

Payload module

IBIS coded mask

JEM-X coded mask

OMC

SPI

Instrument computers
and electronics

IBIS detector

JEM-X detectors

Power regulation

Reaction wheels for
pointing the spacecraft

Data handling and
telecommunication

SPACE INSTRUMENTATION for ASTROPHYSICS

Instrument computers
and electronics

Detector bench

Attitude control
electronics

Batteries

Fuel tanks

Attitude sensors

Service module

solar panels

Emrah Kalemci
Sabancı University

12 - 13 October 2006, Ankara

Sabancı
Üniversitesi

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MOTIVATION

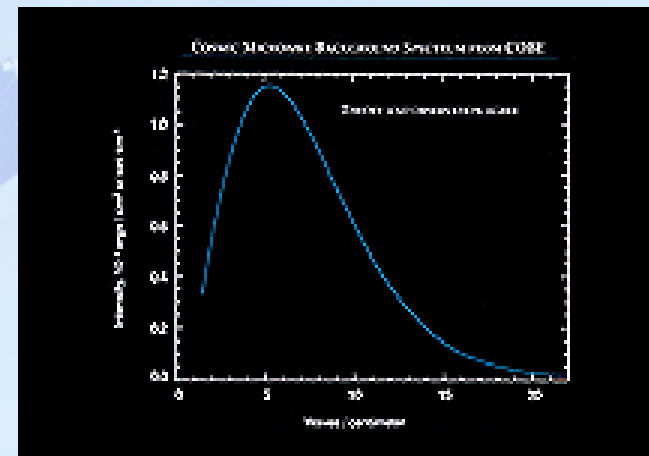
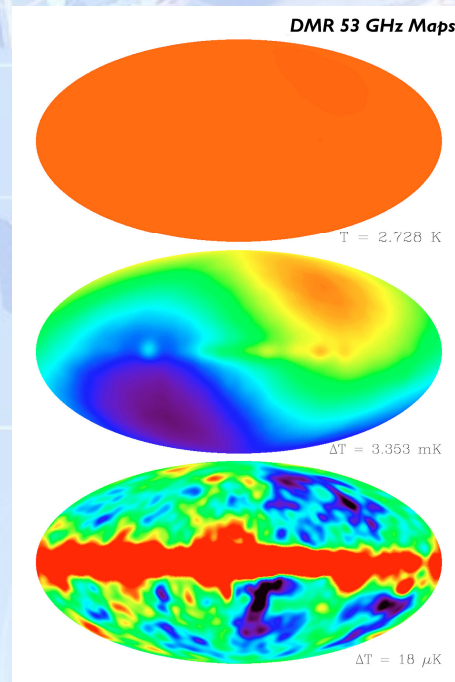
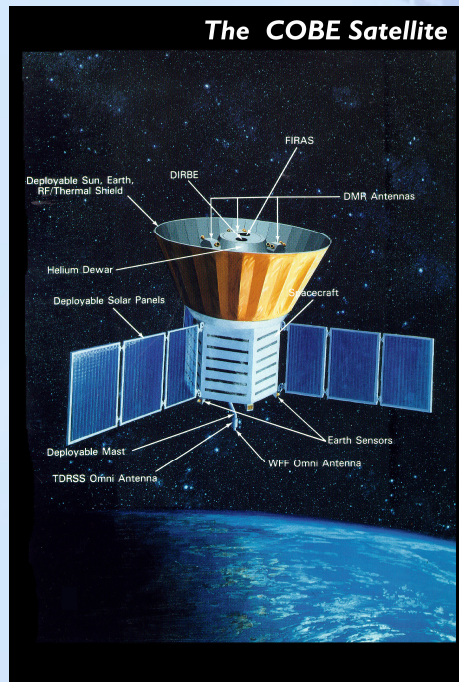
- Space instrumentation:

- Pays well (can earn up to 1.4 M\$)
- Gives you fame and fortune.

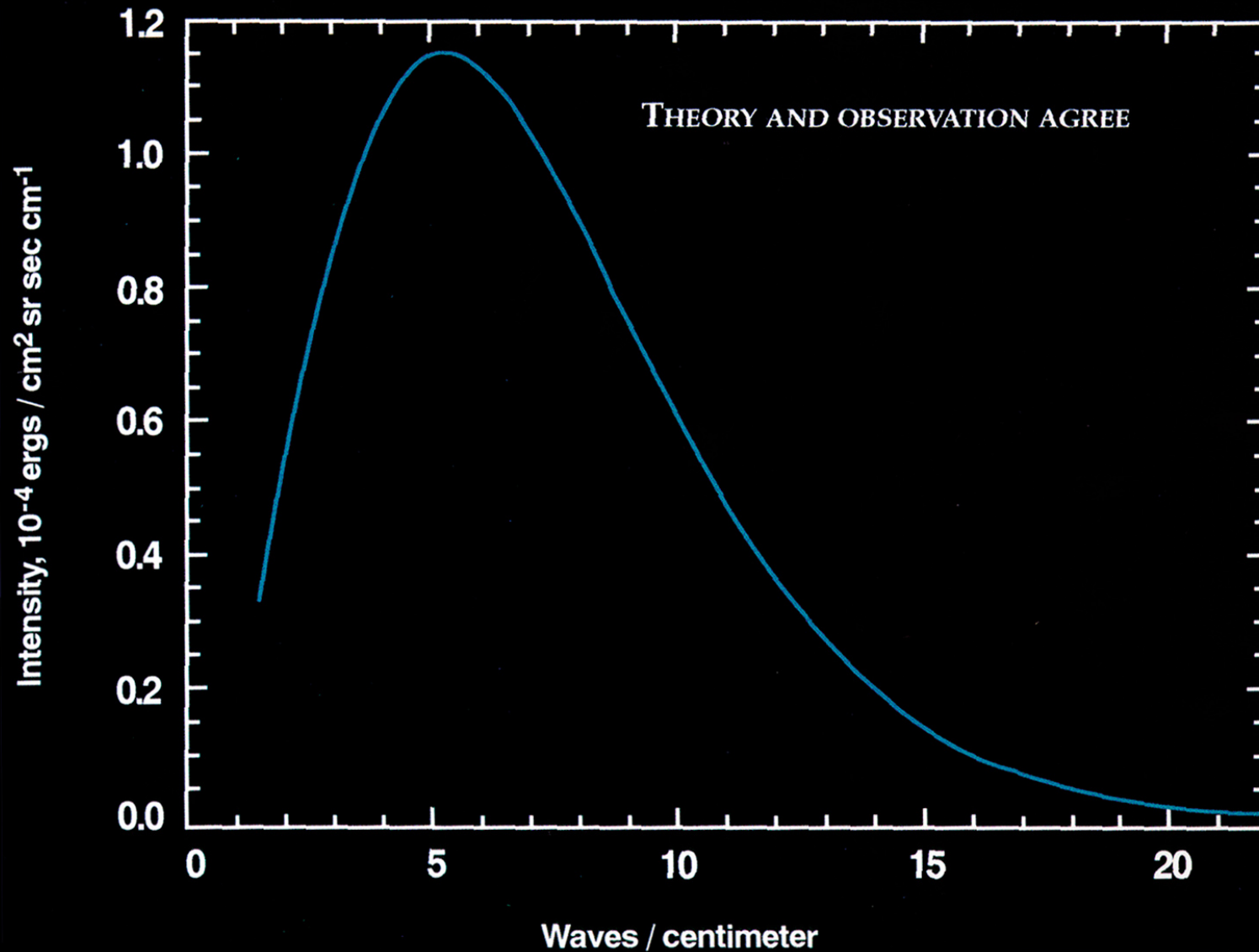
Star trackers

Instrument computers and electronics

2006 Nobel Prize in Physics is given to John C. Mather and George F. Smoot. In 2002, it was Riccardo Giacconi, the father of X-ray satellites.



COSMIC MICROWAVE BACKGROUND SPECTRUM FROM COBE



Crisp imaging, better spectrum.

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Other motivations

IBIS coded mask
JEM-X coded mask
OMC

- **Look up:** Study interesting astrophysical objects and phenomena.
- **Look around:** Atmospheric and magnetospheric studies, solar system.
- **Gather and smash:** Dust and particles from comets, magnetosphere, smash into comets, planets.

• Look down:

Weather Defense Agriculture Telecom GPS ...

Data handling and telecommunication

Service module

solar panels

Star trackers

Instrument computers

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OUTLINE

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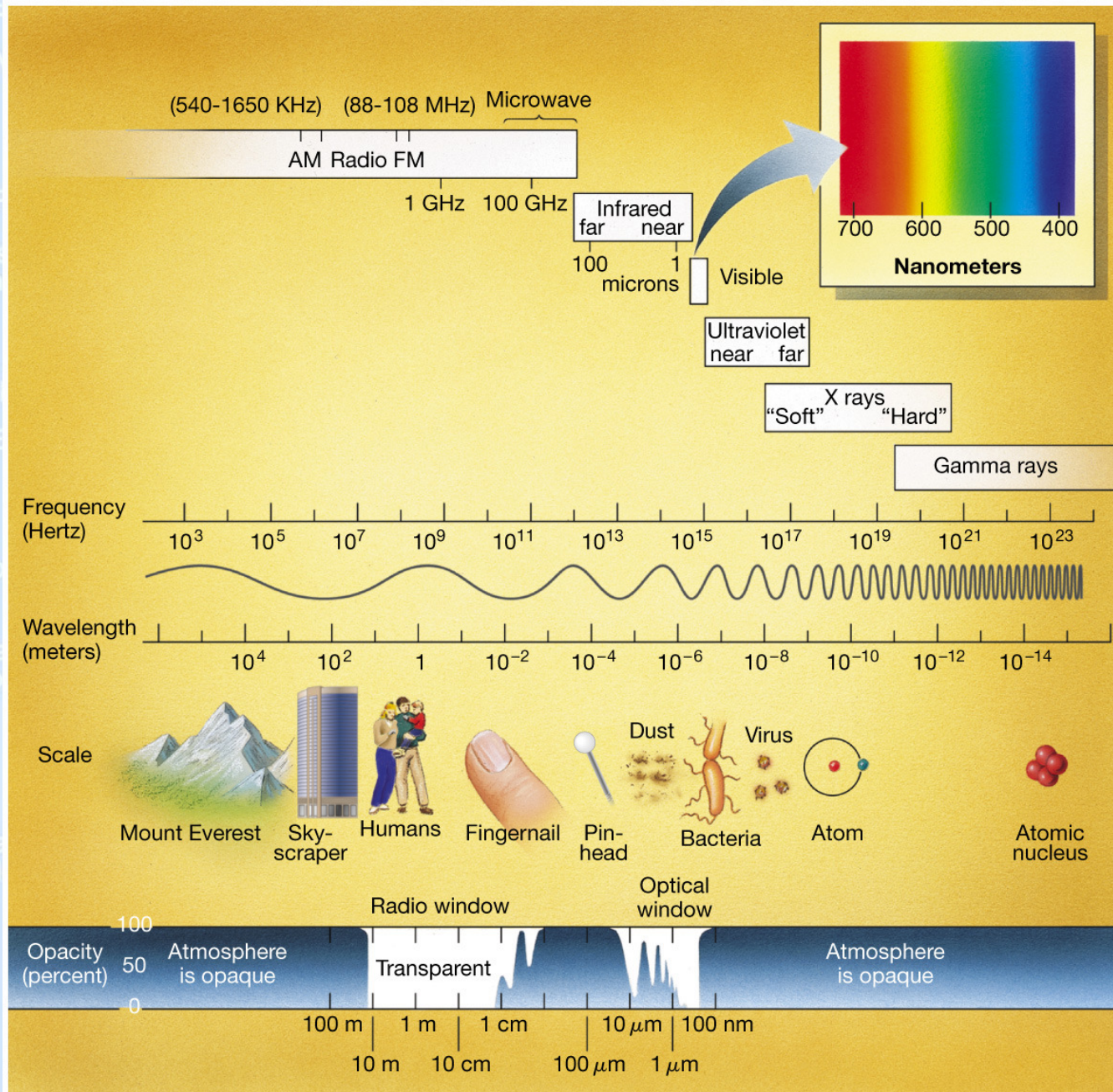
Attitude sensors

solar panels

- Why space astronomy?
- How to reach above the atmosphere?
- Orbits.
- Wavelength vs detector.
 - IR to UV, X-rays, Gamma-rays
- Alternative applications of the technology.
- Future of astrophysical space instrumentation and Turkey's position.

Space based astronomy

IBIS coded mask

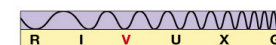
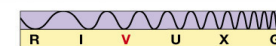
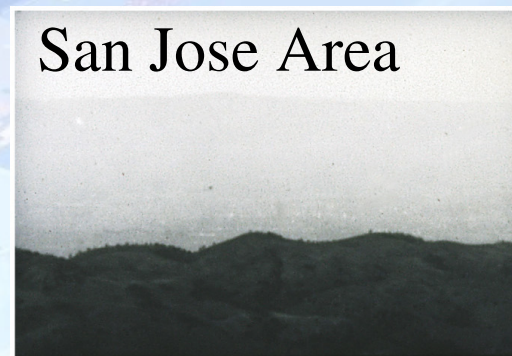


The window for ground based astronomy is limited, one can work in the optical band and in the radio band.

But for most of the electromagnetic spectrum, the atmosphere is opaque, and the instruments need to be carried above the atmosphere.

Why space astronomy, the astrophysical perspective

- **Infrared:** Penetrate through gas and dust ($100\ \mu\text{m} - 1\ \mu\text{m}$):
 - Star formation, center of the Milky Way galaxy, active galaxies, large scale structure of the universe (cosmology), jets.



Why space astronomy, the astrophysical perspective

IBIS coded mask

JEM-X coded mask

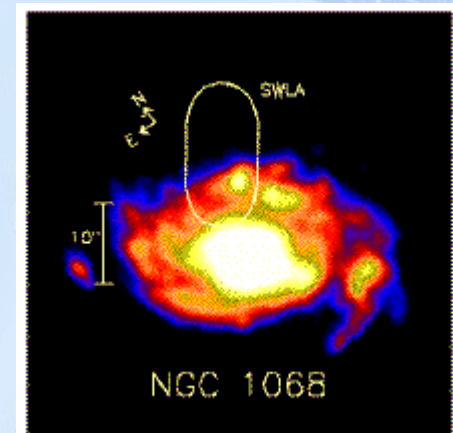
OMC

SPI

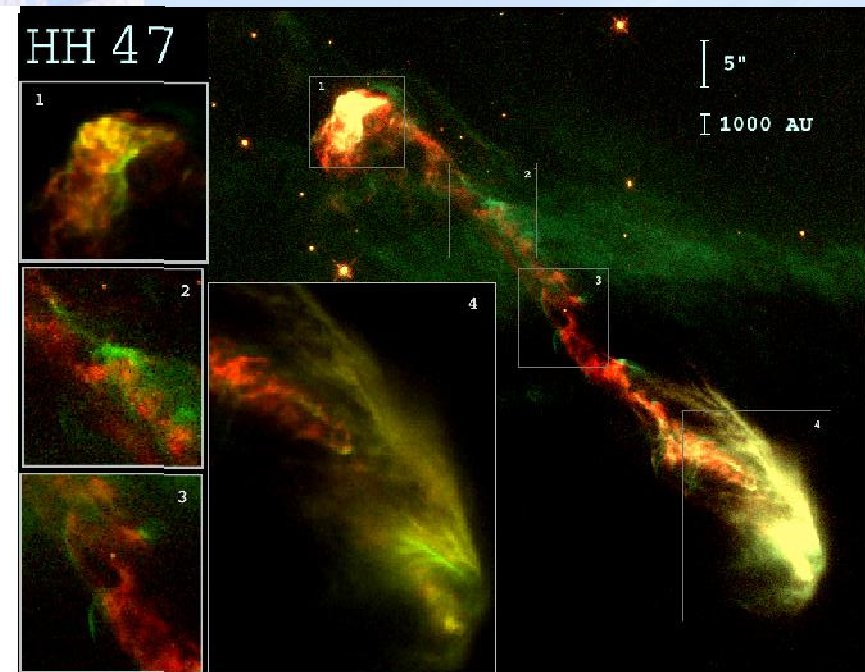
Instrument computers and electronics

IBIS detector

JEM-X detectors



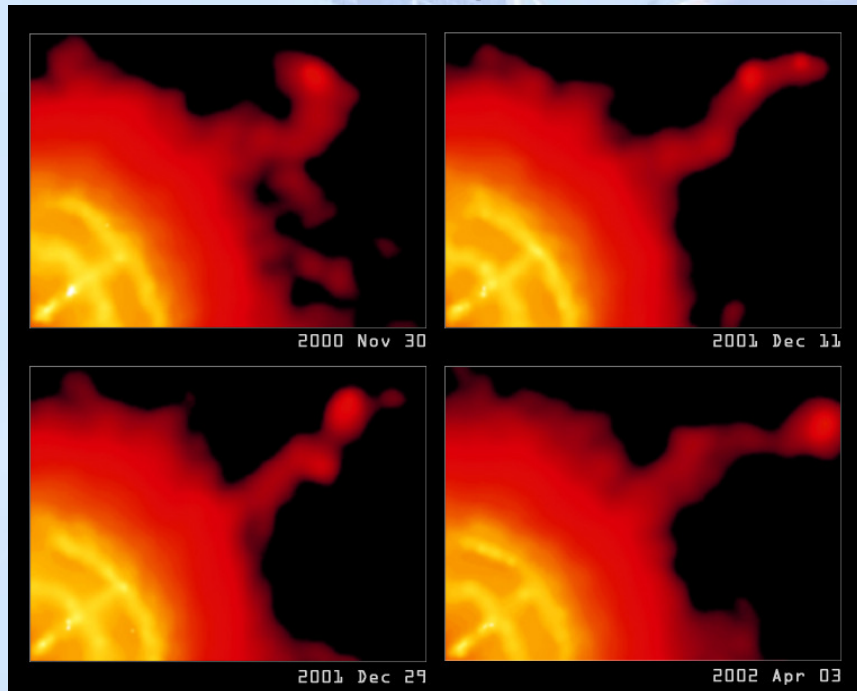
An AGN in UV.



