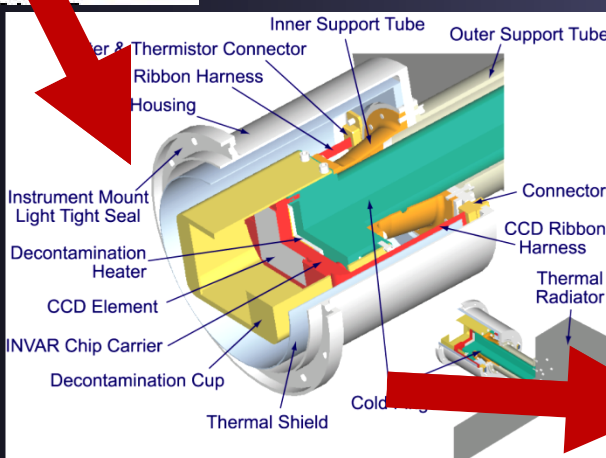
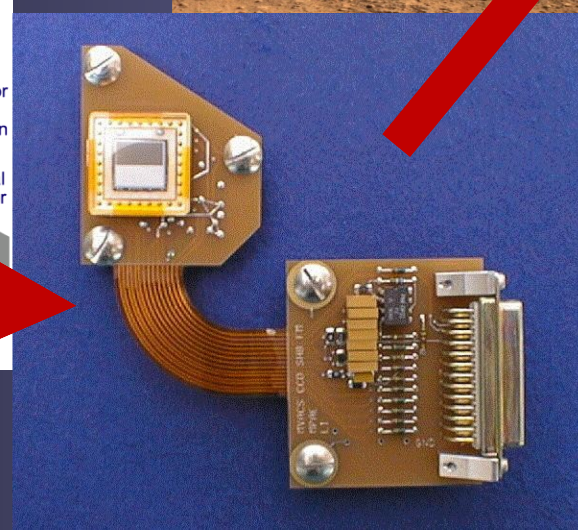
Solar System School

Space Instrumentation





Space Instrumentation - Outline

Introduction I (S.K. Solanki & J. Woch)

- Why we go to Space
- Space Exploration: then and now
- Realization of Space Projects

Introduction II (S.K. Solanki & J. Woch)

- Present and Future Space Missions

Instruments for Solar System Research: Methods, Concepts, Implementation, Results

Focus of lecture series

Focus is on

in-situ and remote sensing instruments on s/c for the exploration of solar system objects (Sun, Planets, Moons, Small Bodies, Heliosphere)

Focus is not on

Astrophysical observatories

Earth observation instruments

Zero-g experiments (biological, material science...)

space applications (telecommunication, navigation ...)

Why go to Space for Solar System Exploration ?

1. Retrieve information carried by E-M radiation not reaching Earth
   (same argument as for astrophysical applications)

Electromagnetic Spectrum

Quantum nature of radiation:

$E_\nu = h\nu = hc/\lambda$

- Radio/Microwave (Frequency/Wavelength) → THz, GHz, MHz, cm, m
- Infra-red/Sub-mm (Wavelength) → μm, mm
- Visible/UV/EUV (Wavelength) → Å, nm ; <100eV
- X-ray, → <1 – >10 keV
  γ-ray,
  Cosmic Rays >1 MeV

Regions of the Spectrum

	Wavelength (m)	Frequency (Hz)	Energy (J)
Radio	$> 1 \times 10^{-1}$	$<3 \times 10^{9}$	$<2 \times 10^{-24}$
Micro-wave	$1 \times 10^{-3} – 1 \times 10^{-1}$	$3 \times 10^{9} – 3 \times 10^{11}$	$2 \times 10^{-24} – 2 \times 10^{-22}$
Infrared	$7 \times 10^{-7} – 1 \times 10^{-3}$	$3 \times 10^{11} – 4 \times 10^{14}$	$2 \times 10^{-22} – 3 \times 10^{-19}$
Optical	$4 \times 10^{-7} – 7 \times 10^{-7}$	$4 \times 10^{14} – 7.5 \times 10^{14}$	$3 \times 10^{-19} – 5 \times 10^{-19}$
UV	$1 \times 10^{-8} – 4 \times 10^{-7}$	$7.5 \times 10^{14} – 3 \times 10^{16}$	$5 \times 10^{-19} – 2 \times 10^{-17}$
X-ray	$1 \times 10^{-11} – 1 \times 10^{-8}$	$3 \times 10^{16} – 3 \times 10^{19}$	$2 \times 10^{-17} – 2 \times 10^{-14}$
γ-ray	$< 1 \times 10^{-11}$	$> 3 \times 10^{19}$	$> 2 \times 10^{-14}$

