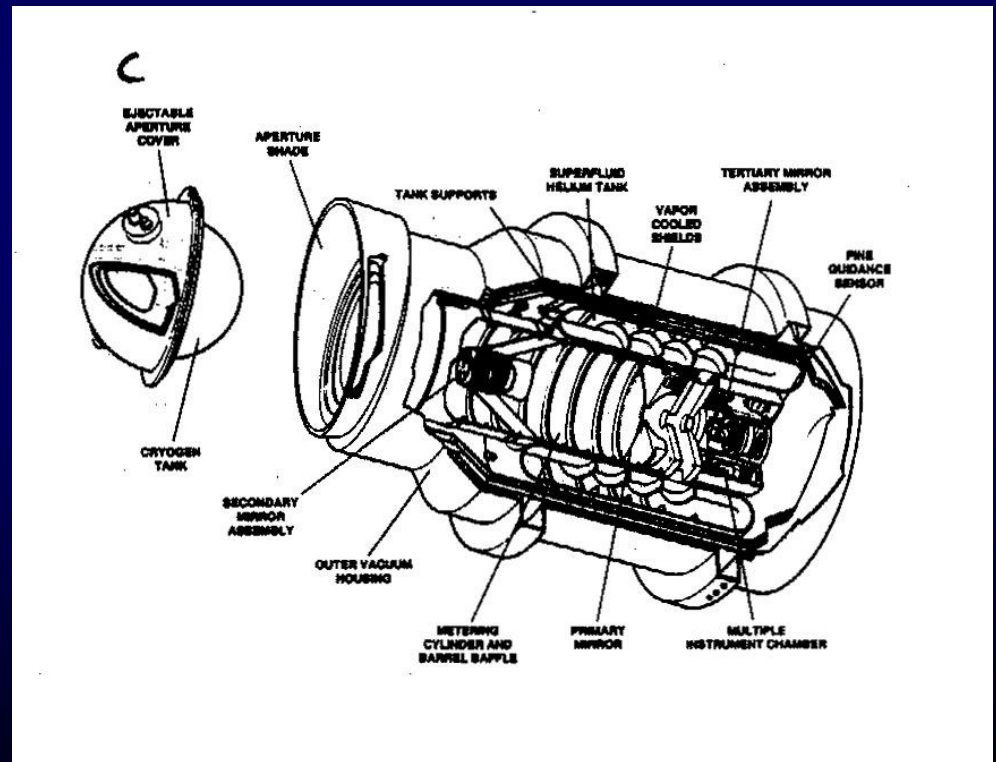
Far Infrared - mm

- The situation here is similar to the situation in the X-rays.
- The Earth atmosphere is simply opaque – all but a few windows open only in extremely cold and dry sites.



Far Infrared - mm

- Qui l' energia dei fotoni è molto bassa (centesimi di eV !)
- C'è quindi l' ulteriore necessità di raffreddare lo strumento (rivelatori e telescopio) a temperature criogeniche.
- Per questo motivo l' astrofisica FIR si è sviluppata addirittura dopo quella X, con osservazioni da pallone prima, e poi con i satelliti a partire dal 1983 (IRAS).
- Satelliti IR-FIR-MM:
- IRAS, COBE, ISO, MSX, SPITZER, WMAP PLANCK,...

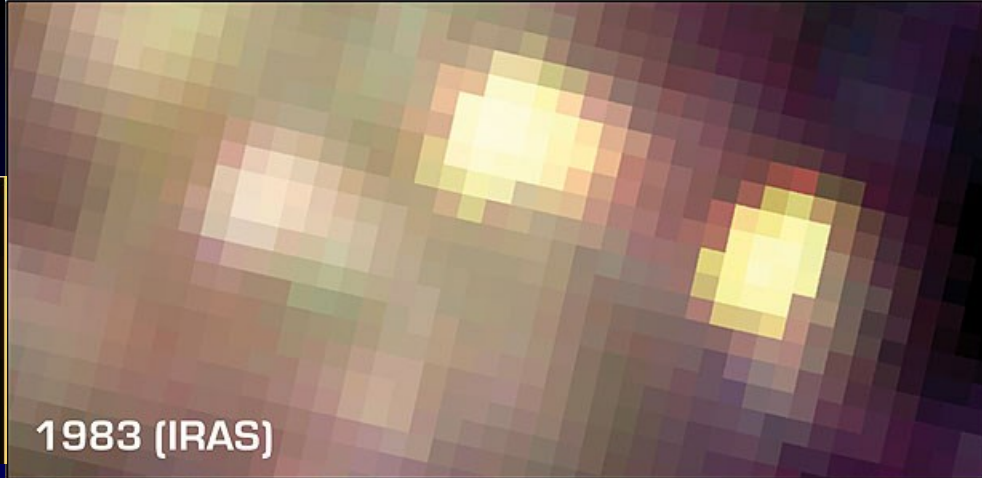


Far Infrared - mm

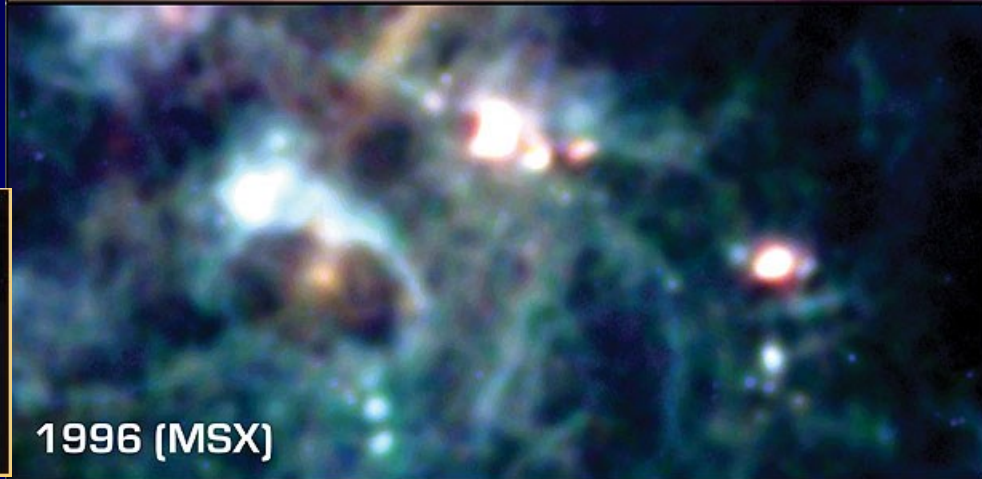
PROGRESSO



1983 (IRAS)