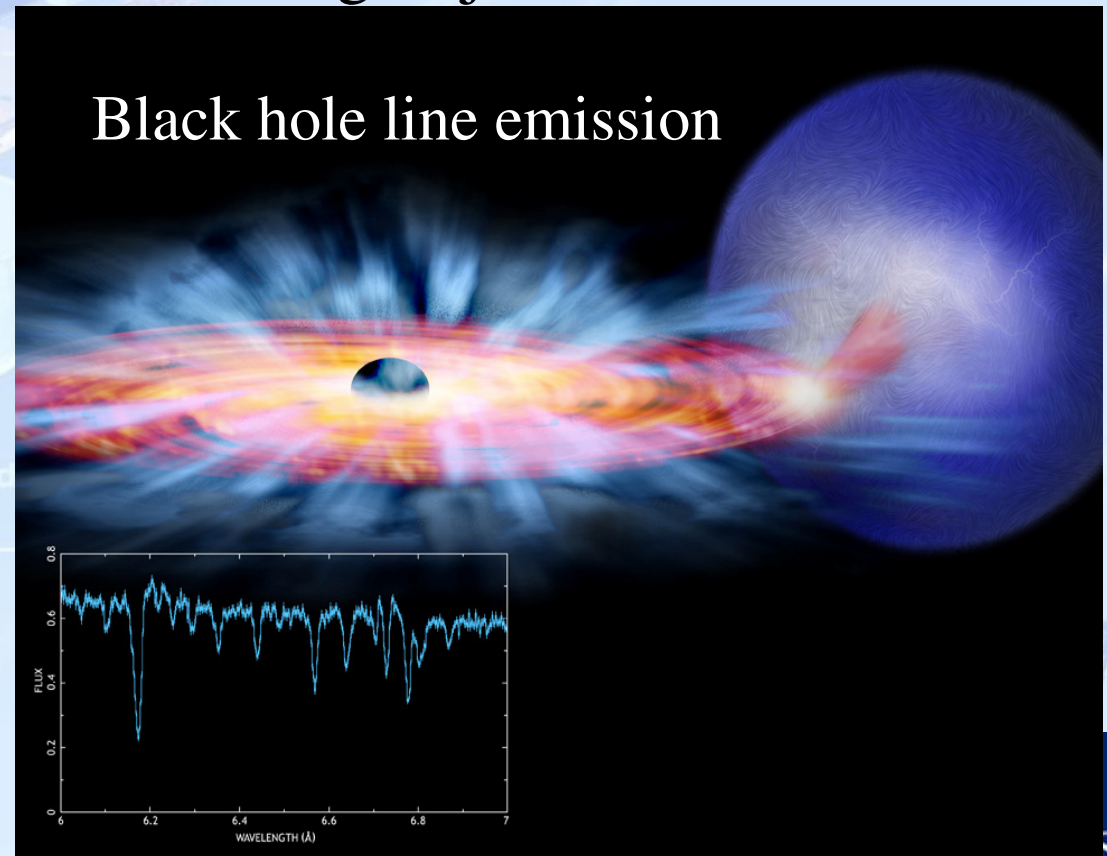
FUSE image of an AGN.

Why space astronomy, the astrophysical perspective

- X-rays (1keV - 200 keV): Energetic and penetrating (3 nm – 0.03 nm):
 - Stellar atmospheres, neutron stars and black holes, active galactic nuclei, intra-cluster hot gas, jets, GRB afterglows.

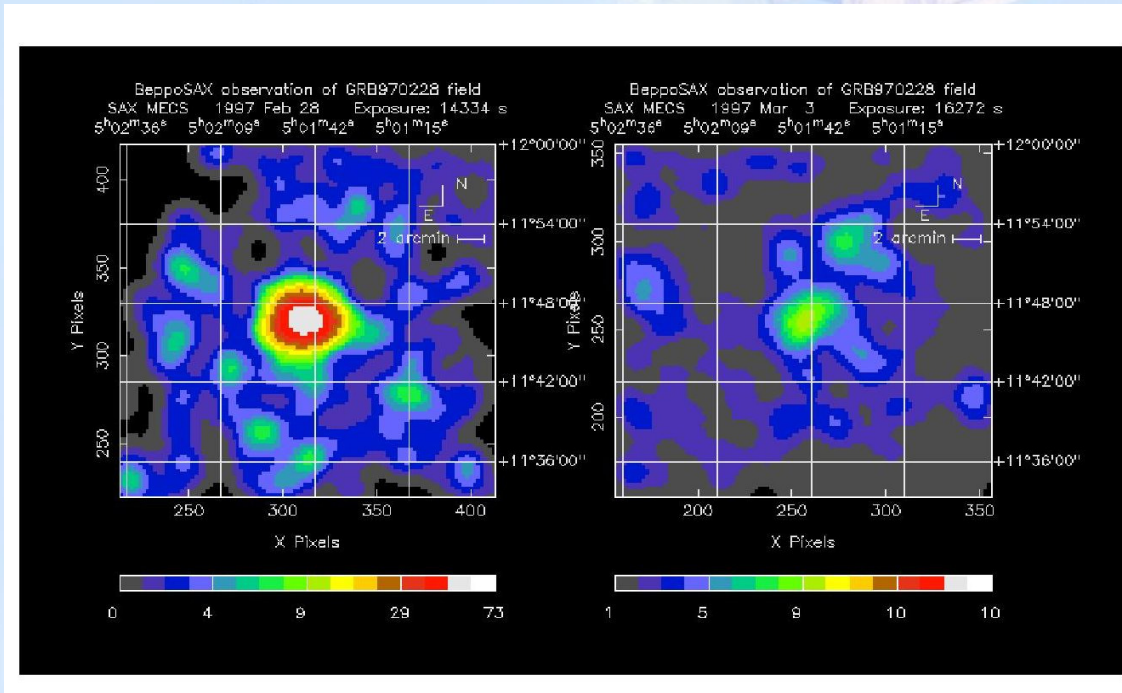


Vela powering its nebula and a jet

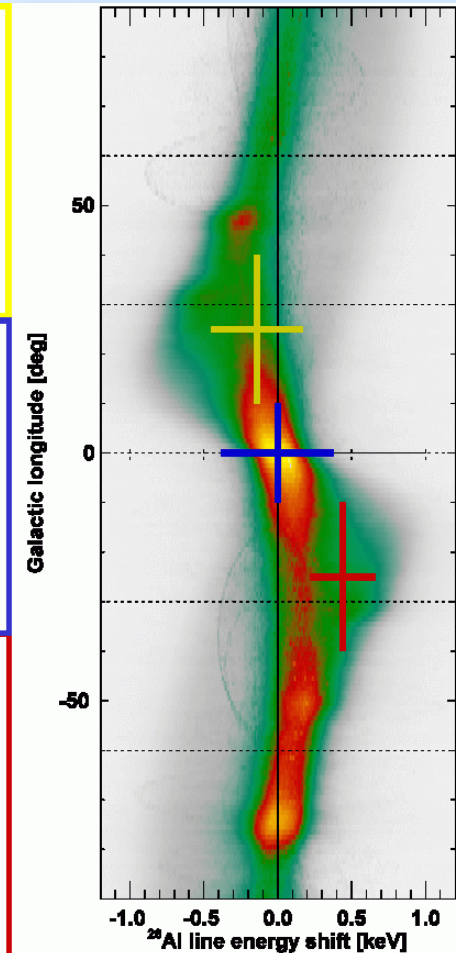
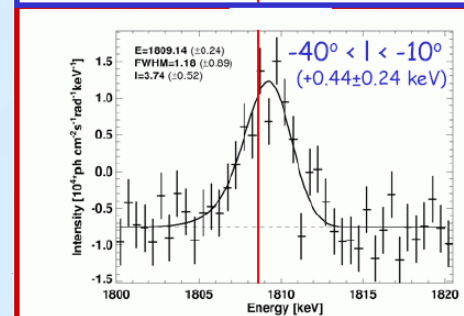
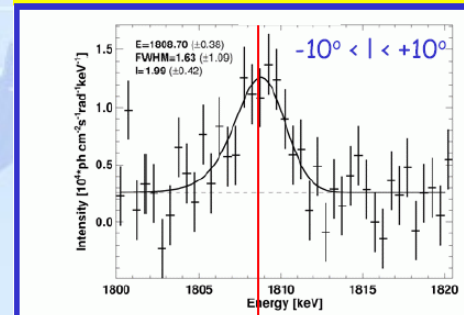
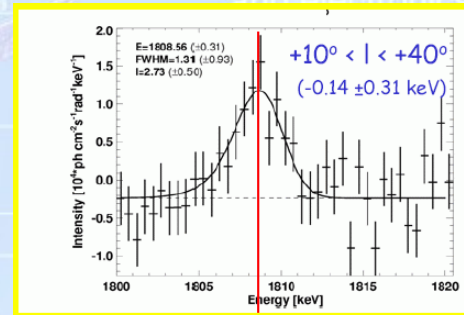


Why space astronomy, the astrophysical perspective

- Gamma-rays (> 200 keV):
 - Neutron stars, black holes, gamma-ray bursts, nucleo-synthesis.



Beppo-Sax detection of the host galaxy of a GRB.



HOW TO REACH ABOVE the ATMOSPHERE:



Ballooning



Sounding rockets

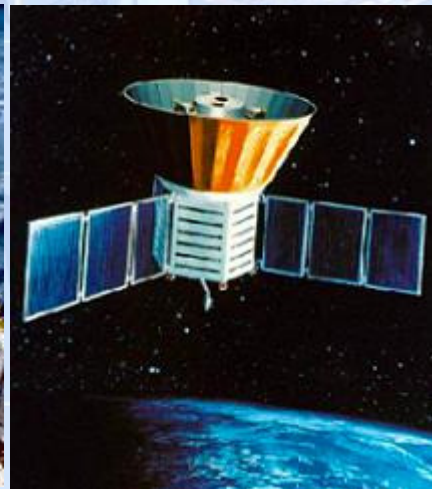


Specially designed planes

HUBBLE is the only servicable satellite!!!



On space stations



Satellites, like COBE !



NICMOS on HUBBLE



SPITZER satellite

Ballooning:

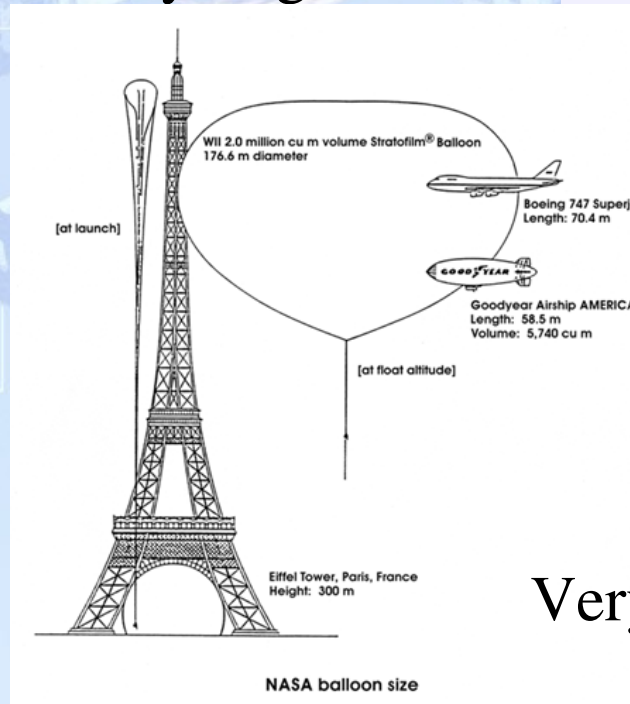
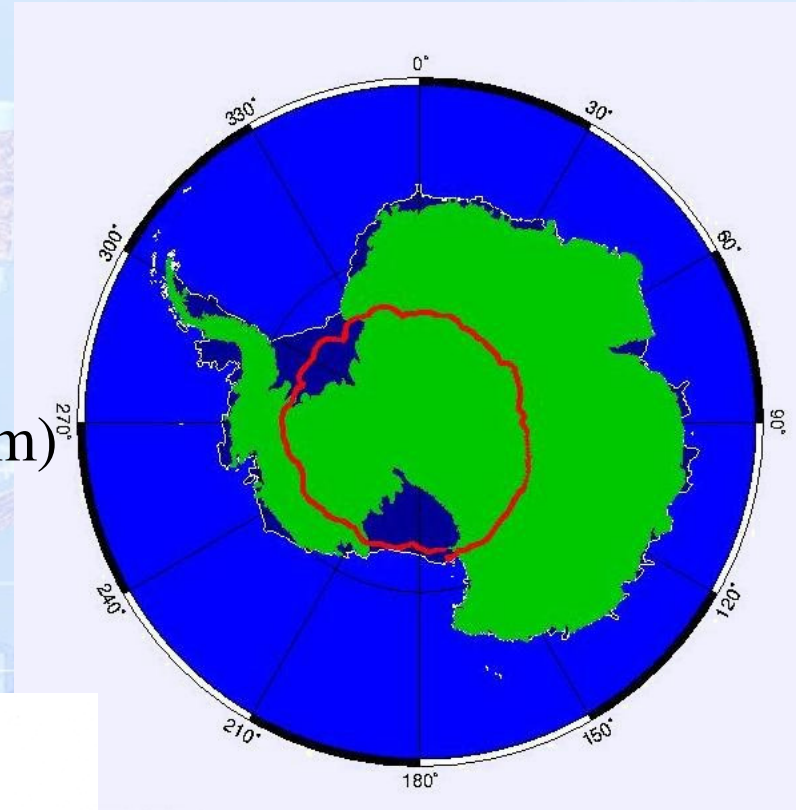


Climbs above 42 kms.

Uses stable winds

Very thin (0.002 cm) but strong material

Very large



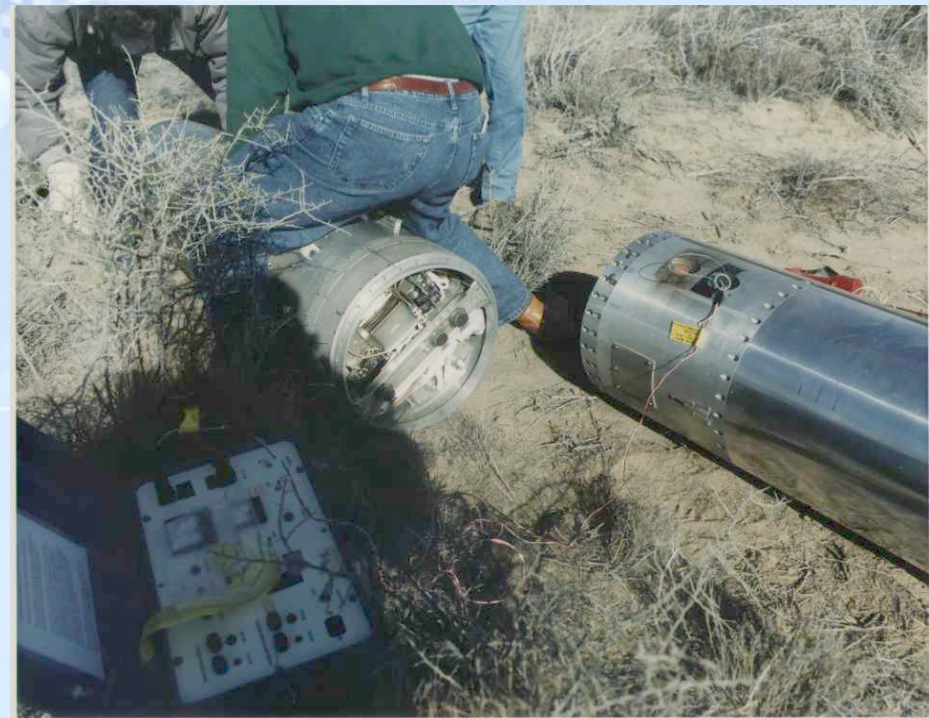
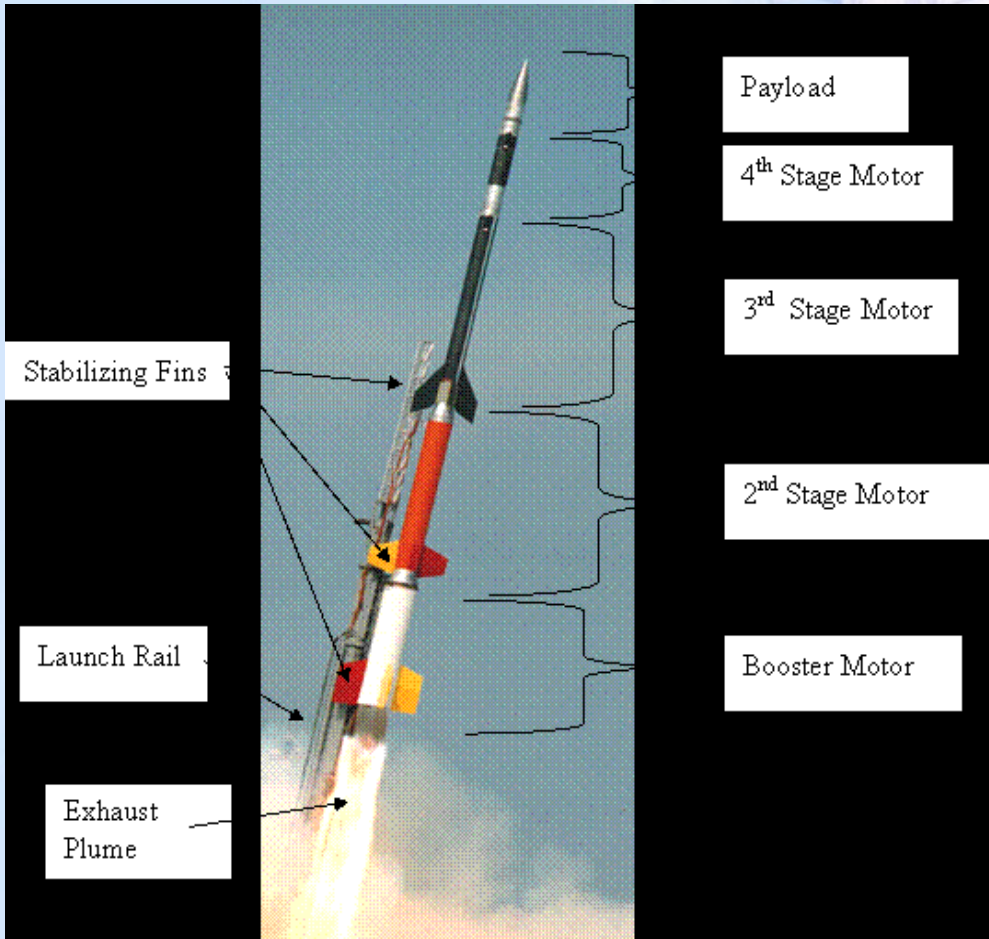
Very difficult !