EM Spectrum - What gets through to Earth

	Wavelength (m)	Frequency (Hz)	Energy (J)
Radio	$> 1 \times 10^{-1}$	$<3 \times 10^{9}$	$<2 \times 10^{-24}$
Micro-wave	$1 \times 10^{-3} – 1 \times 10^{-1}$	$3 \times 10^{9} – 3 \times 10^{11}$	$2 \times 10^{-24} – 2 \times 10^{-22}$
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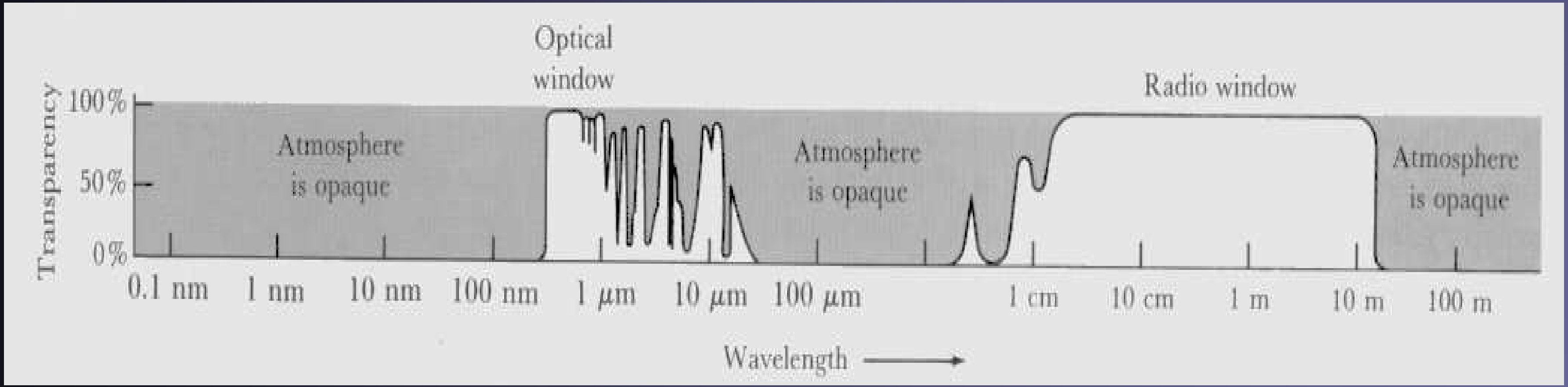
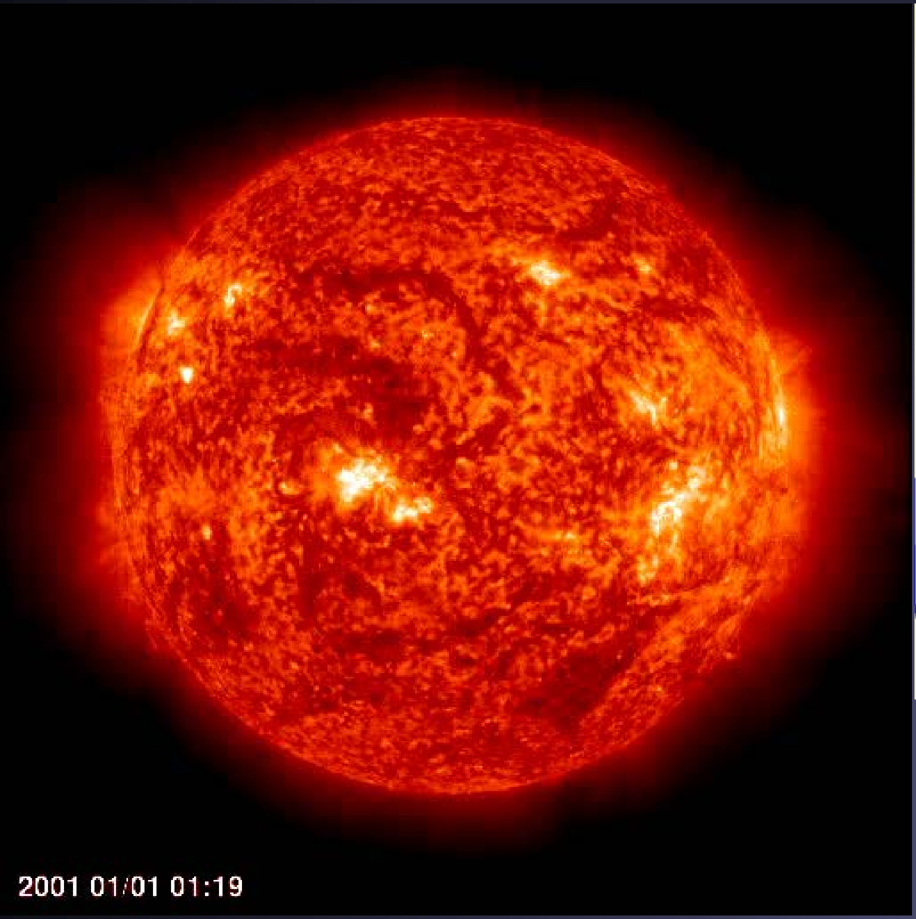
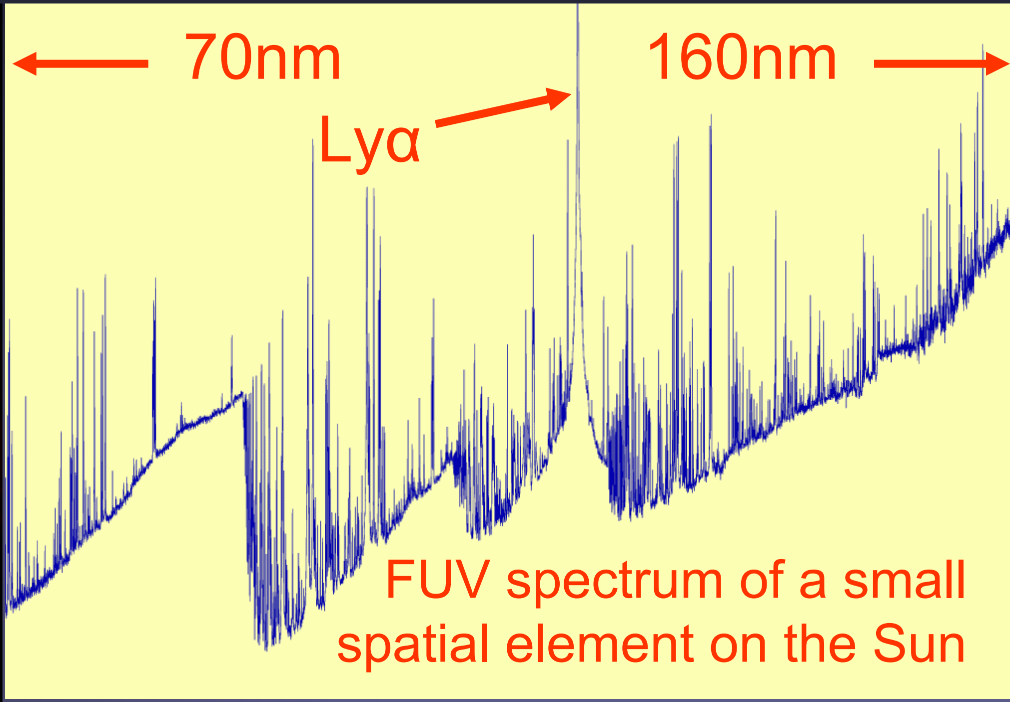