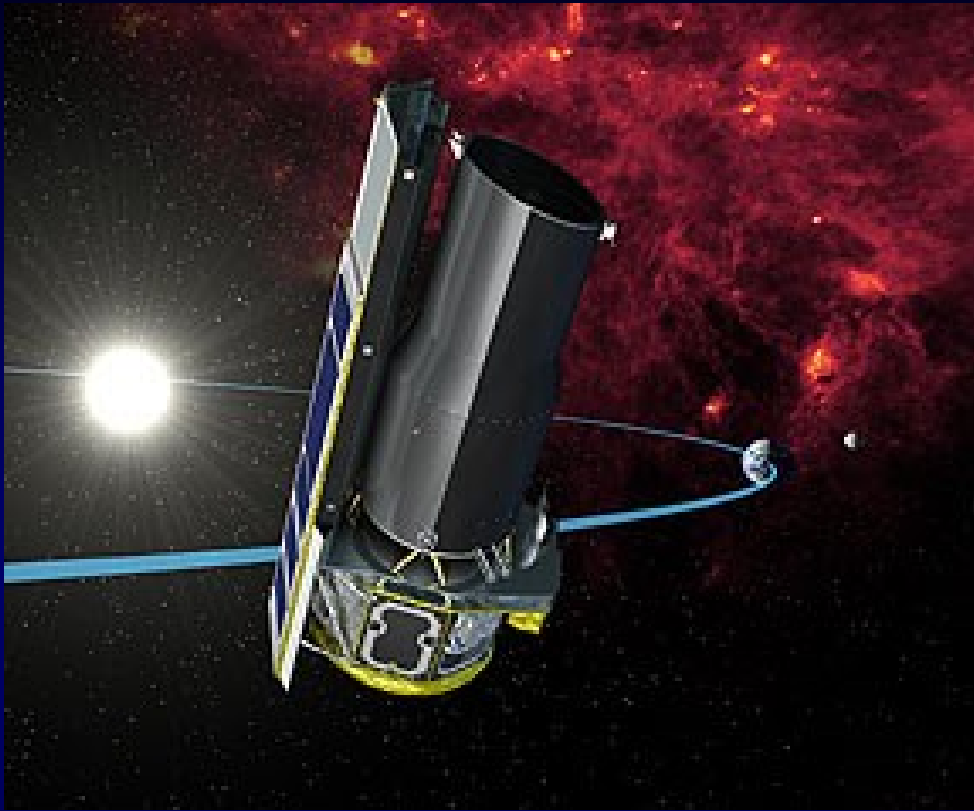
1996 (MSX)



2003 (Spitzer)