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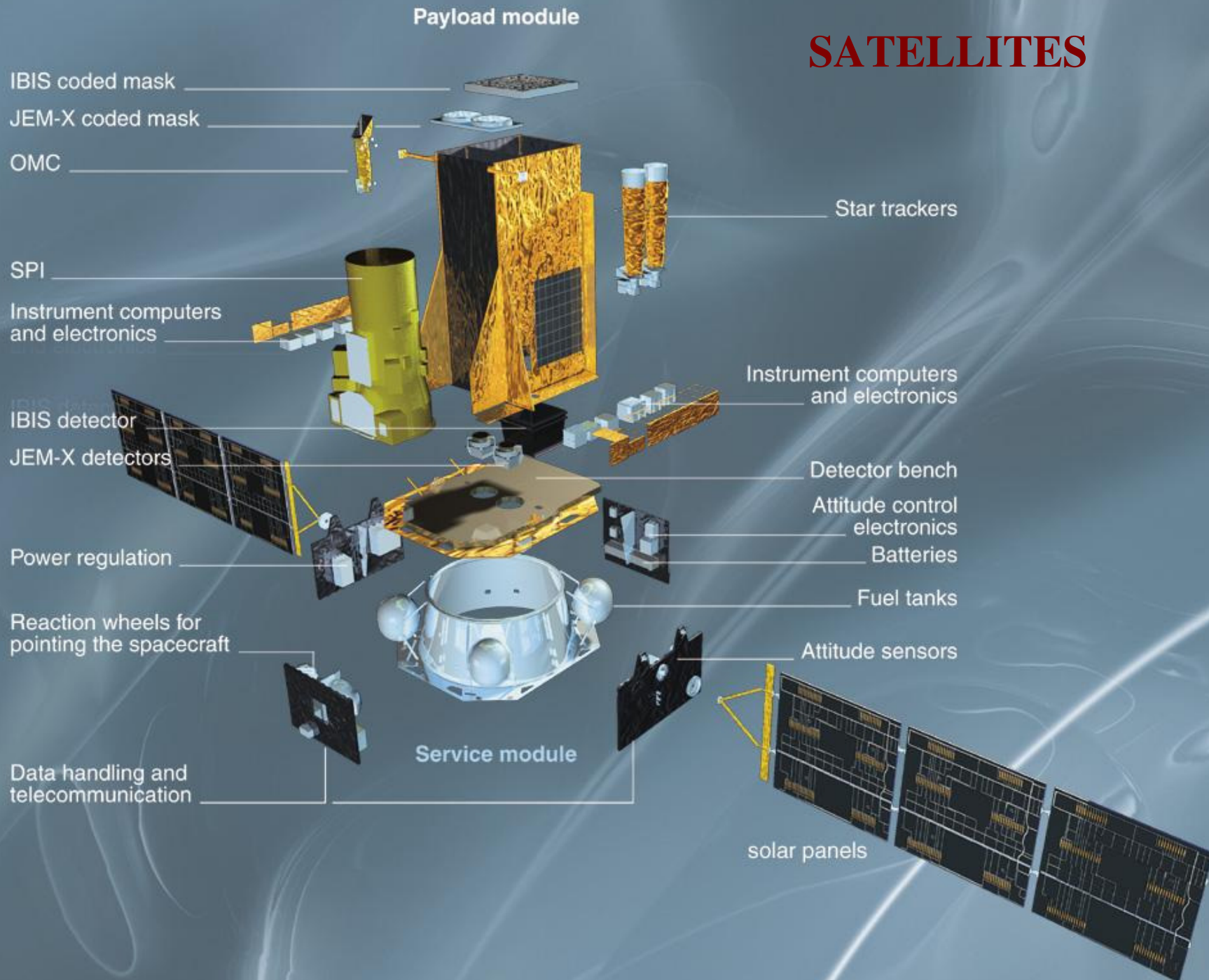
Sounding rockets:

Quick, low cost access to upper atmosphere with reusable (not always!) instruments. Rotates with a fixed period allowing pointed observations (without superb accuracy). Depending on weight, can go up to 1400kms and stays there for hundreds of seconds.

Payload module

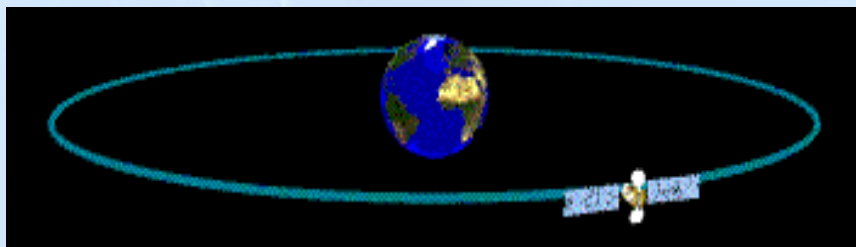
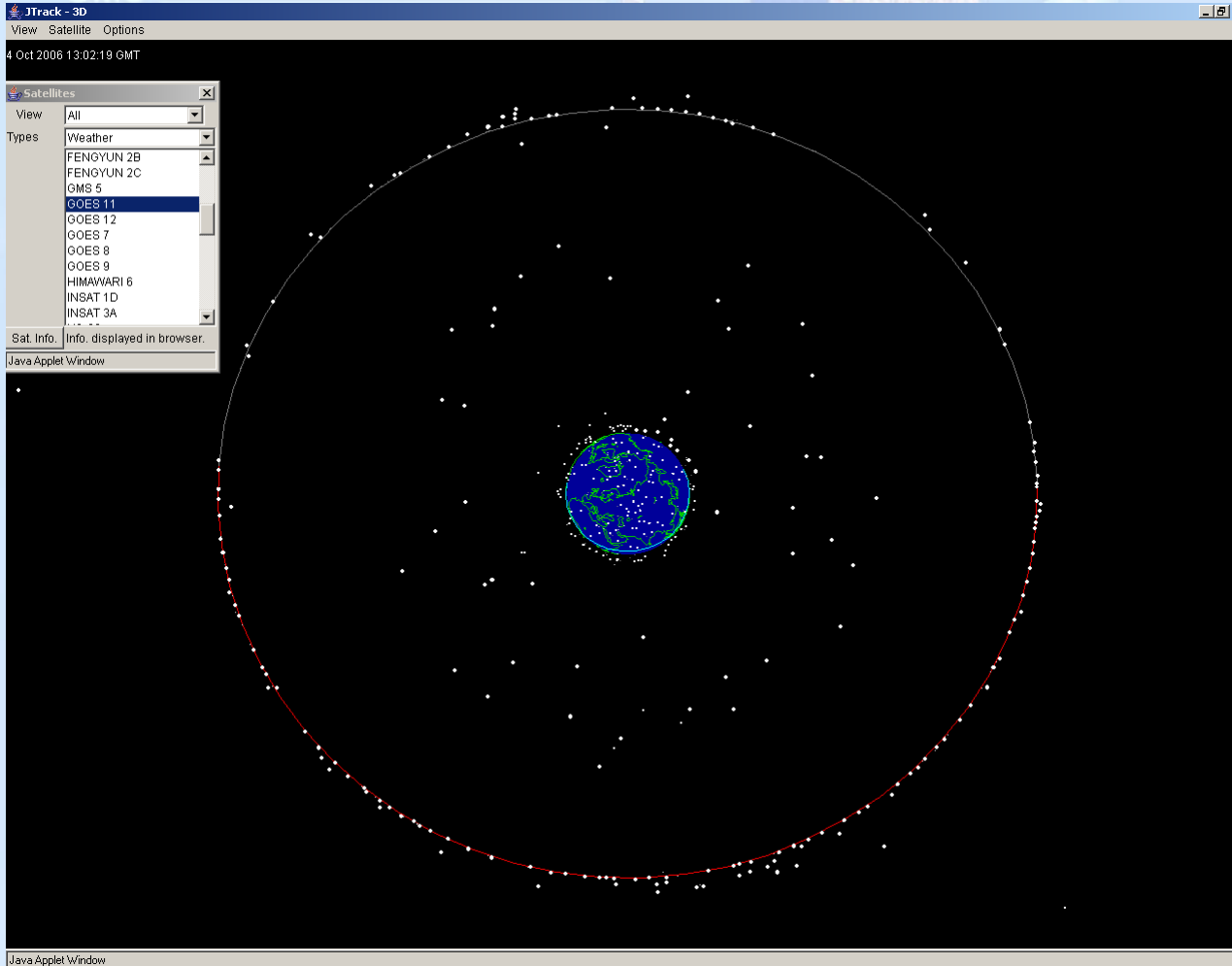


SATELLITES



Orbits

Geostationary orbit:



35800 km above earth's surface, the satellites revolve synchronously with earth's rotation.

Good for looking down to the same area on earth, continuous contact with ground station, see near half of earth's surface:

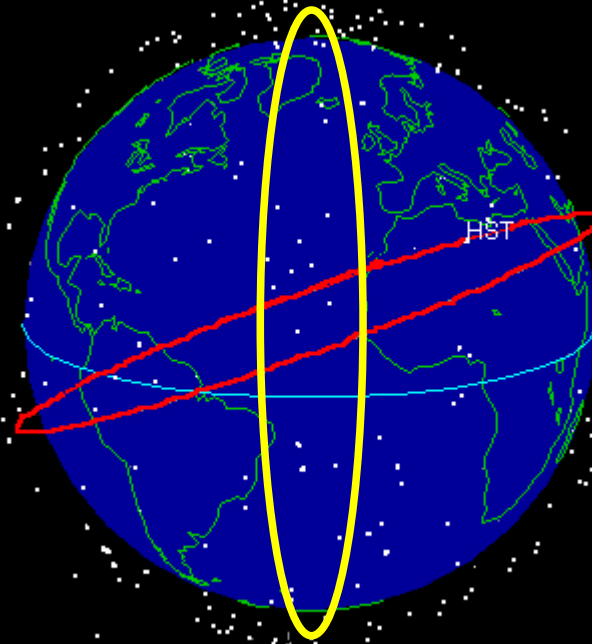
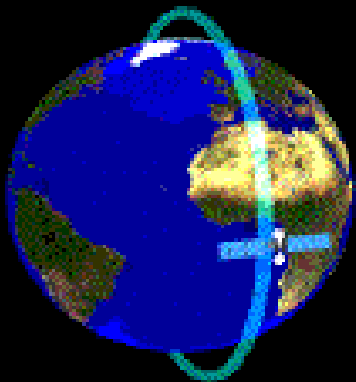
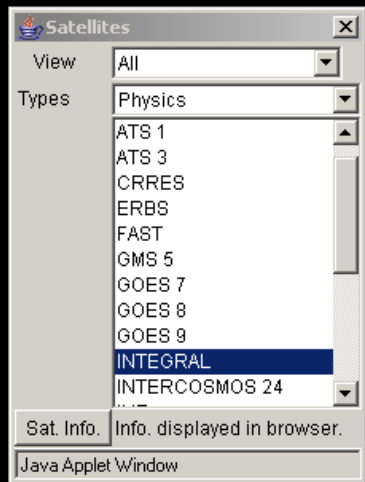
Weather

TV broadcast

Communication

Not very good for astrophysical or defense related applications. Expensive to put into orbit.

Asynchronous Orbits



Low earth orbits
(500-1000 km)
earth observation
and scientific.
Subtype: polar
Excellent coverage
for mapping and
photography.

Asynchronous Orbits

Satellites

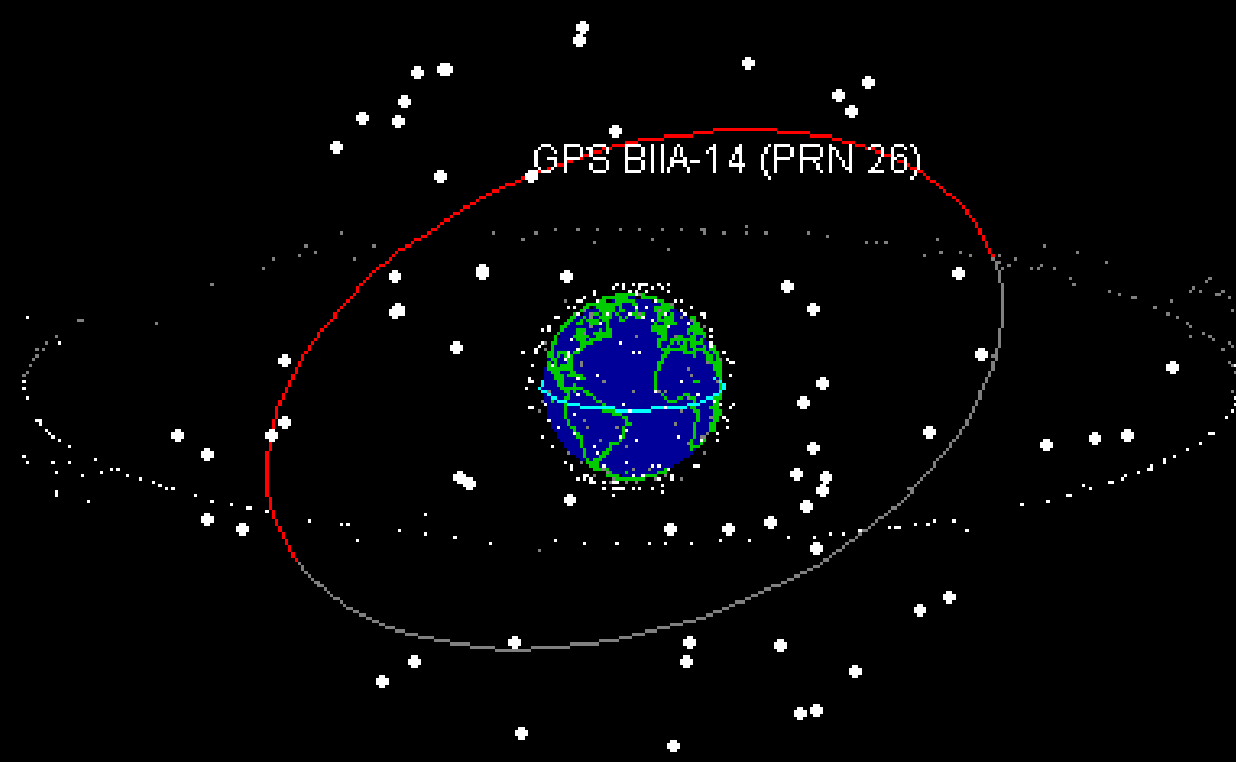
View: All

Types: Physics

- ATS 1
- ATS 3
- CRRES
- ERBS
- FAST
- GMS 5
- GOES 7
- GOES 8
- GOES 9
- INTEGRAL
- INTERCOSMOS 24

Sat. Info. Info. displayed in browser.

Java Applet Window



Medium Earth Orbits

5000 - 10000 km Science (between radiation belts)
10000 - 20000 km GPS navigation

Satellites

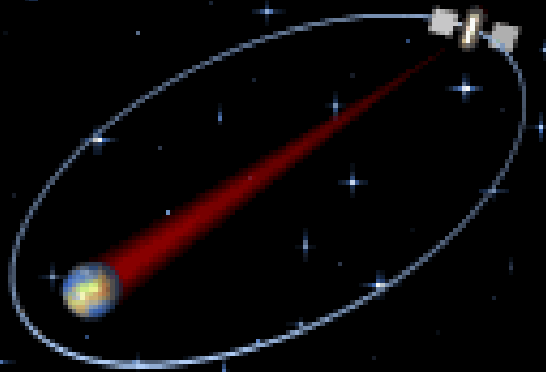
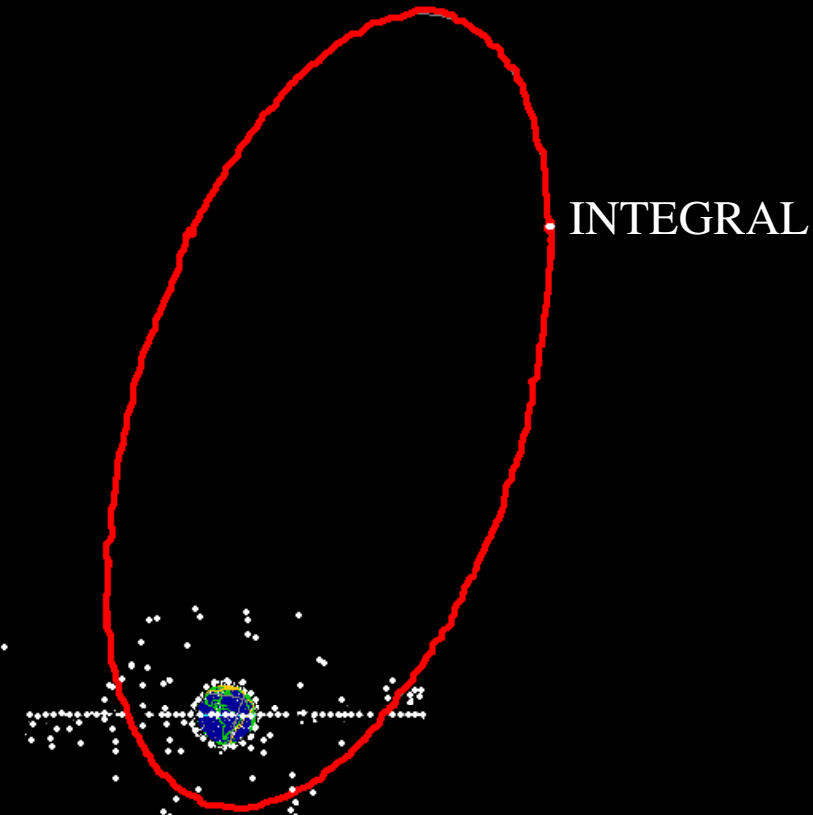
View: All

Types: Physics

- ATS 1
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- GOES 7
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- GOES 9
- INTEGRAL**
- INTERCOSMOS 24

Sat. Info. Info. displayed in browser.