Photon absorption by the atmosphere of the Earth

EUV observations from space



EIT movie at 30.4 nm

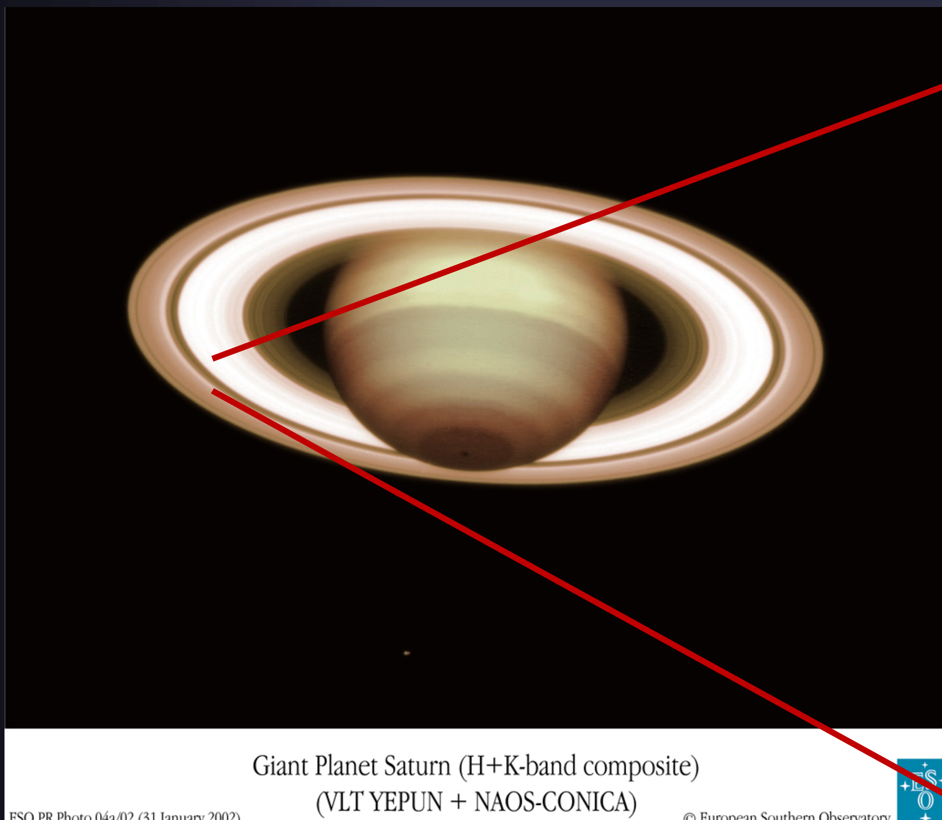


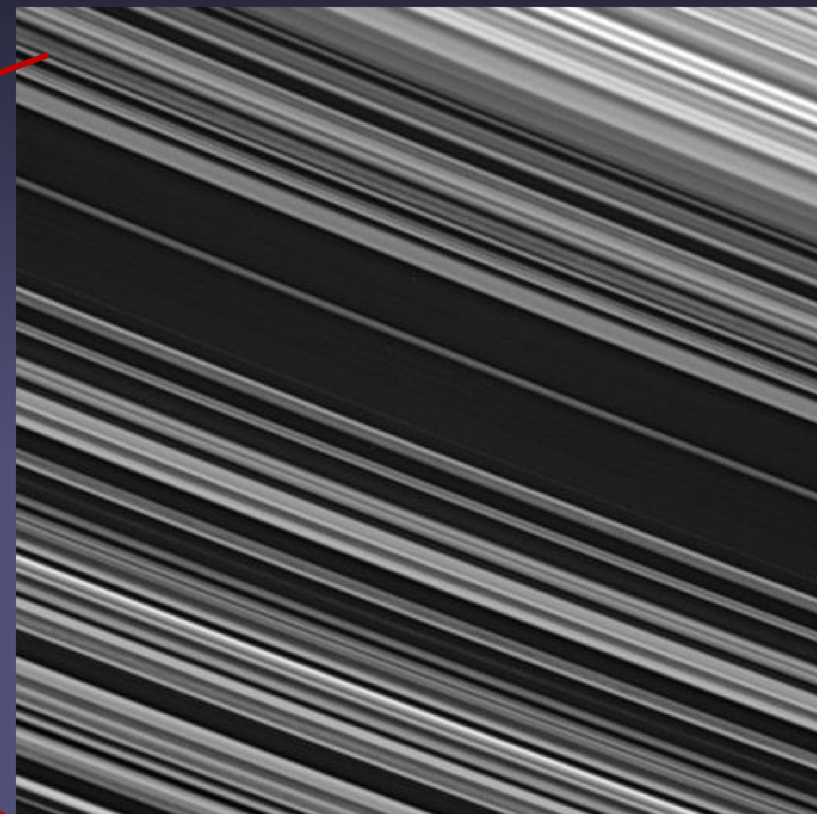
SUMER spectrum

Why go to Space for Solar System Exploration ?

1. retrieve the information carried by E-M radiation not reaching Earth
2. increase resolution

Why go to Space for Solar System Exploration ?