Spitzer

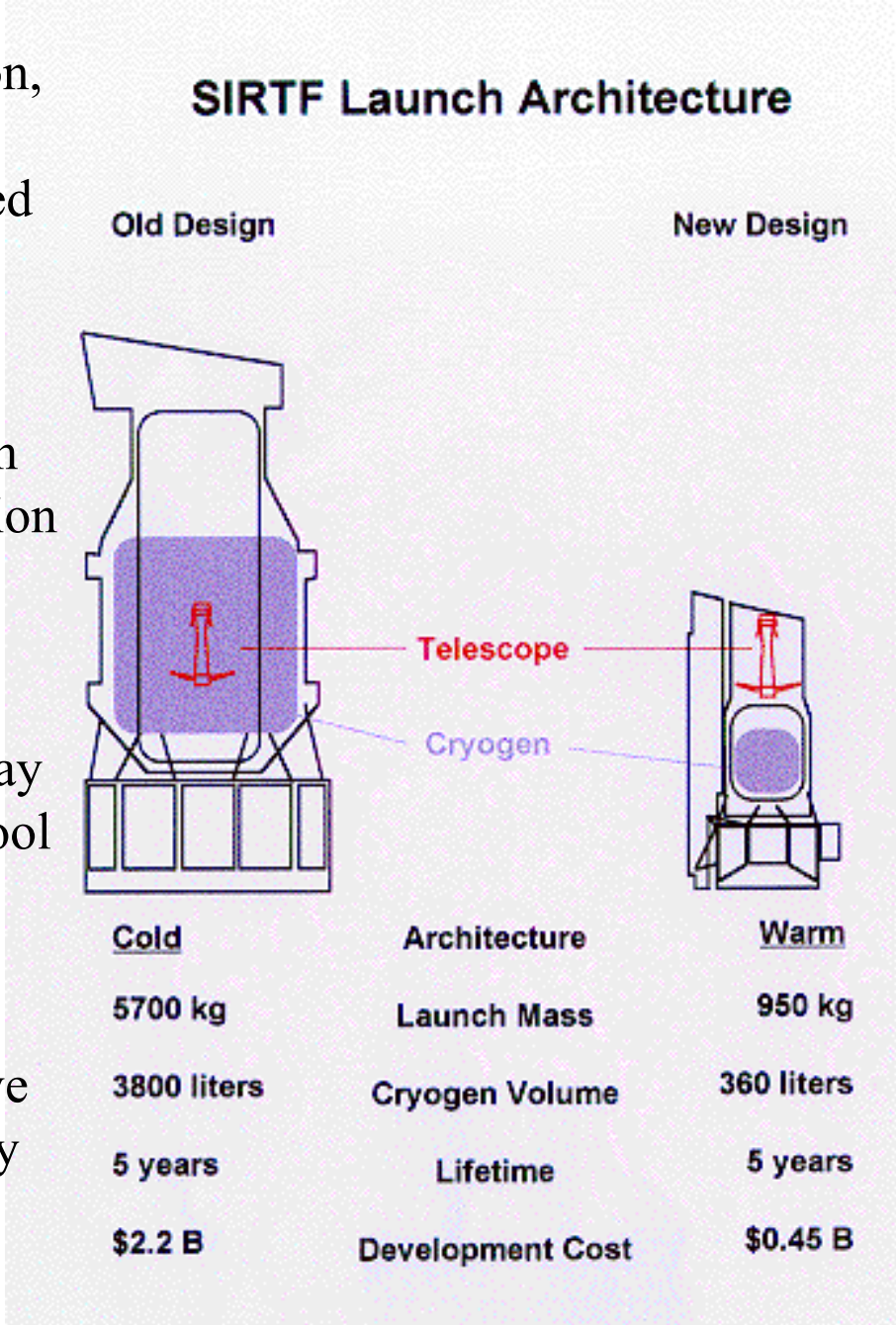


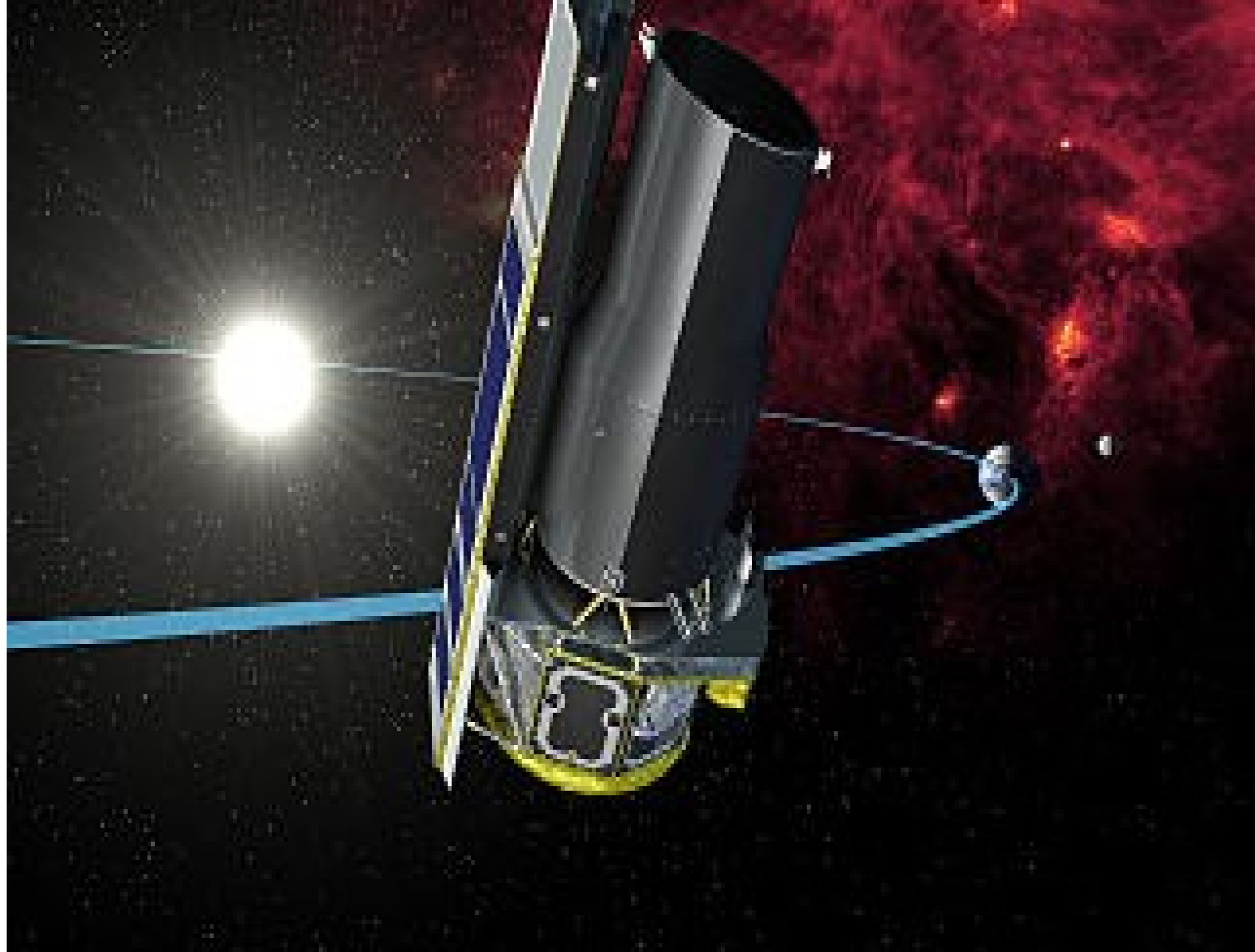
The **Spitzer Space Telescope** was launched into space by a Delta rocket from Cape Canaveral, Florida on 25 August 2003. Supposed to last 2.5-year mission, Spitzer obtained images and spectra radiated by objects in space between wavelengths of 3 and 180 microns. Equipped with a 0.85-meter telescope and three cryogenically-cooled science instruments, (http://www.nasa.gov/mission_pages/spitzer/main/index.html) Note: Spitzer ran out of helium on may 15^o, 2009 (IRAC still works) <http://www.spitzer.caltech.edu/>

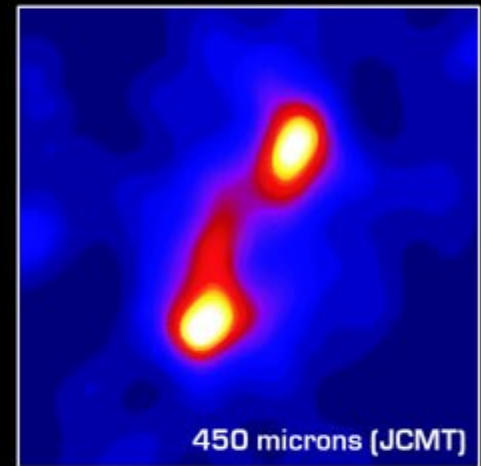
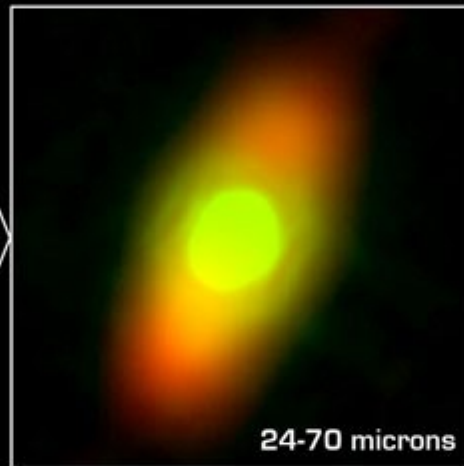
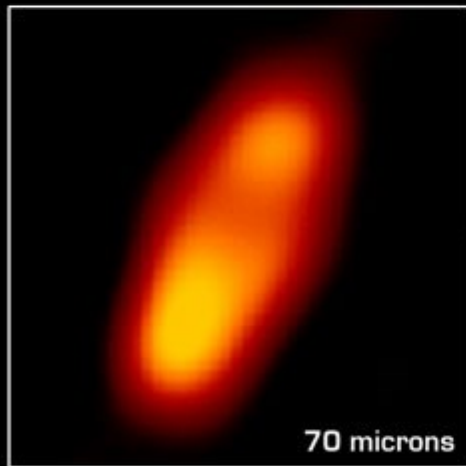
Because infrared is primarily heat radiation, the telescope must be cooled to near absolute zero so that it can observe infrared signals from space without interference from the telescope's own heat.