Java Applet Window



Highly eccentric orbits,
scientific only.

Where are astronomy satellites?

IBIS coded ma

JEM-X co

OMC

SPI

Instrumen
and electr

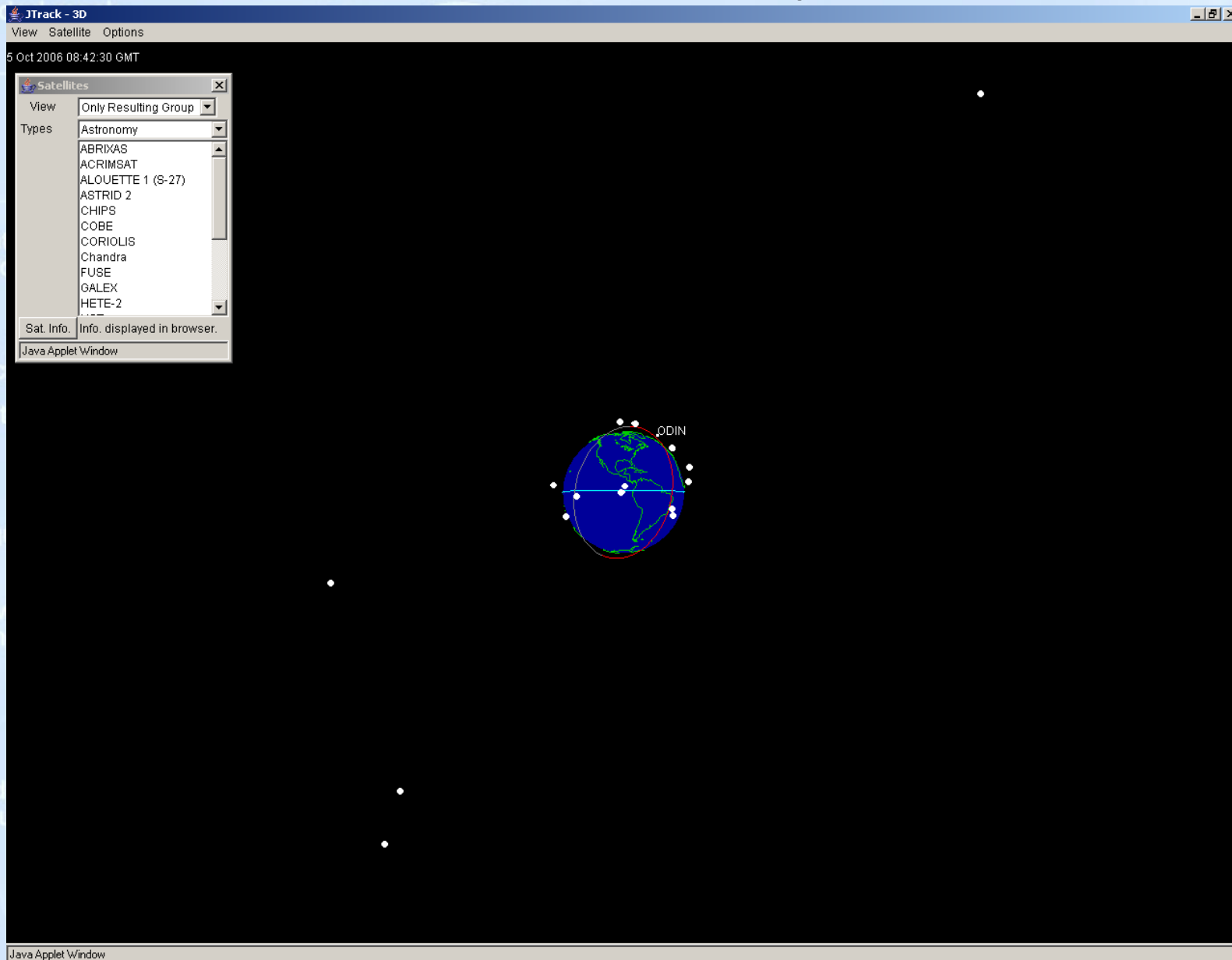
IBIS detec

JEM-X de

Power reg

Reaction v
pointing th

Data hand
telecomm



Mostly LOE!

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Why low earth orbit?

Two harmful radiation belts exist: at ~3000 km (5000 km thick) and at 16000 km (~7000 km thick). **Below 1000 km is ok for satellites.**

2 problems with radiation belts: Within the belts very high background, energetic particles affect semiconductor detectors, and degrades electronic circuits.

Above the belts, cosmic ray background high.

Easy for maneuvering, cheap and easy to place into orbit (one phase launch)

Why not low earth orbit

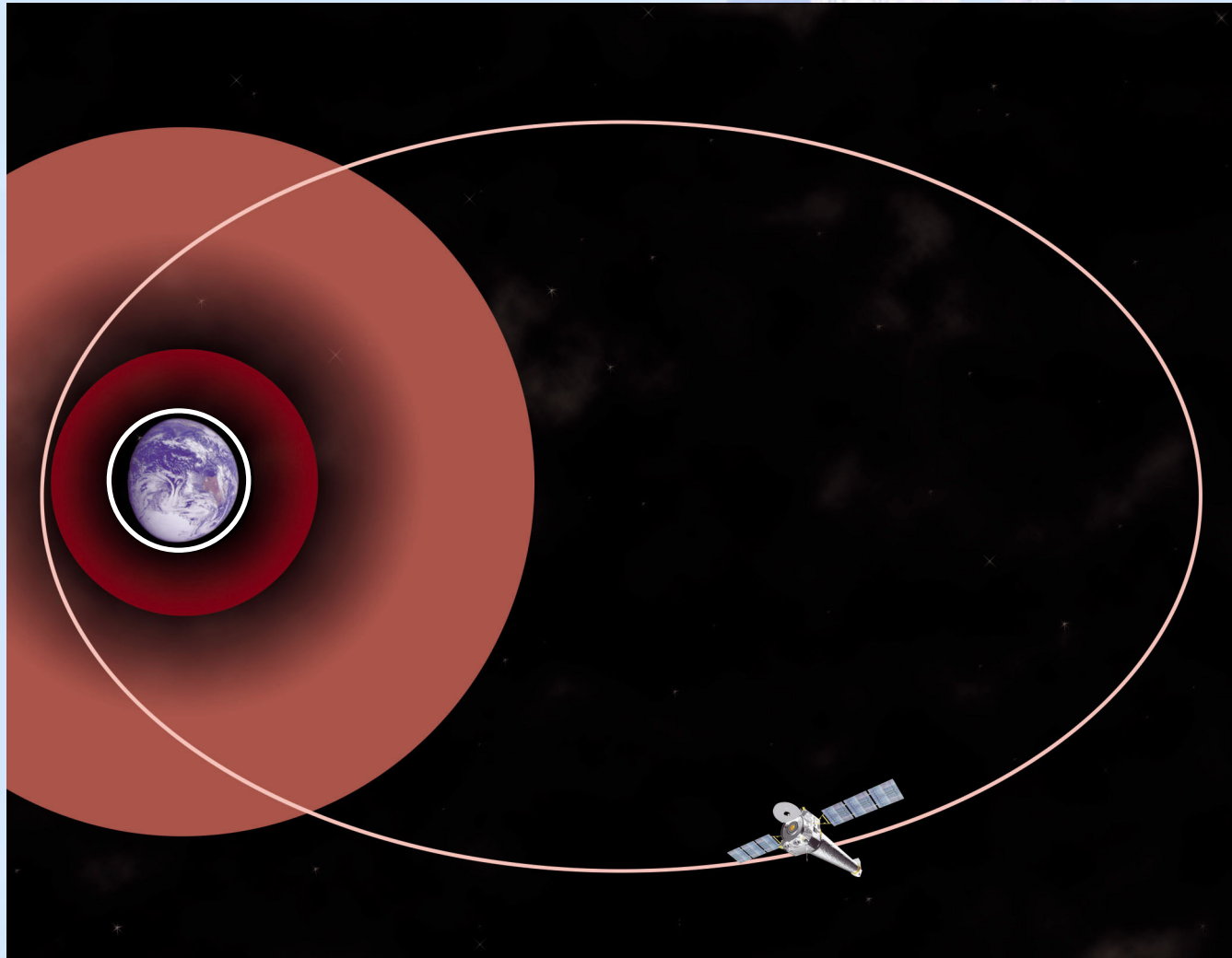
- Large eclipses due to earth. Impossible for continuous coverage (Efficiency 65-70%).
- Still particle problem with the South Atlantic Anomaly.
- Limited contact with ground bases.

IBIS coded mask _____

JEM-X coded mask _____

OMC _____

Eccentric orbits:



- Much better efficiency and coverage.
- Higher overall background
- Higher exposure to radiation belts
- 2 stage launch. Expensive

Special orbits

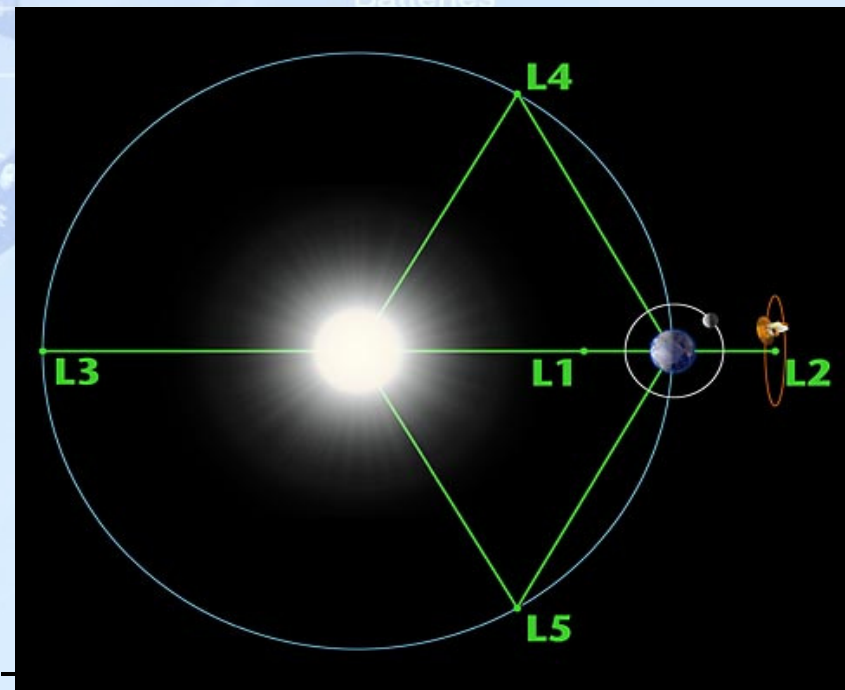
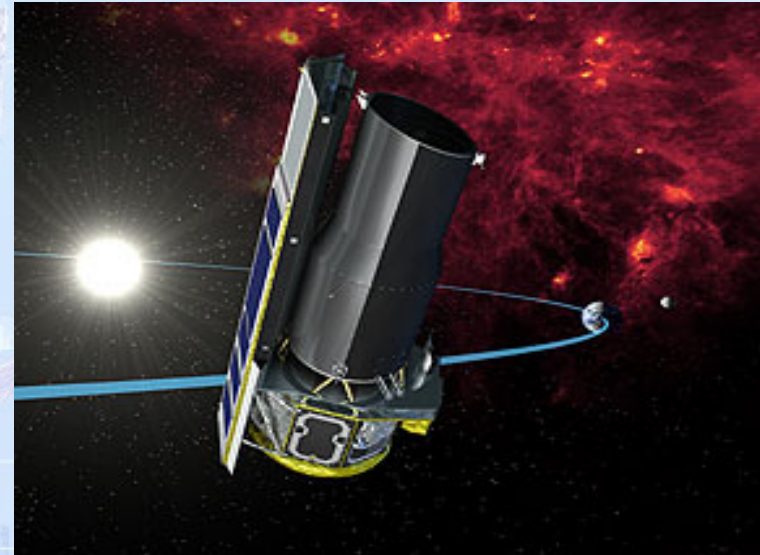
- **Trailer:**

Trails earth. Stays cool, require much less liquid Helium.

Separates 0.1 AU/year.

- **Lagrange point**

Stays at unstable lagrange points L1 (like sun observing SOHO) or L2 (like WMAP). Need adjustments every 20 days- no radiation belt, 100% efficiency.



Payload module

Technology for different wavelength regimes

IBIS coded mask

JEM-X coded mask

OMC

SPI

Instrument computers and electronics

IBIS detector

JEM-X detectors

Power regulation

Reaction wheels for pointing the spacecraft

Data handling and telecommunication

Star trackers

Instrument computers and electronics

Detector bench

Attitude control electronics

Batteries

Fuel tanks

Attitude sensors

Service module

solar panels

- IR to UV
- X-rays
- Gamma-rays
- Focusing, imaging, spectroscopy.

Infrared to Ultraviolet, technology:

Focusing:

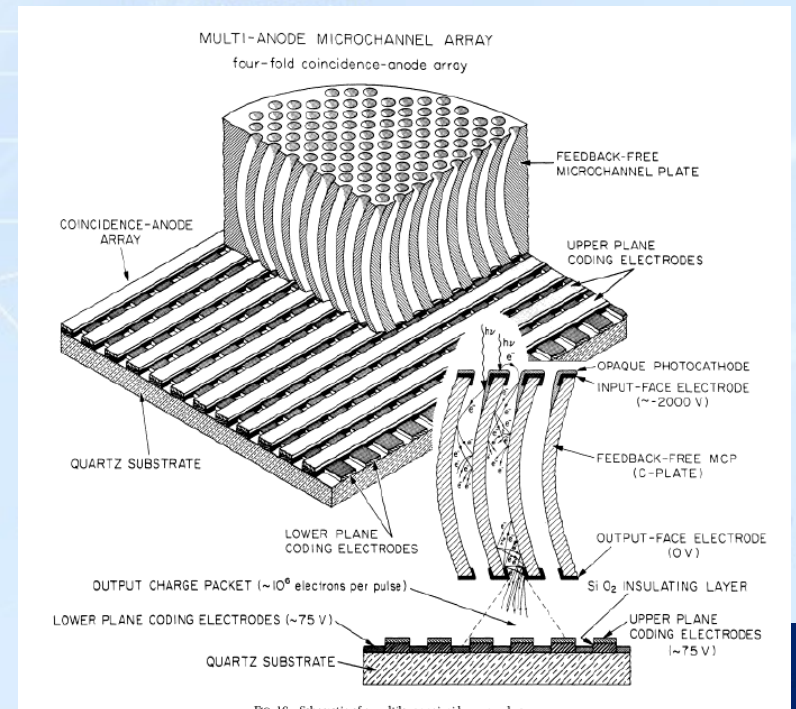
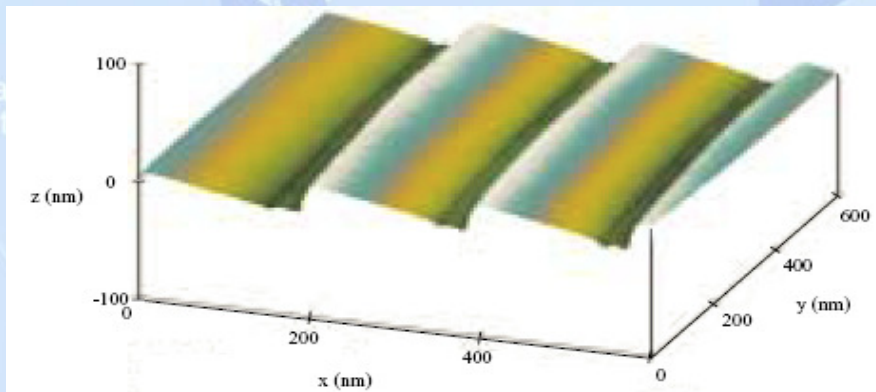
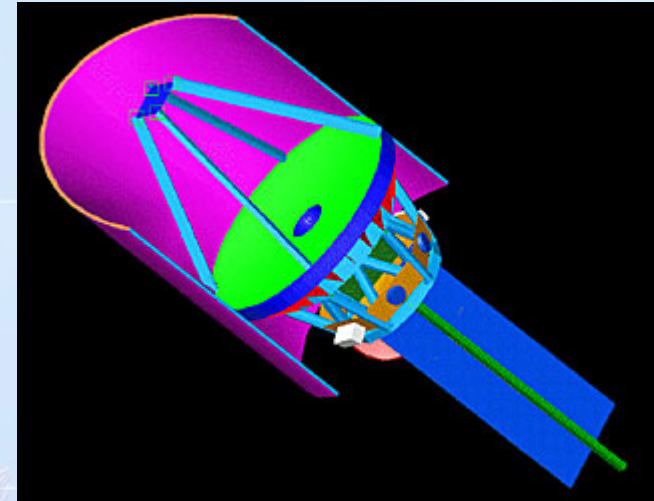
Reflecting telescopes
(EUV grazing incidence).

Imaging:

CCDs and microchannel plates.

Spectroscopy:

Gratings (and or prisms) coupled with CCDs,
photomultiplier tubes and microchannel plates.