Saturn and Rings
from Earth (ESO VLT)

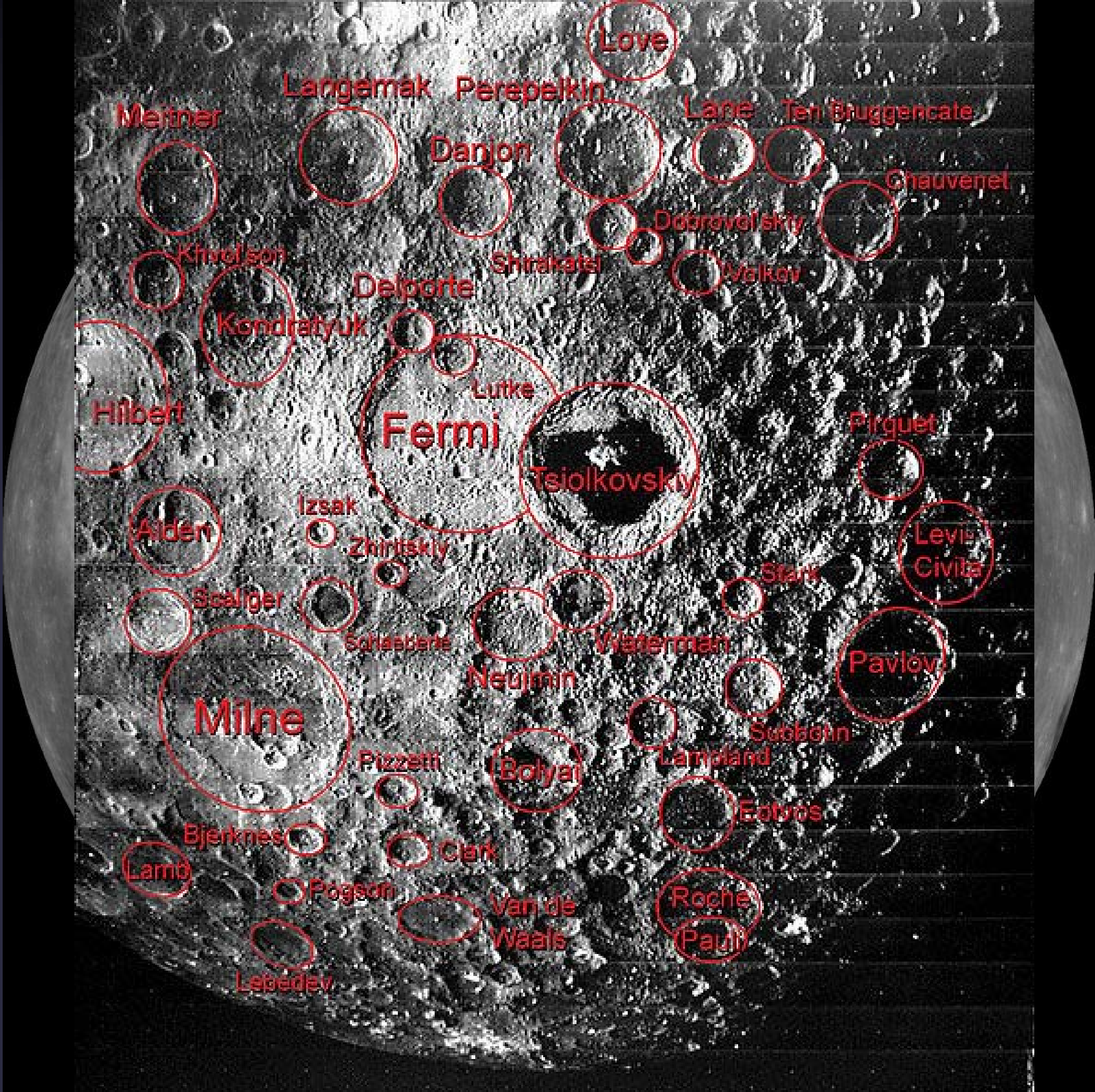
Spokes Zone in the B Ring of Saturn
from space (Cassini)

Why go to Space for Solar System Exploration ?