Also, the telescope must be protected from the heat of the Sun and the infrared radiation put out by the Earth. To do this, Spitzer carries a solar shield and will be launched into an Earth-trailing solar orbit. This unique orbit places Spitzer far enough away from the Earth to allow the telescope to cool rapidly without having to carry large amounts of cryogen (coolant).

This innovative approach, and the radiative cooling of the telescope, have significantly reduced the cost of the mission.





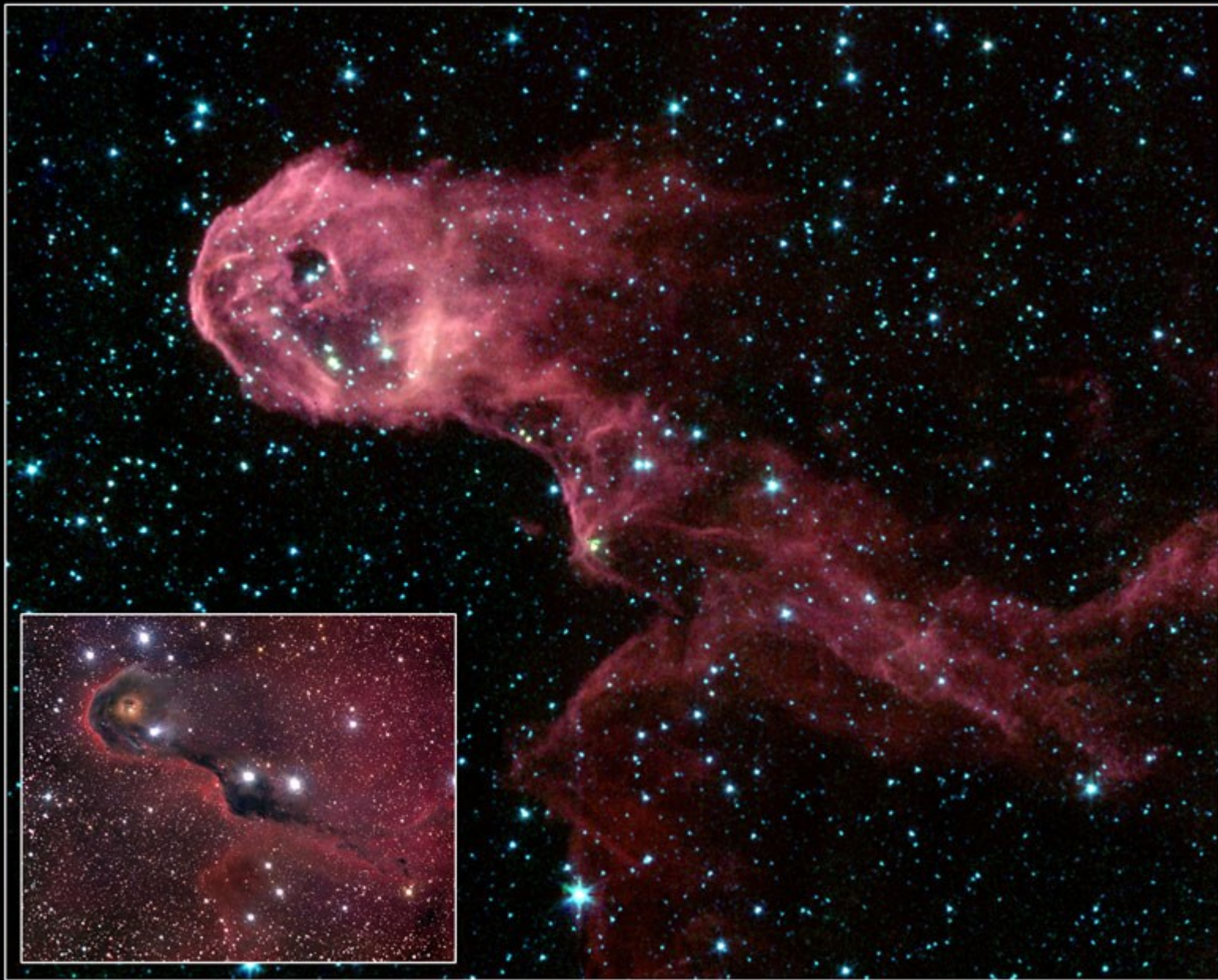


Fomalhaut Circumstellar Disk

NASA / JPL-Caltech / K. Stapelfeldt (JPL)

Spitzer Space Telescope • MIPS

ssc2003-06i



Dark Globule in IC 1396

Spitzer Space Telescope • IRAC

Inset: visible light composite (CFHT & DSS)