Aside 1, cooling and thermal control

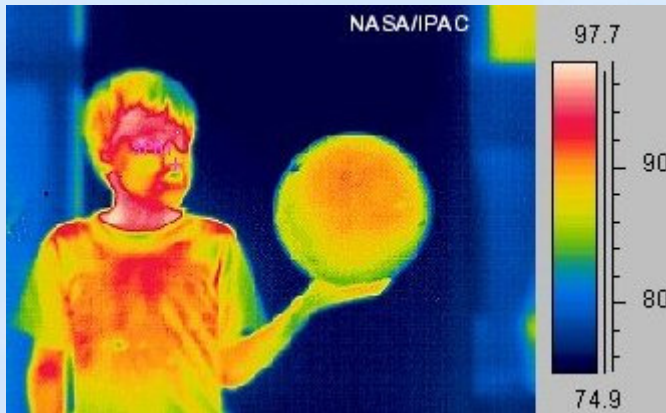


Image taken by an IR detector.

Most materials at their nominal temperatures emit radiation mostly in the infrared band! IR detectors and telescopes must be cooled down to near zero temperatures.

Small band-pass semiconductor detectors are also need to be cooled to reduce noise.

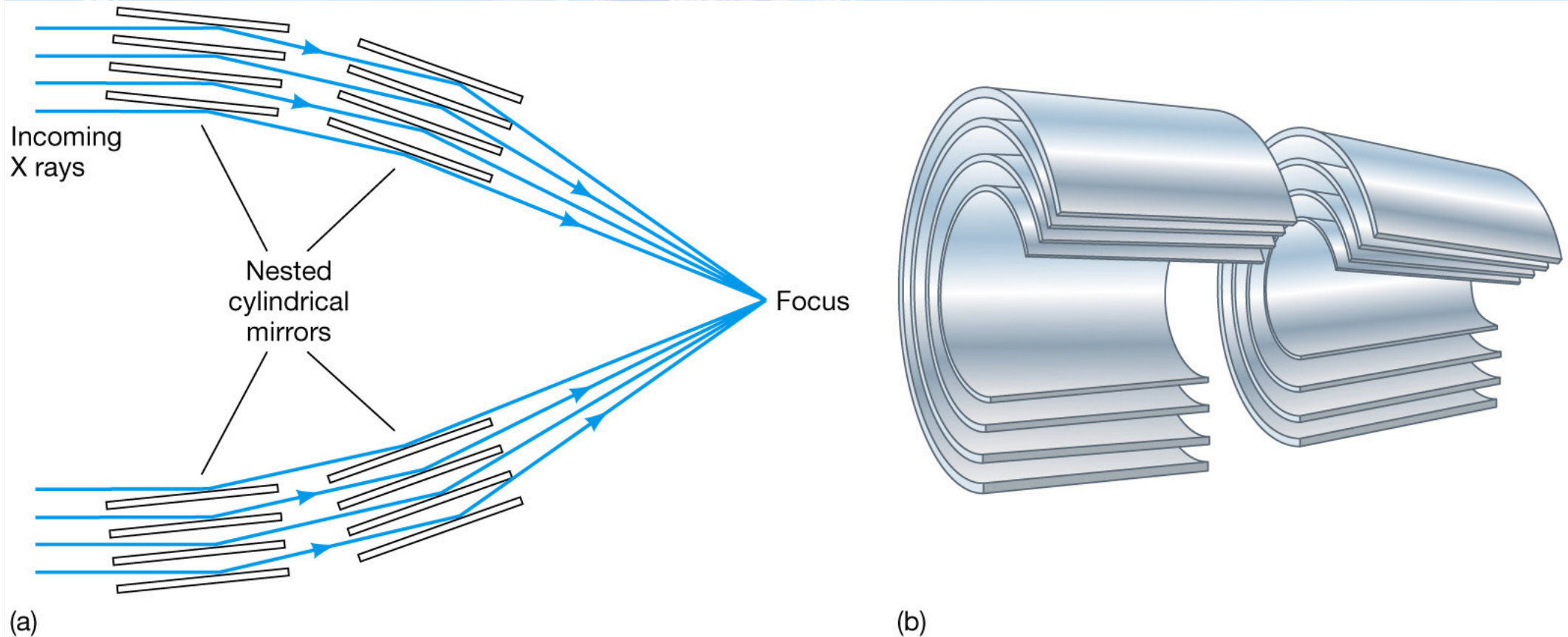
Remember, the only way to get rid of heat is radiation. Surfaces are covered by thermal blankets, and thermal modeling of the entire satellite is absolutely essential for good performance.



X-ray astronomy, imaging:

IBIS coded mask

Very difficult to focus and detect. They are so energetic that they either pass through an object, scattered, or just absorbed. They are reflected only if the scattering angle is very small. Up to 10 keV, they can be focused through “grazing incidence telescopes”.



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With special coatings, the energy range can go up to 30 keV.

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Imaging and spectroscopy, X-ray CCDs

The operating principle of X-ray CCDs are similar to the optical CCDs. X-ray CCDs can also determine the energy of the photon if only one photon hits the pixel before the readout. High resolution spectroscopy can be done with gratings.

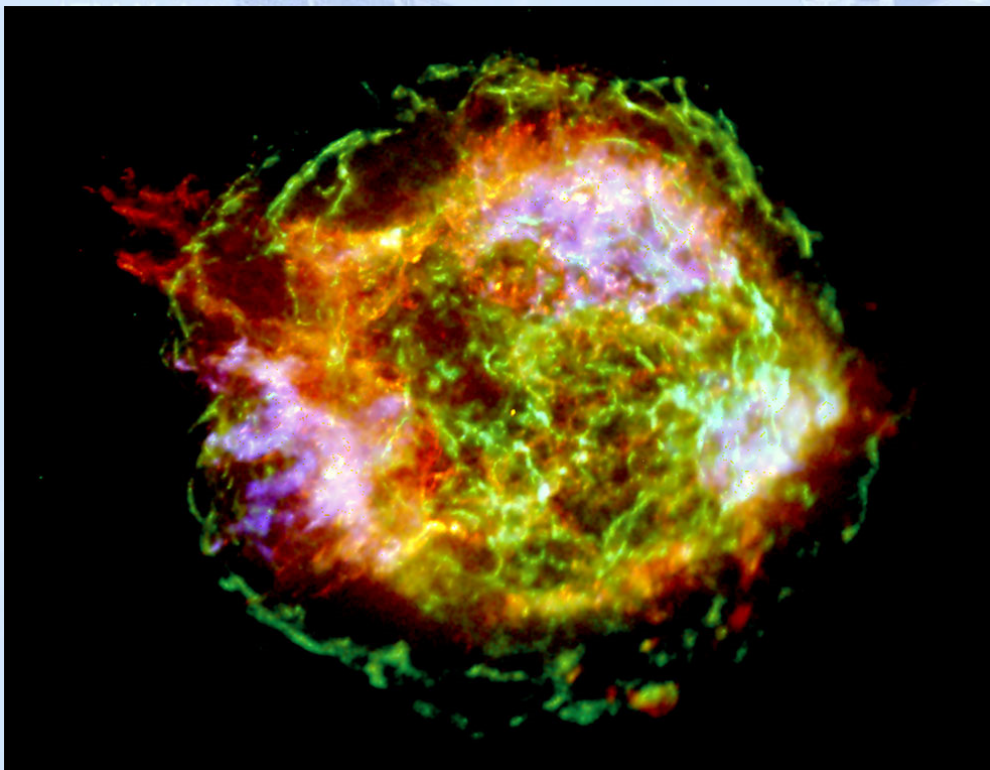


Batteries

Fuel tanks

Altitude sensors

Chandra X-ray observatory



IBIS detector

Formation of heavy elements in a supernova explosion.

Astronomy above 10 keV (0.1 nm), hard X-rays to Gamma-rays

JEM-X coded mask

OMC



Reaction wheels for attitude control of the spacecraft

RXTE

Data handling and telecommunication

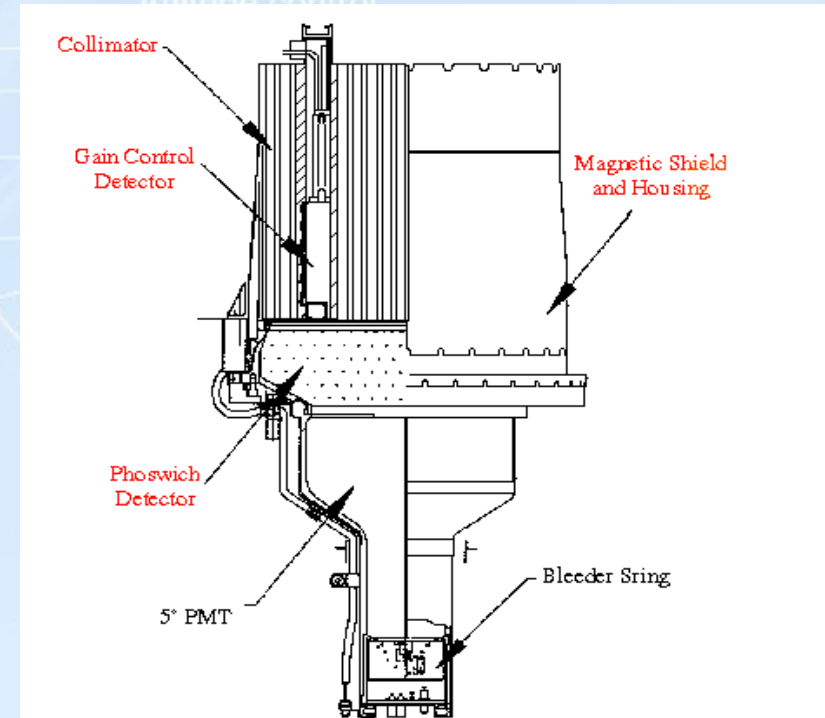
Imaging also becomes very difficult. Collimators are used for non-imaging applications.

Above a certain energy, it becomes harder to stop X-rays, and the detector technology changes entirely.

Proportional counters: high pressure gas

Scintillation detectors: NaI crystals

Semiconductor detectors: Si, Ge, CdZnTe



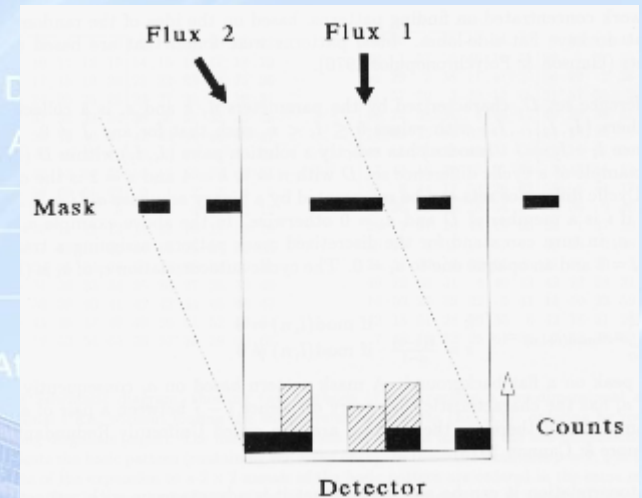
Imaging and spectral above 20 keV, entering the Gamma-ray domain

IBIS coded mask

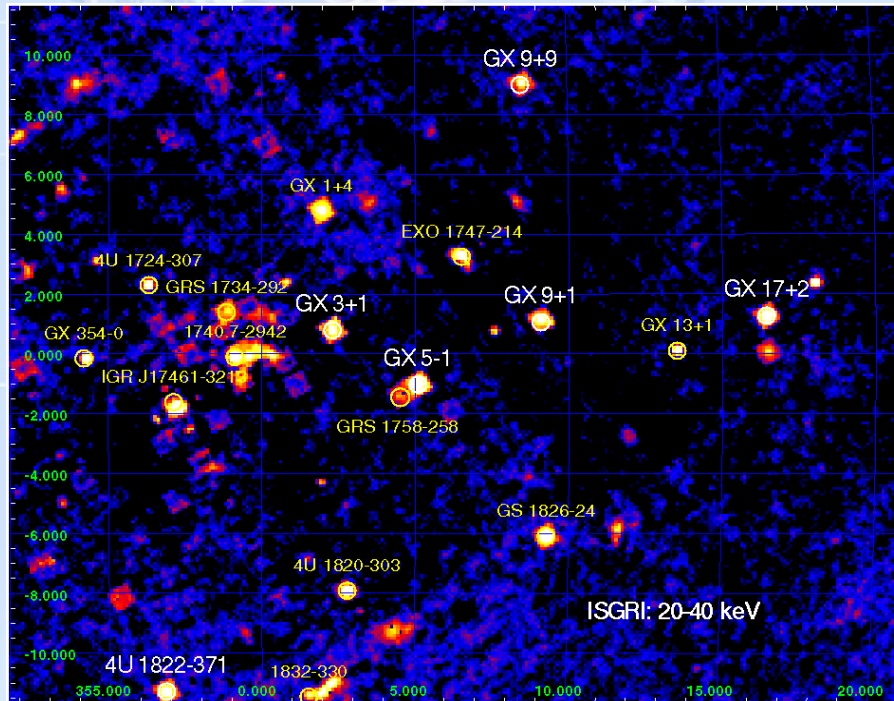
Coded-mask imaging



The combined shadow of several sources through a specifically designed mask can be used to determine the directions of each source.



SWIFT coded-mask

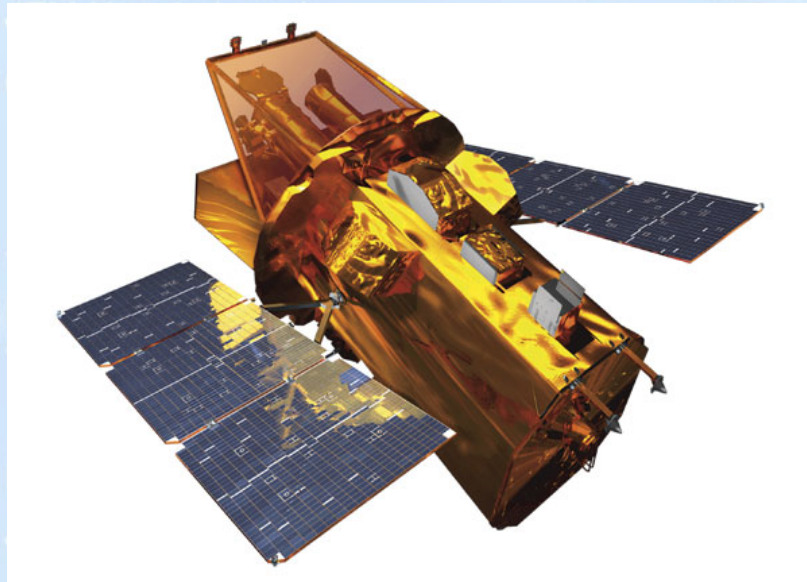


Coded mask image in hard X-rays (20-40 keV)

Payload module

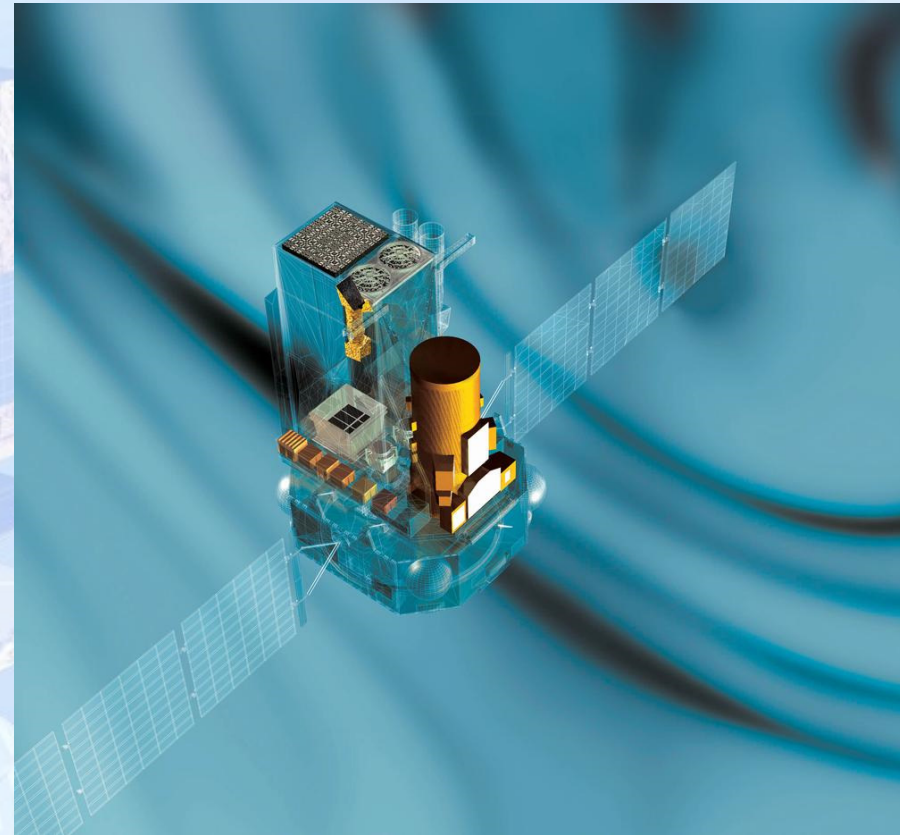
Hard X-ray and gamma-ray instruments:

IBIS coded mask



Power
Reaction wheels for pointing
on the fly.

Data handling and teleco
On board pointing decisions.



Attitude sensors

Service module

INTEGRAL, a complete hard X-ray and gamma-ray observatory.