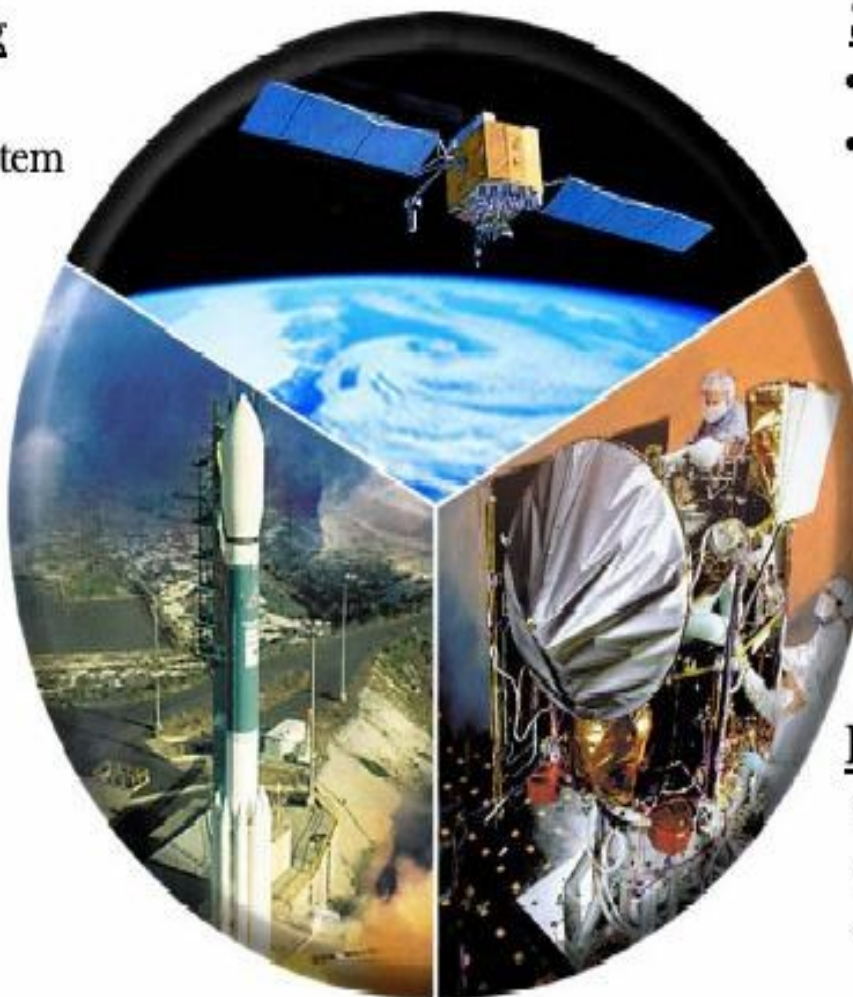
Satellite Industry Overview

Satellite Manufacturing

- Satellite Manufacturing
- Component and Subsystem Manufacturing

Ground Equipment

- Mobile Terminals
- Gateways
- Control stations
- VSATs & USATs
- DBS dishes
- Handheld phones



Satellite Services

- Transponder Leasing
- Retail/Subscription Services
 - Direct-to-home
 - Wireless telephone
 - Data services
 - Direct radio
 - Remote sensing

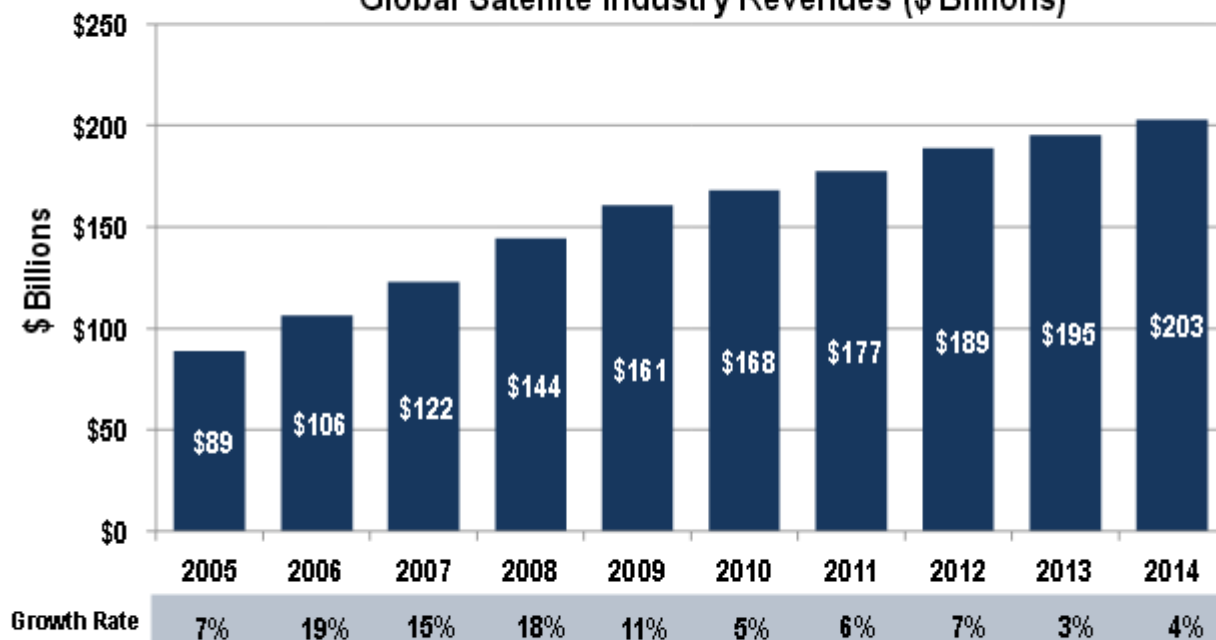
Launch Industry

- Launch Services
- Vehicle Manufacturing
- Component and Subsystem Manufacturing

Global Satellite Industry Revenues



Global Satellite Industry Revenues (\$ Billions)

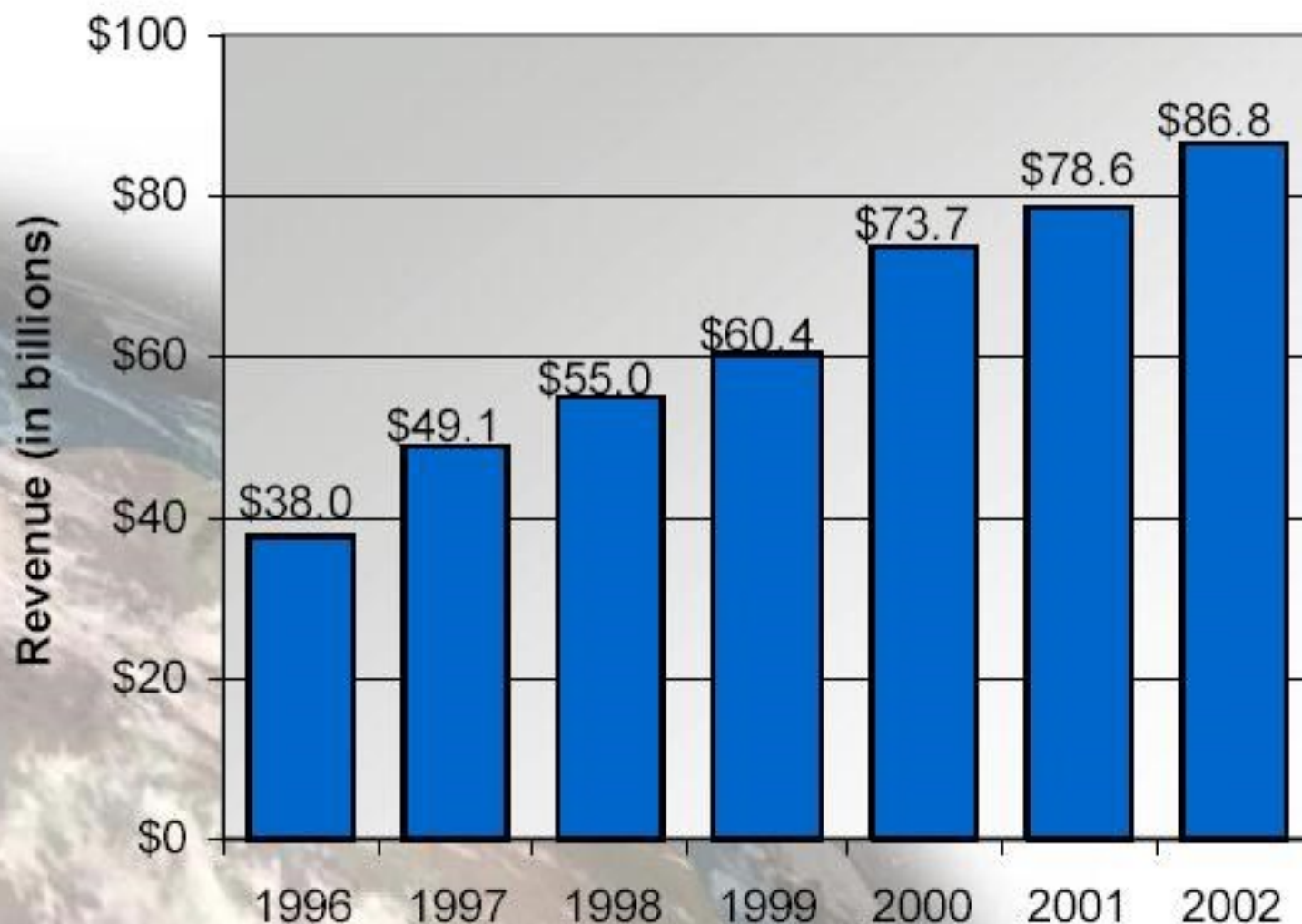


2.3X

Ten-Year
Global Industry
Growth

Global satellite industry grew 4% in 2014, slightly above worldwide economic growth (2.6%) and U.S. growth (2.4%)

World Satellite Industry Revenues



- Fixed satellite services grew by 4%
 - » Revenues for transponder agreements grew 4% compared to no growth in 2013
 - » Revenues for managed services grew 4% compared to no growth in 2013
- Mobile satellite services grew 25%
 - » Mobile satellite voice revenues grew 19%, compared to 11% in 2013
 - » Mobile satellite data revenues grew 27%, compared to 5% in 2013
 - Data services for aviation major contributor to mobile satellite data growth
- Earth observation services revenues grew 9%
 - » Continued growth by established satellite remote sensing companies, with government sales driving demand
 - » New entrants continued to raise capital, develop satellites, and deploy initial constellations

- **Keys to success for today's satellite broadband:**
- **Comparable to terrestrial**
 - » Comparable to cable and fiber in terms of speed and price
 - » Available nationwide, not just in select areas
- **Maturation and combining of advanced technologies** (frequency reuse, spot beams, and on-board processing) defined new, high throughput satellites (HTS)
- **Substantial reduction in cost per unit of throughput**
- **Growing demand and customer confidence due to high data rates and reliable service**
 - » Satellite broadband operator ranked first in peak period download speeds among 14 terrestrial and satellite broadband providers in the FCC 2013 and 2014 reports "Measuring Broadband America"

1990s

- Large constellations proposed, all canceled
- Expensive technology
- Cost-effective terrestrial competition