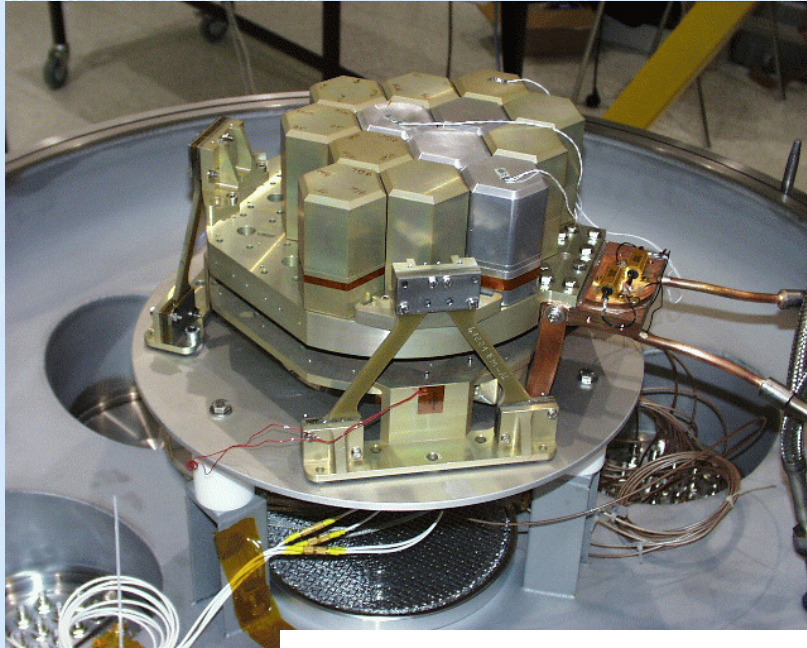
Hard to re-point.

solar panels

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INTEGRAL – SPI, going up in energy to MeV (0.001 nm) range.

FEM-X coded mask



electronics

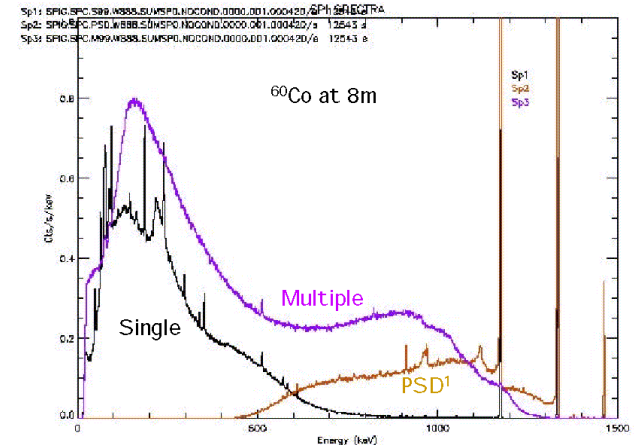
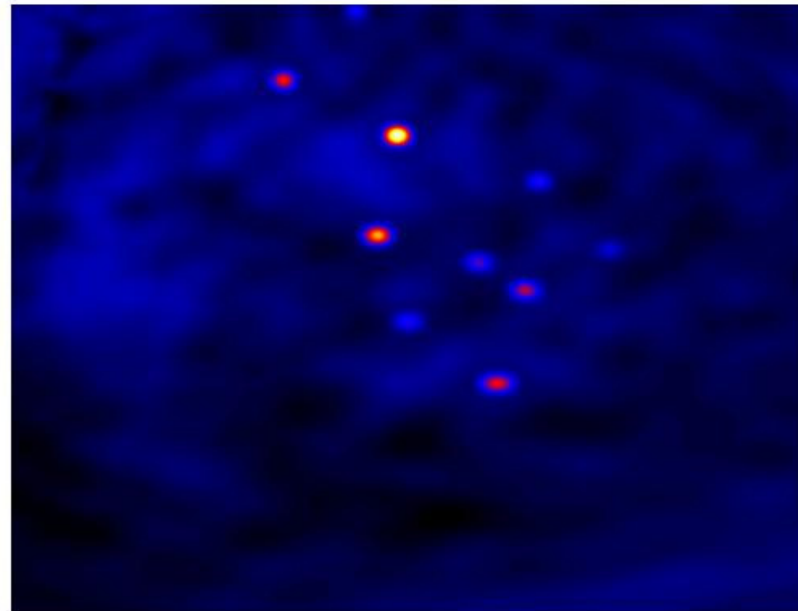
Batteries

The coded mask.

Ge crystals

Reaction wheels pointing the spacecraft

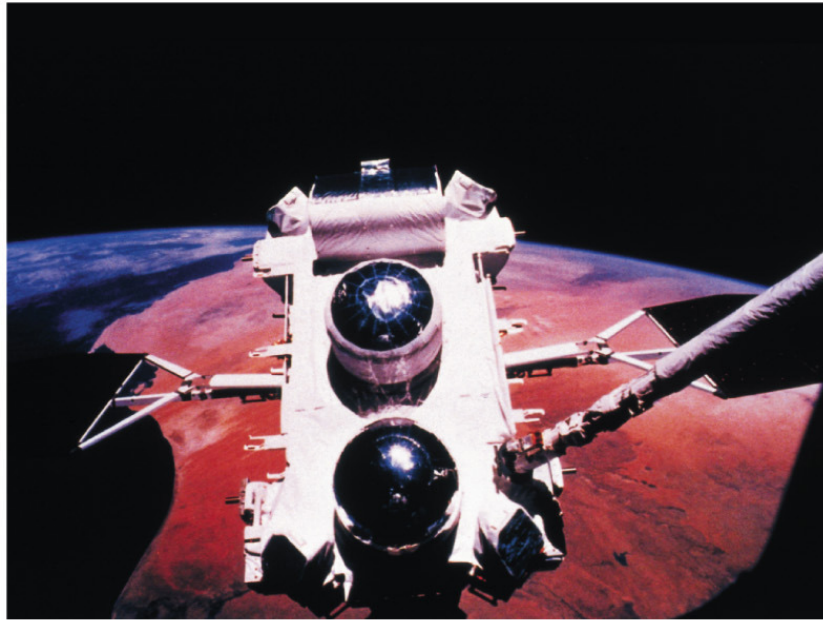
Data handling and telecommunication



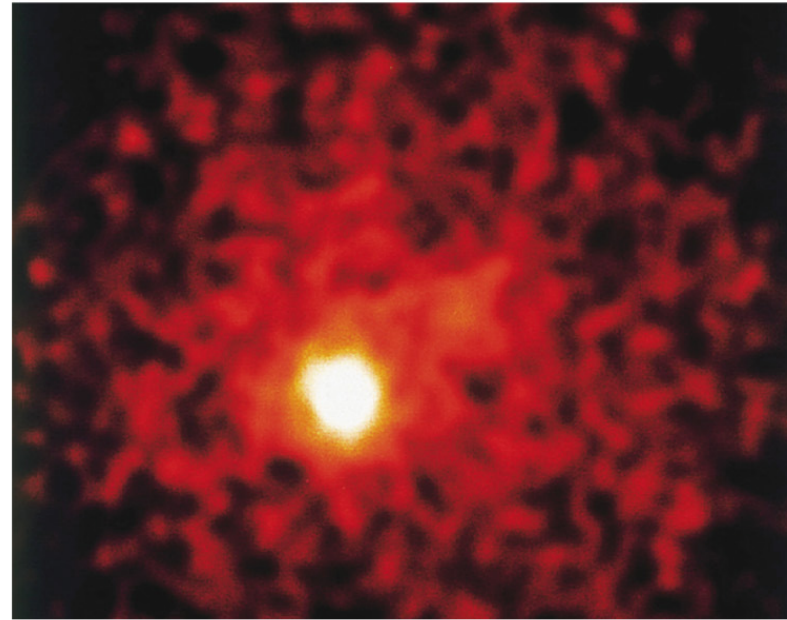
superb energy resolution



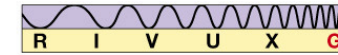
Gamma-ray instruments, Compton imaging



(a)



(b)



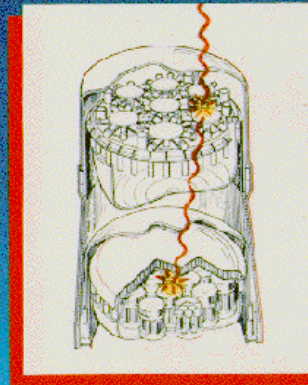
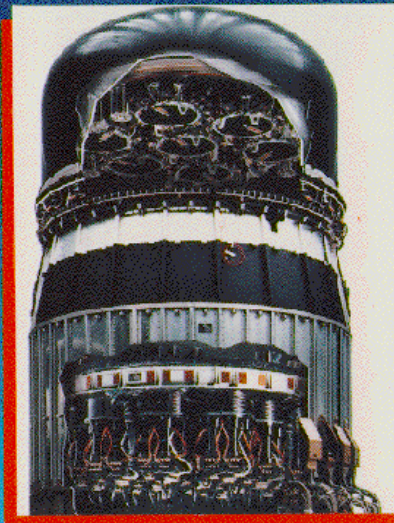
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CGRO

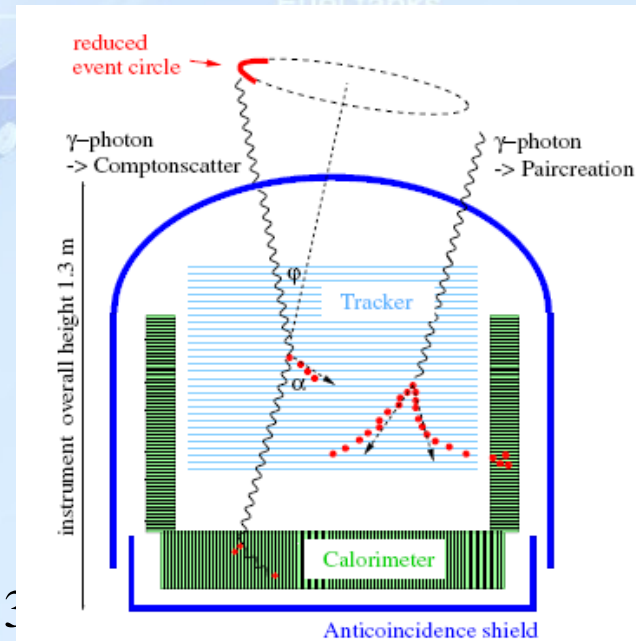
Reaction pointing

Data handling telecomm

Imaging Compton Telescope (COMPTTEL)



12 - 13



MEGA

abancı
versitesi

Aside 2, Cosmic Ray difficulty

Creates high background:

Cosmic rays scattered from the spacecraft can mimic actual signal, causing the largest background source for high energy detectors. On top of that, the background is time dependent due to nuclear activation.

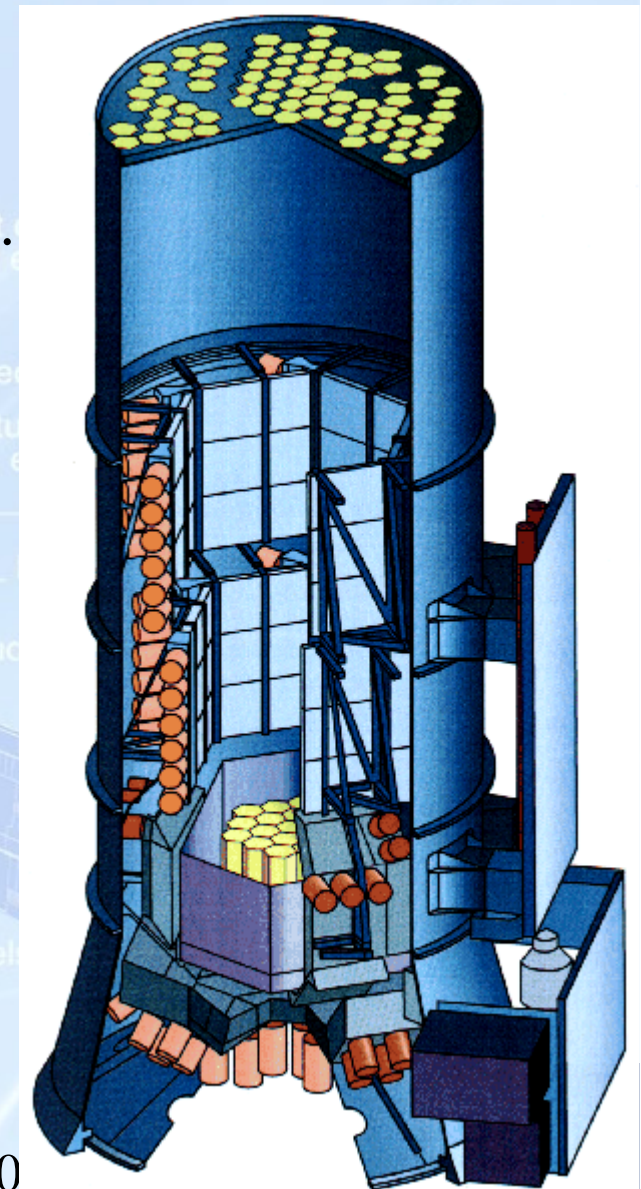
Need to use

Anti-coincidence shields

Time dependent GEANT modeling

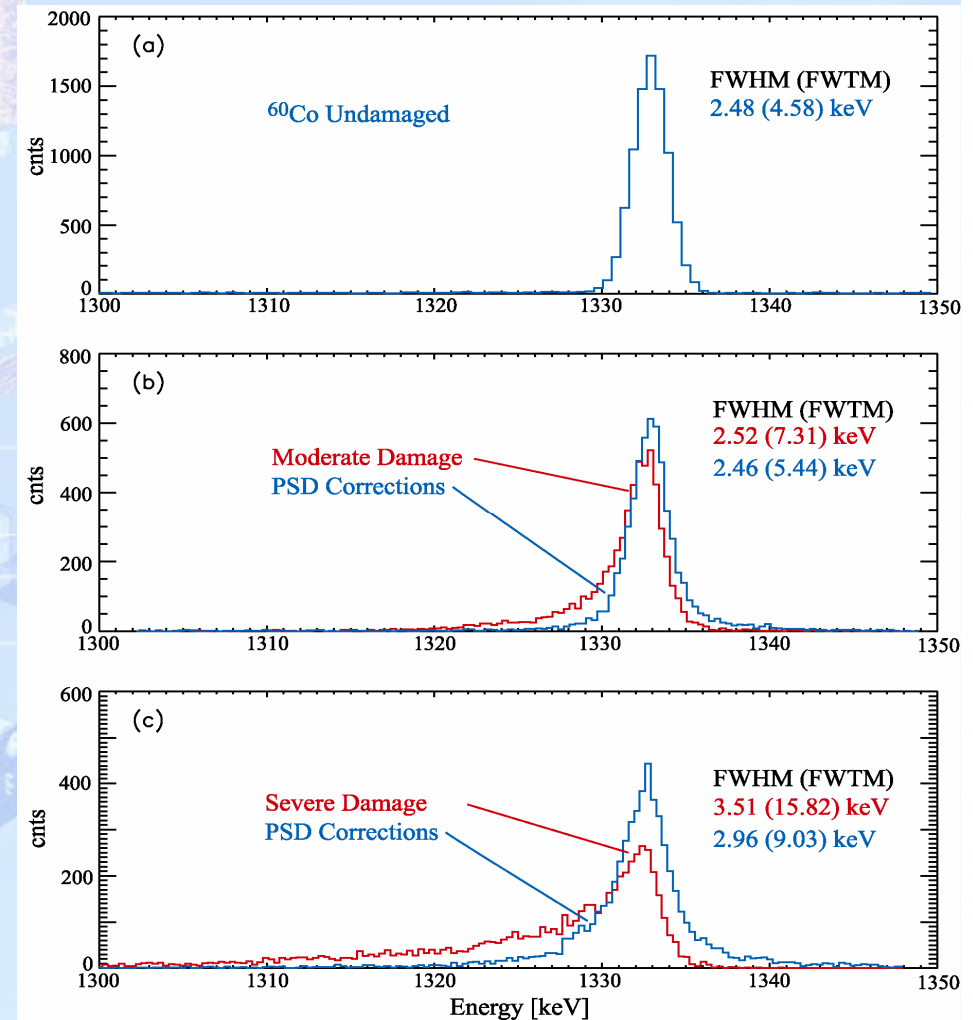
Pulse shape discrimination techniques

to reduce - understand background.