2000s

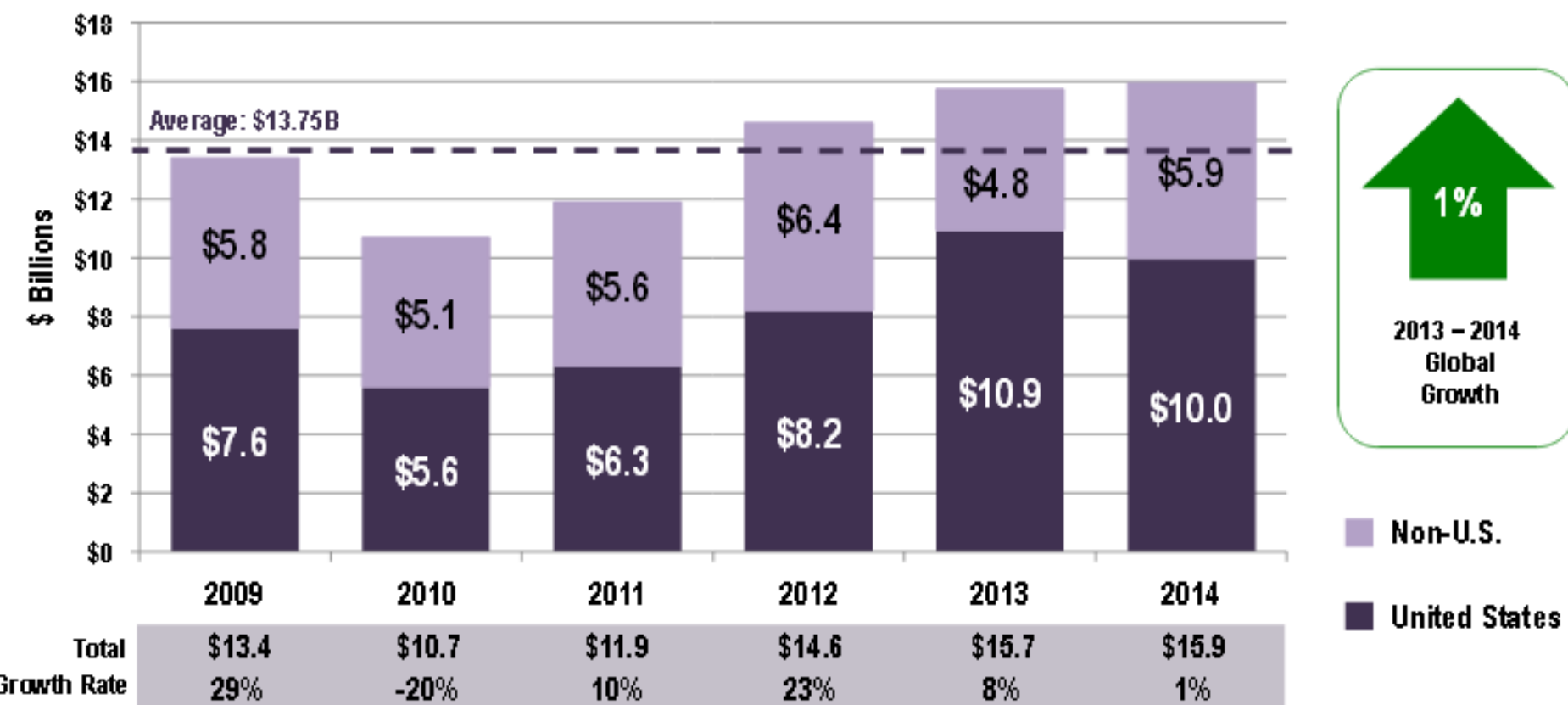
- Smaller regional systems proposed and deployed
 - » Wildblue
 - » Spaceway
- Technical success, test bed for new technologies, bandwidth cost reduction
- Acquisitions by established players

Present

- Five major systems today and expanding:
 - » Eutelsat Tooway, HughesNet, ViaSat Exede, Inmarsat Global Xpress, O3b
- Four providers affiliated with established satellite operators (DTH, FSS, or MSS)
- 50% revenue growth over 5 years
- Subscribers grew 14% annually, tracking the revenue growth



Satellite Manufacturing Revenues



- Worldwide 2014 revenues totaled \$15.9 billion
- U.S. share of global revenues was 63%, a decrease from 69% in 2013

NOTE: Satellite manufacturing revenues are recorded in the year the launch was conducted.



Case Study: Very Small Satellites



Continued and growing interest in inexpensive very small satellites

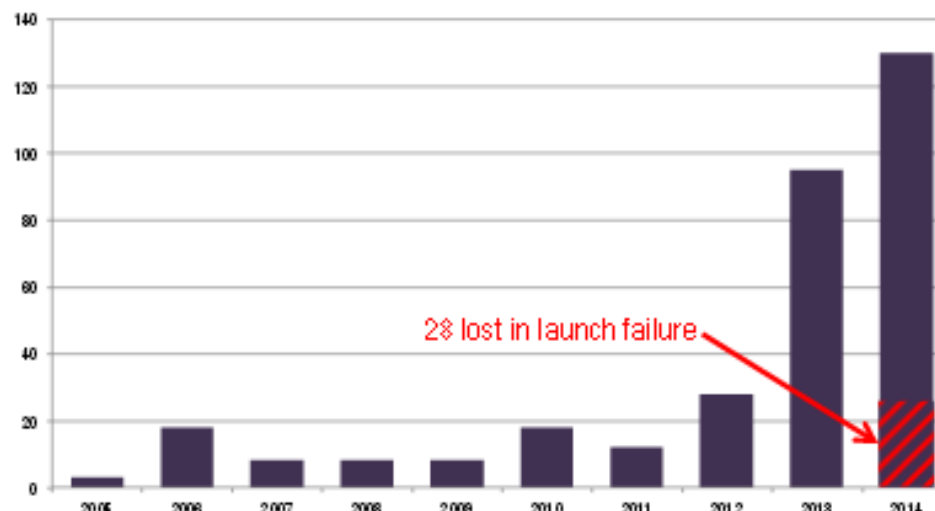
CubeSats are an established “kit” form of very small satellite in use for academic, government, and, increasingly, commercial purposes

- ✧ 130 CubeSats were launched in 2014, up from 91 in 2013, with 28 sent into orbit via ISS (28 CubeSats lost in Antares failure in October)
- ✧ 101 commercial CubeSats launched in 2014 for Earth observation services and communications, up from 8 in 2013. The vast majority (93) are built and operated by Planet Labs
- ✧ Total expenditure to build all CubeSats since 2005 estimated at less than \$100M
- ✧ Growing concern regarding collisions with CubeSats – NASA first major operator to say it has moved satellites to avoid CubeSats

Commercial constellations using customized very small satellites (under 200 kg) are in development

- ✧ Skybox: High resolution, multispectral sensors, up to 24 sats planned, 2 launched to date
- ✧ OneWeb: Telecommunications, function more as nodes compared to traditional comsats, 100s of satellites planned, zero launched to date

Number of CubeSats Launched by Year (2005-2014)



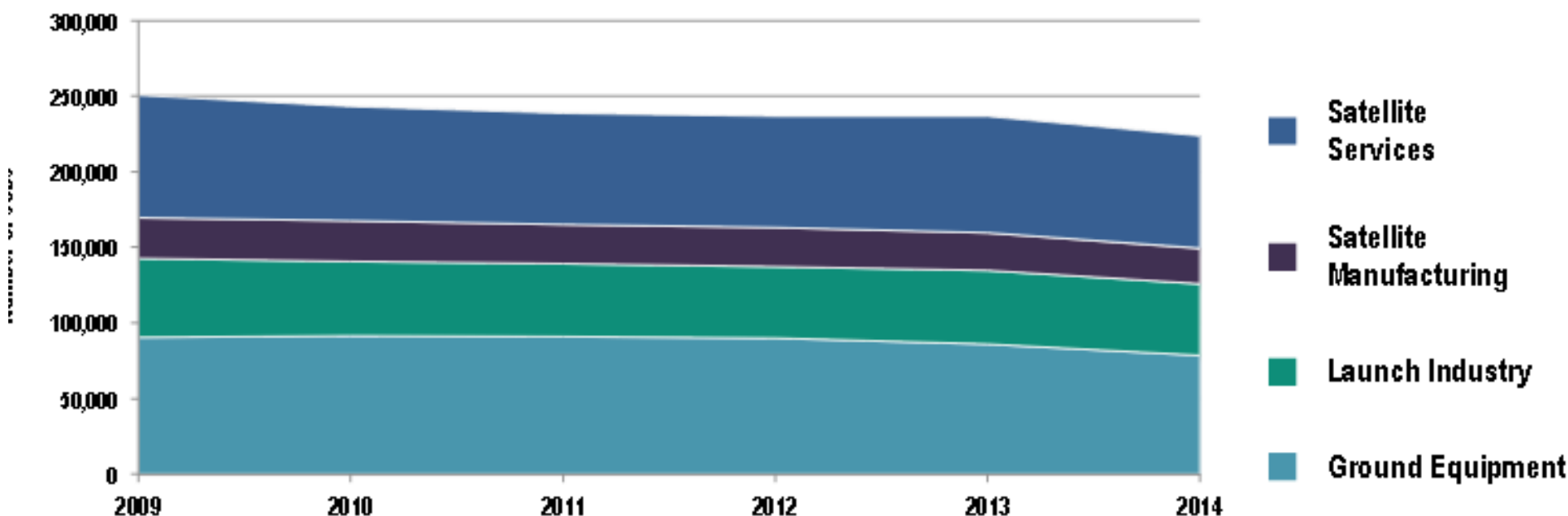
What is a CubeSat?

- A CubeSat is a cube-shaped satellite bus measuring 10cm on a side, with a mass of 1-2 kilograms
- Can be stacked together (2U, 3U, 6U) depending on mission
- Costs
 - ✧ **Low Cost:** Basic 1U Cube Sat bus kits can be purchased for \$10,000; with payload development it will cost roughly \$100,000 per unit
 - ✧ **Moderate Cost:** Boeing-built CubeSat platforms for NRO are expected to cost no more than \$250,000
 - ✧ **Higher Cost:** NASA expects that CubeSats used for planetary science missions may cost \$3-\$10 million

2014 U.S. Employment Estimates (Private Sector Employment Only)

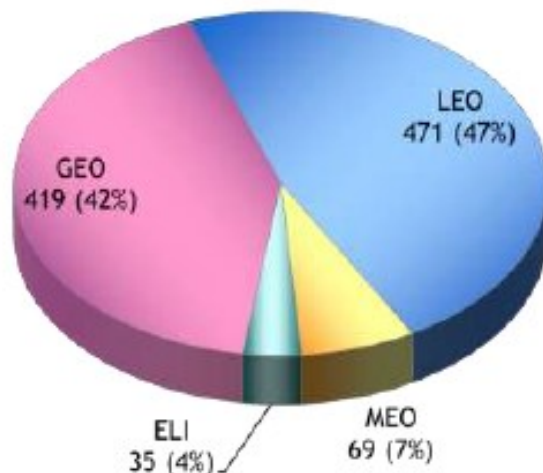


- In 2014, satellite industry employment in the U.S. decreased by 13,289 jobs (-6%)
- Four of the satellite industry segments lost jobs as of 2014 (compared to 2013)
 - » Satellite Services employment decreased by 3,060 jobs, or -4% (2013: +5%)
 - » Satellite Manufacturing employment decreased by 1,508 jobs, or -6% (2013: -4%)
 - » Launch Industry employment decreased by 1,071 jobs, or -2% (2013: +2%)
 - » Ground Equipment employment decreased by 7,650 jobs, or -9% (2013: -4%)



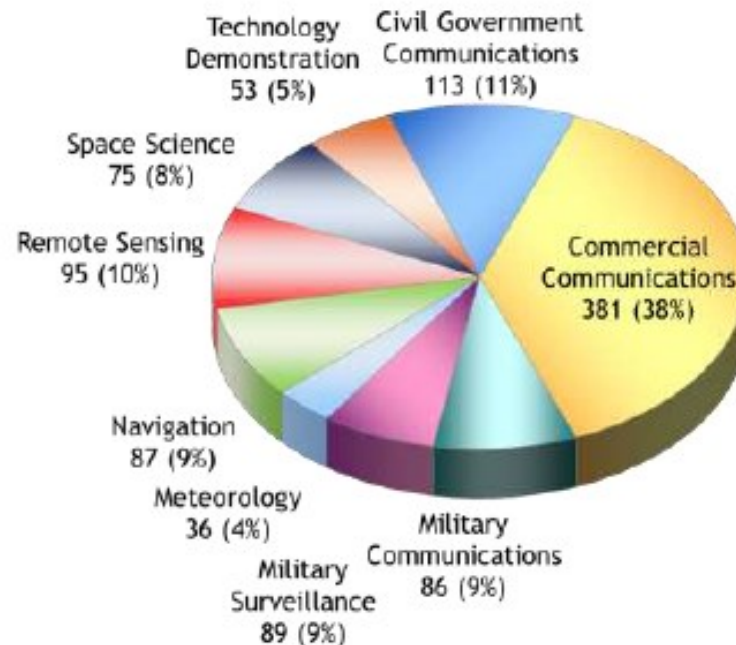
The Satellite Network in Context

Operational Satellites (May 2012)
By Orbit



LEO = Low Earth Orbit
MEO = Medium Earth Orbit
ELI = Elliptical Orbit
GEO = Geosynchronous Orbit

Operational Satellites (May 2012)
By Function



- Of the 994 satellites on orbit, 38% are commercial communications satellites
 - An additional 20% are civil government or military communications satellites
 - The relative proportion comprised by communications satellites remained consistent from 2011 to 2012