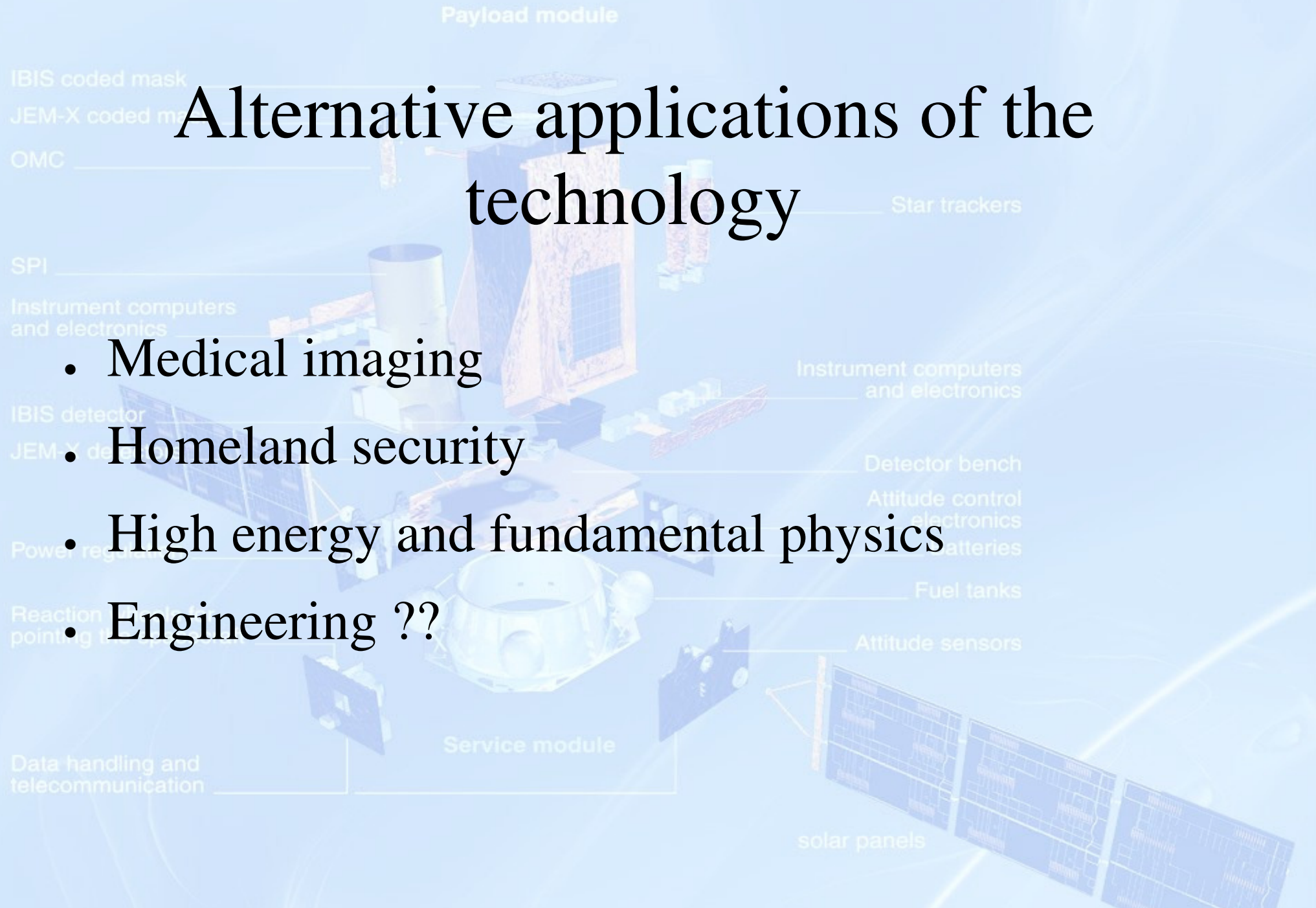
Aside 2, Cosmic ray difficulty

- Cosmic rays also affect electronic boards & semiconductor detectors because of lattice deformations and ionization effects:
- For detectors, causes more charge trapping, incomplete charge collection and poorer energy resolution. Require risky annealings to fix the problem. PSD corrections can be applied in the meantime.
- For electronic boards, even single effects can cause latchups and noisy or unusable systems. (2 of the 19 Ge detectors of INTEGRAL are dead!)
- Radiation hardening techniques, both physical and logical, must be applied. **Redundancy is essential for space instrumentation.!**



Alternative applications of the technology

- Medical imaging
- Homeland security
- High energy and fundamental physics
- Engineering ??



Medical Imaging

Payload module

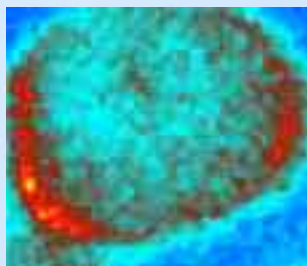


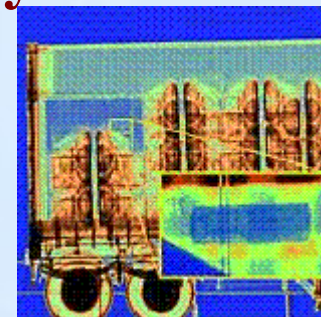
Image of tumor

Image of a SN remnant

Radioactive tracers are injected into tissues and real time images of the tracers can be obtained with excellent spatial resolution.

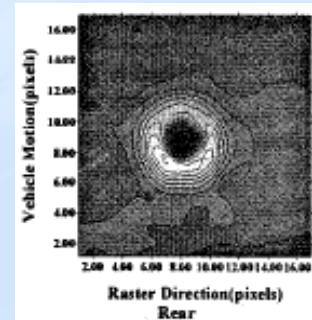
Homeland security

Imaging behind objects



Star trackers

Mine recognition



Radioactive material recognition

High energy and fundamental physics



AGILE - GLAST test at CERN

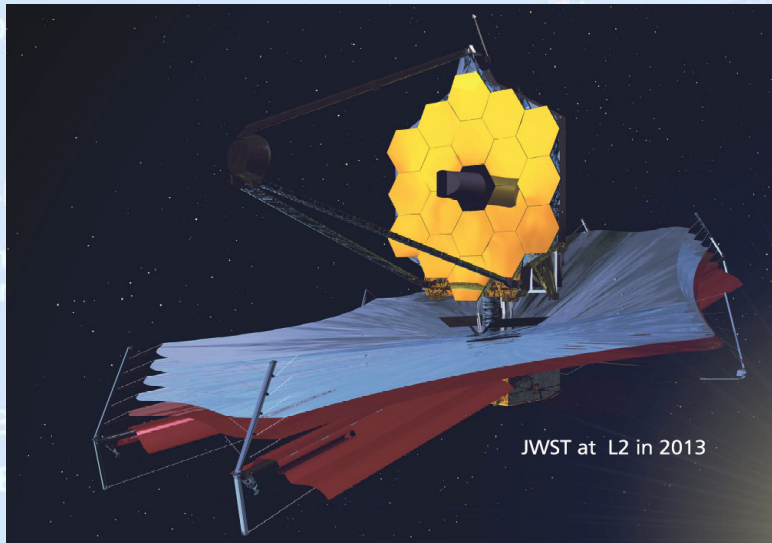


Spare XMM/MOS CCD used for pion mass measurement

High energy detector technology very similar.

Same modeling tools are used (GEANT)

The future of space based astronomy



JWST at L2 in 2013

JWST

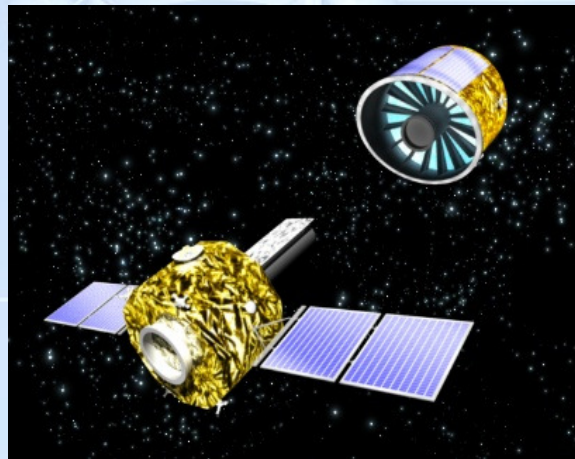
•Not very bright for NASA, thanks to Moon&Mars initiative of G.W: Bush. JWST is the only big project left, and SMEX - MIDEX - University satellites stopped.

•ESA currently doing better and has numerous projects.

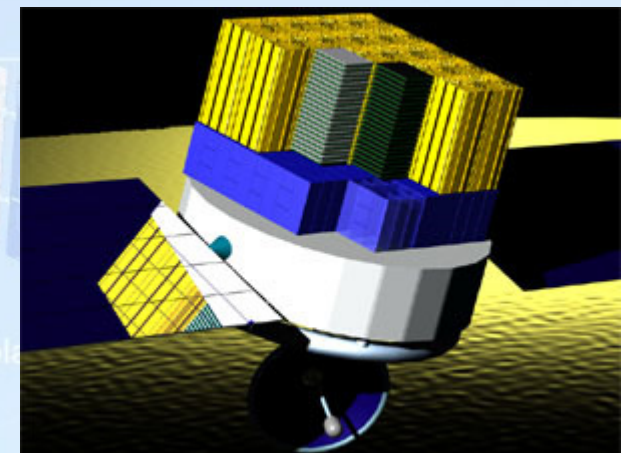
•India and China wants to get a piece of the action.



Constellation X

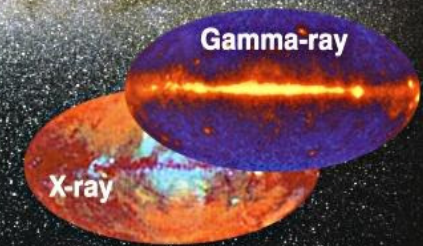
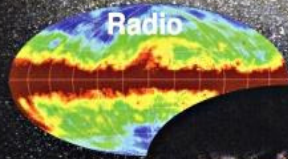


XEUS



GLAST

ASTROSAT



THE INDIAN SIGNATURE IN SPACE ASTROPHYSICS

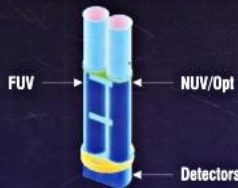
Science Objectives

- Multiwavelength spectral and timing studies of X-ray binaries, pulsars, SNRs, AGNs, galaxy clusters
- High resolution studies of galaxy morphology in UV
- Sky survey in hard X-ray and UV bands
- Detection of new X-ray transients and routine monitoring of bright X-ray sources
- UV background studies

Multiwavelength studies

Most astronomical objects in the Universe emit radiation spanning the complete electromagnetic spectrum from long wavelength radio waves to very short wavelength gamma rays. Thus for a detailed understanding of the physical processes that give rise to wavelength dependent, time variable phenomena, it is essential to carry out simultaneous multiwavelength observations.

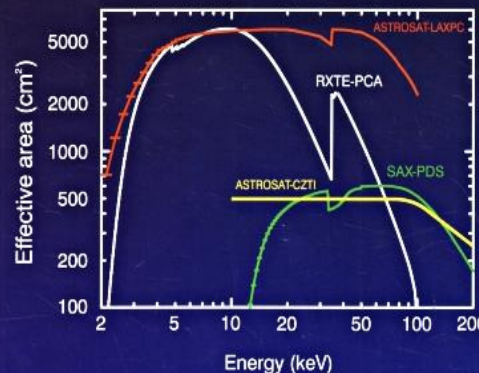
Ultra-Violet Imaging Telescope (UVIT)



Soft X-Ray Telescope (SXT)



Astrosat is India's first satellite dedicated to multiwavelength astronomy. It will be launched into a 650 km, low inclination ($<10^\circ$) orbit by the PSLV in 2007. The 5 payloads permit simultaneous observations of cosmic objects at UV, soft X-ray and hard X-ray regions of the electromagnetic spectrum.



Large Area Xenon Proportional Counter (LAXPC)



Scanning Sky Monitor (SSM)



CdZnTe Imager (CZTI)



	UVIT / OPT	SXT	LAXPC	CZTI	SSM
Detector	UV: photon counting CCD Opt: CCD photometer	X-ray CCD (at the focal plane)	Proportional counter	CdZnTe detector array	Position-sensitive proportional counter
Imaging / non-imaging	imaging	imaging	non-imaging	imaging	imaging
Optics	Twin Ritchey Chretien 2 mirror system	Conical foil (~Wolter-I) mirrors	Collimator	2-D coded mask	1-D coded mask
Bandwidth	1300-3200 Ang	0.3 - 8 keV	3 - 100 keV	10 - 100 keV	2 - 10 keV
Geometric Area (cm²)	1250	250	10800	1000	180
Effective Area (cm²)	60 (depends on filter)	125@0.5 keV 200@1-2 keV 25@6 keV	8000@5-30 keV	1000 (E>10 keV)	~40 @ 2 keV 90 @ 5 keV (Xe gas)
Field of View	0.50° dia	0.35° (FWHM)	1° x 1°	17° x 17°	6° x 90°
Energy Resolution	<1000 Å (depends on choice of filters)	2% @ 6 keV	9% @ 22 keV	5% at 10 keV	19% @ 6 keV
Angular Resolution	1.8 arcsec	3 - 4 arcmin (HPD)	~(1-5) arcmin (in scan mode only)	8 arcmin	~10 arcmin
Time resolution	10 ms	2.6s, 0.3s, 1ms	10 microsec	1 ms	1 ms
Typical observation time per target.	30 min	0.5 - 1 day	1 - 2 days	2 days	5 min
Sensitivity (Obs. Time)	21 st magnitude (5σ) (1800s)	10 microCrab (5σ) (10000 s)	0.1 milliCrab (3σ) (1000 s)	0.5 milliCrab (3σ) (1000s)	~30 milliCrab (3σ) (300s)

Multiwavelength images courtesy HEASARC : IR image of galaxy (credit : Univ. Of Massachusetts and IPAC/CALTECH)

Xenon / Methane and a little car exhaust is the perfect combination for X-ray detection!



12 - 13 October 2006, Ankara

Future of space astrophysics in Turkey

• Past and current developments:

- Space physics has been underway thanks to Bilten (TÜBİTAK Uzay)
- BILSAT, first Turkish earth observing satellite is in orbit since 2003.
- A group of engineers and laboratories experienced with space technology is present at BILTEN.
- A few researchers (at Sabancı, METU, and Çukurova) actively works on astrophysical instrumentation in Turkey, and some Turkish researchers work (has worked) abroad (at New Hampshire, Danish National Space Center, UC Riverside, Japan Space Agency, UC San Diego and UC Berkeley)

Future of space astrophysics in Turkey

- **ASTRONS**, a first and a strong step towards astrophysical instrumentation in Turkey
 - FP6 Transfer of Knowledge project, starts December 1, 2006, 4 years. PI Ali Alpar, co-PI Ümit Kızıloğlu.
 - Aims for exchange of researchers and information.
 - There is no institutional restriction for outgoing researchers, can be from any institute in Turkey.
 - Total grant 1.1 M€ for visits, 2 postdocs at Sabancı and also 4 workshops at Sabancı.

ASTRONS, the partners

THEORY

- Un. of Amsterdam, Netherlands
- Crete University, Greece
- Max Planck institute fur Astrophysik, Germany.

INSTRUMENTATION

- Warwick University, UK (ground based)
- Leicester University, UK (and theory)
- Danish National Space Center, Denmark
- Centre d'Etude Spatiale Rayonnements, France
- Max Planck institute fur Extreterrestische Physik

Payload module

IBIS coded mask

JEM-X coded mask

OMC

The last word

Star trackers

Instrument computers
and electronics

Detector bench

Attitude control
electronics

Batteries

Fuel tanks

Attitude sensors

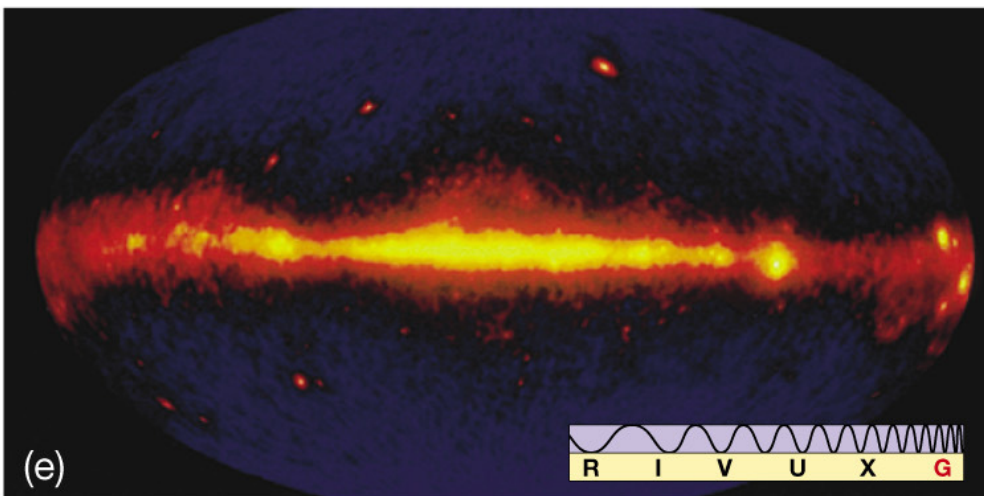
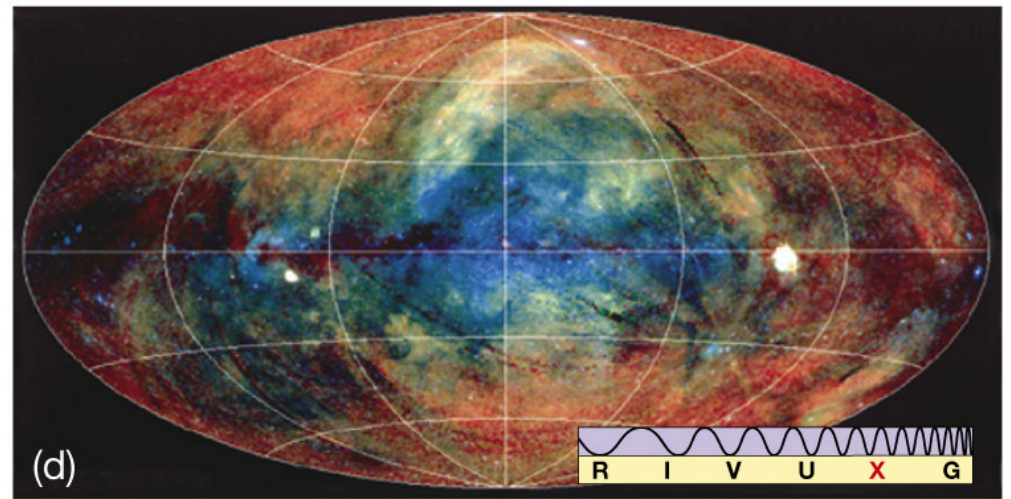
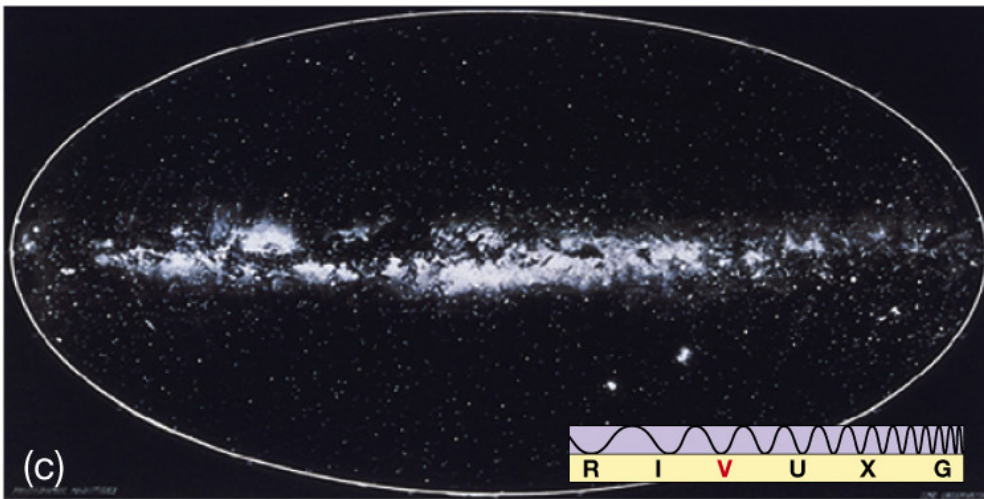
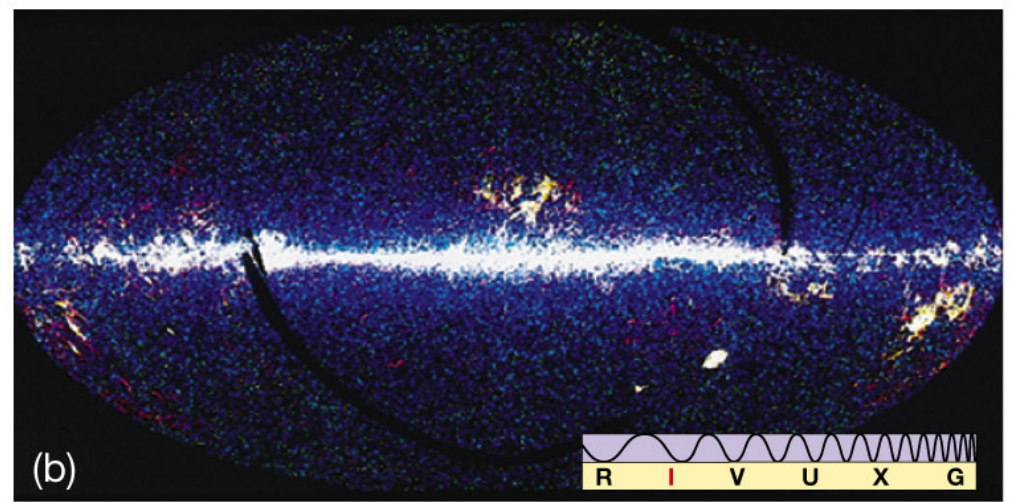
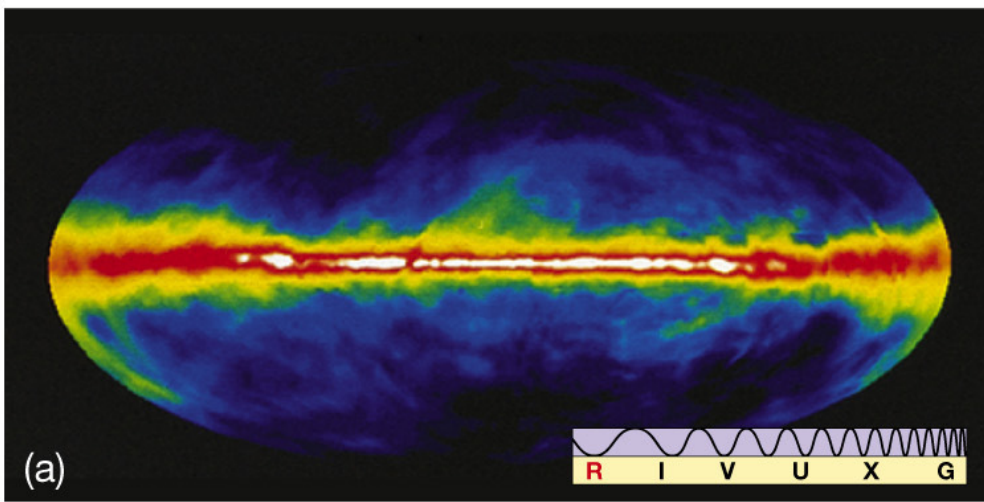


telecommunication

solar panels

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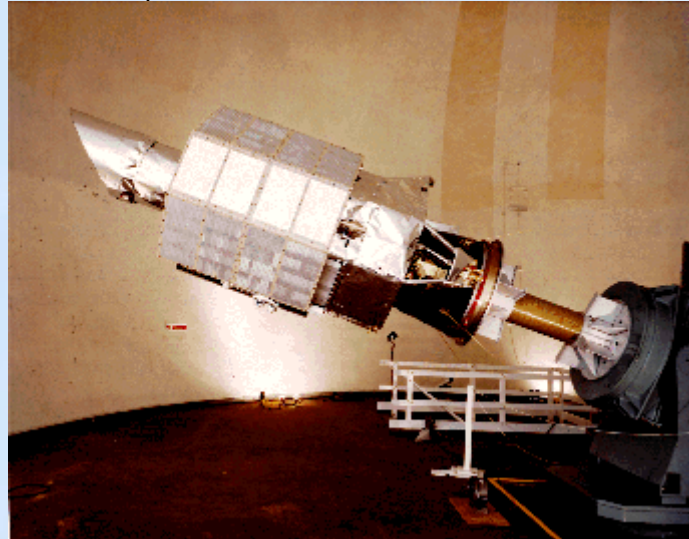
Sabancı
Üniversitesi



Q: Which figure is NOT a false color image?

Ultraviolet astronomy (400 μm – 10 nm):

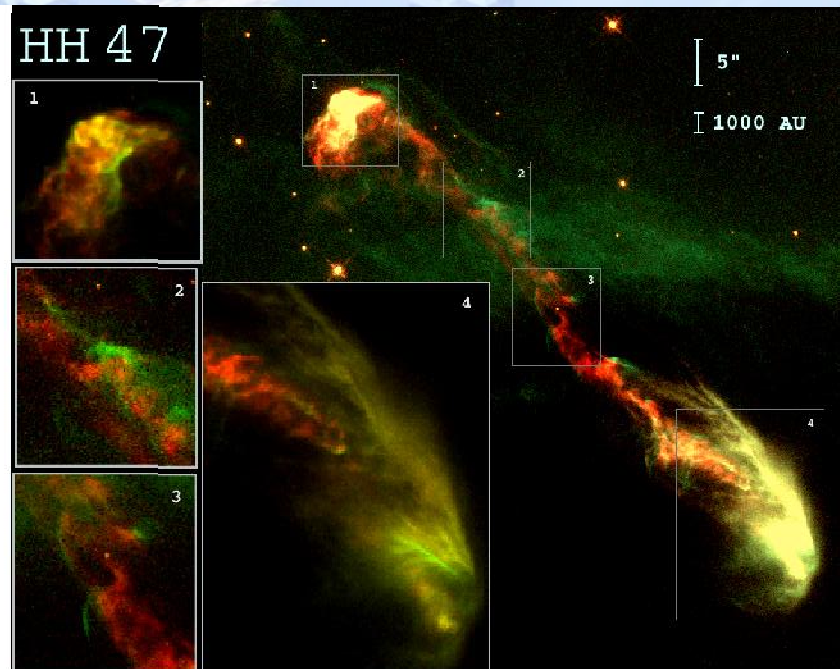
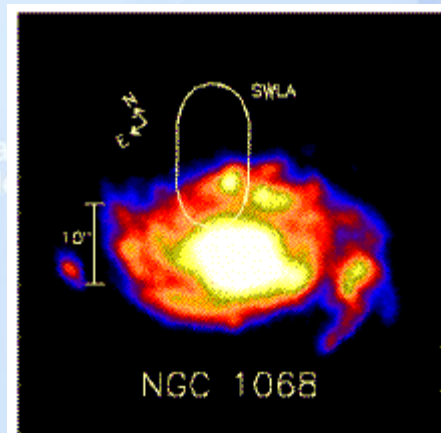
Rockets, balloons and satellites are essential for UV astronomy as the atmosphere is completely opaque to this part of the EM spectrum. Traces hot activity centers.



The International Ultraviolet Explorer was the longest lasting space mission and produced significant amount of UV data.

Power regulation

Reaction wheels for pointing the spacecraft



FUSE is now producing much detailed images.

Some instruments on HST also works in UV band.

TABLE 5.1 Astronomy at Many Wavelengths

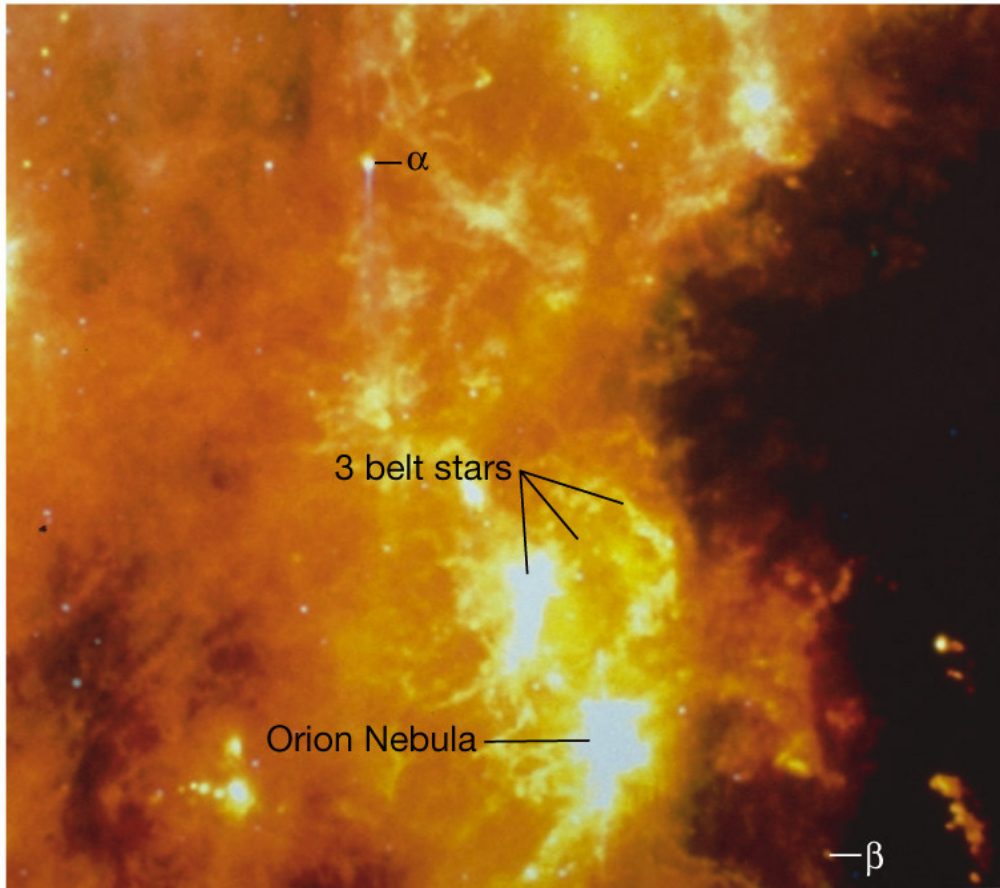
	General Considerations	Common Applications (Chapter Reference)
<i>Radio</i>	Can penetrate dusty regions of interstellar space Earth's atmosphere largely transparent to these wavelengths Can be detected in the daytime as well as at night High resolution at long wavelengths requires very large telescopes or interferometers	Radar studies of planets (2,9) Planetary magnetic fields (11) Interstellar gas clouds and molecules (18) Galactic structure (23, 24) Galactic nuclei and active galaxies (23, 24) Cosmic background radiation (27)
<i>Infrared</i>	Can penetrate dusty regions of interstellar space Earth's atmosphere only partially transparent to infrared radiation, so some observations must be made from space	Star formation (19,20); ec stars (20) Center of the Milky Way galaxy (23) Active galaxies (24) Large-scale structure of the universe (25, 27)
<i>Visible</i>	Earth's atmosphere transparent to visible light	Planets (7–14) Stars and stellar evolution (17, 20, 21) Normal and Active Galaxies (23, 24) Large-scale structure of the universe (25)
<i>Ultraviolet</i>	Earth's atmosphere is opaque to ultraviolet radiation, so observations must be made from space	Interstellar medium (19) Hot stars (21)
<i>X ray</i>	Earth's atmosphere is opaque to X rays, so observations must be made from space. Special mirror configurations are needed to form images	Stellar atmospheres (16) Neutron stars and black holes (22) Active galactic nuclei (24) Hot gas in galaxy clusters (25)
<i>Gamma ray</i>	Earth's atmosphere is opaque to gamma rays, so observations must be made from space. Cannot form images	Neutron stars (22) Active galactic nuclei (24)

Back to infrared astronomy:

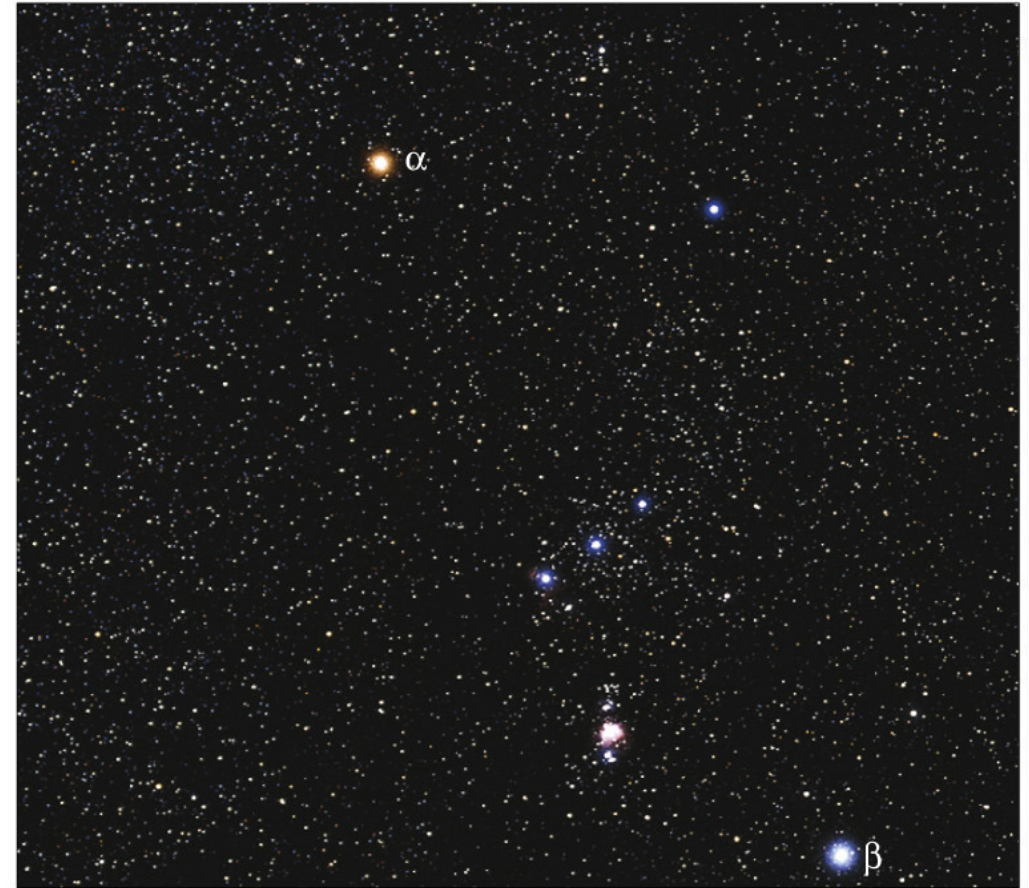
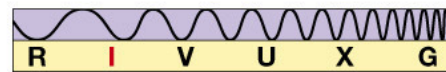
IBIS coded mask

JEM-X coded mask

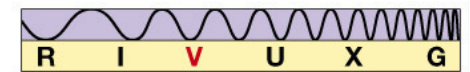
False color images, an important concept.



(a)



(b)



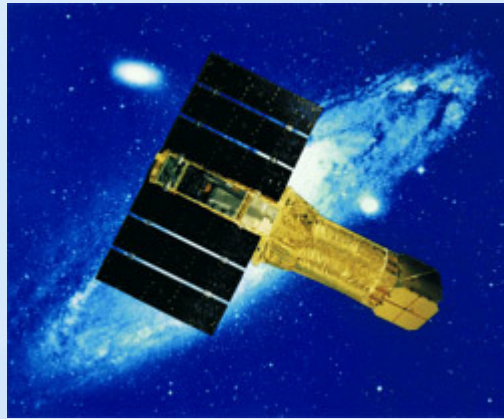
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Previous case shows the penetrating power through cold gas. Here, infrared shows (IRAS) the presence of hot gas which is not observable in visible light.

Parade of X-ray observatories:

IBIS coded mask

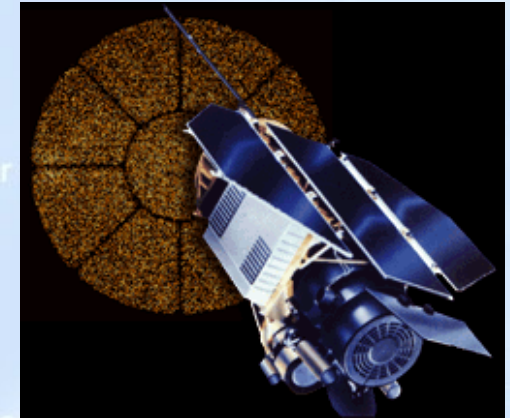
Payload module



IBIS detector
JEM-X detectors
ASCA



Beppo SAX



Star

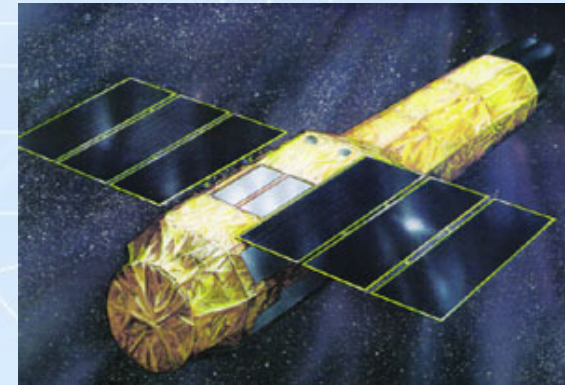
Rosat



Chandra



XMM-Newton



Suzaku

solar panels

Instrument computers
and electronics

Detector bench
Attitude control

12 - 13 October 2006, Ankara