1. retrieve the information carried by E-M radiation not reaching Earth
2. improve spatial resolution
3. observe regions ‘invisible’ from Earth

The far side of the Moon

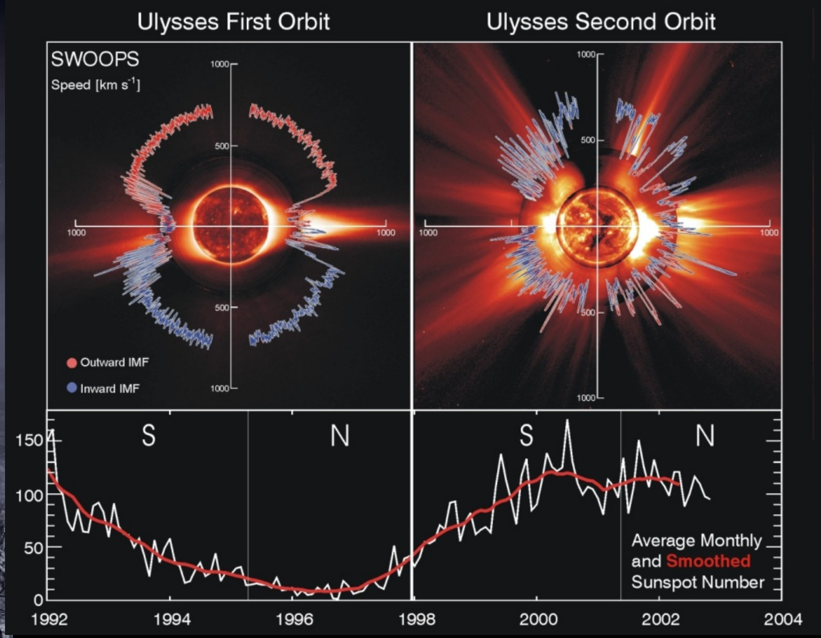
(*Clementine*)



Why go to Space for Solar System Exploration ?

1. retrieve the information carried by E-M radiation not reaching Earth
2. increase spatial resolution
3. observe regions ‘invisible’ from Earth
4. perform in situ measurements in solar system body environments (surfaces, atmospheres magnetospheres) and in interplanetary space


Rosetta lander


Ulysses First Orbit
Ulysses Second Orbit
SWOOPS
Speed [km s-1]
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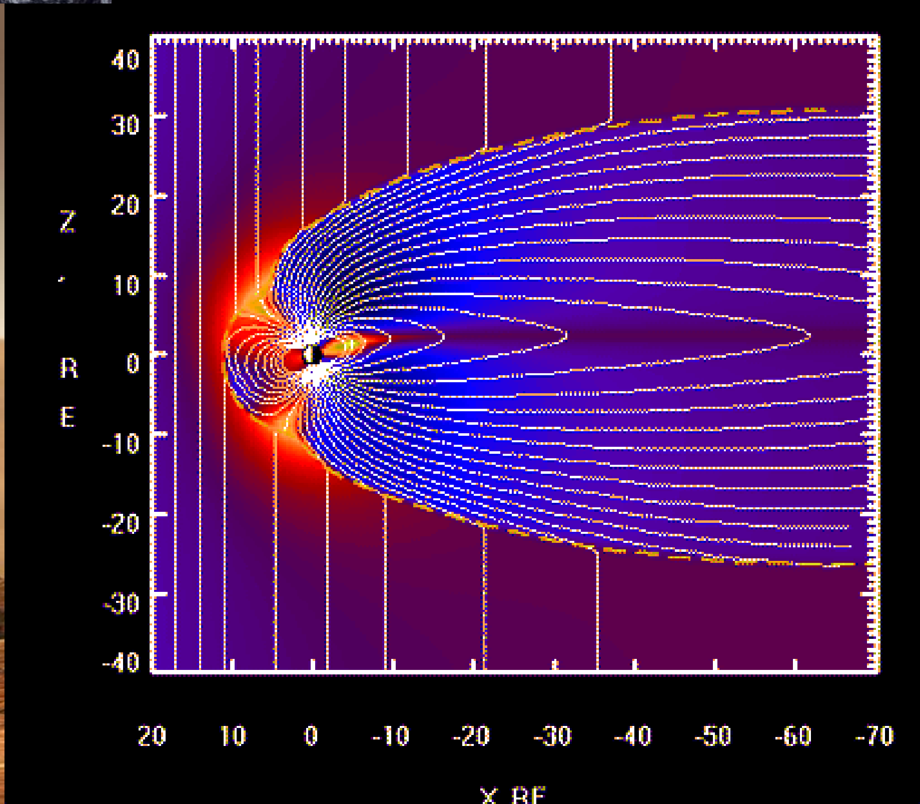
Sunspot Number


Spirit and Opportunity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Solar System Science: then & now

The research field 'Solar System Science' is very much coupled to the 'space age' i.e., availability of rockets.

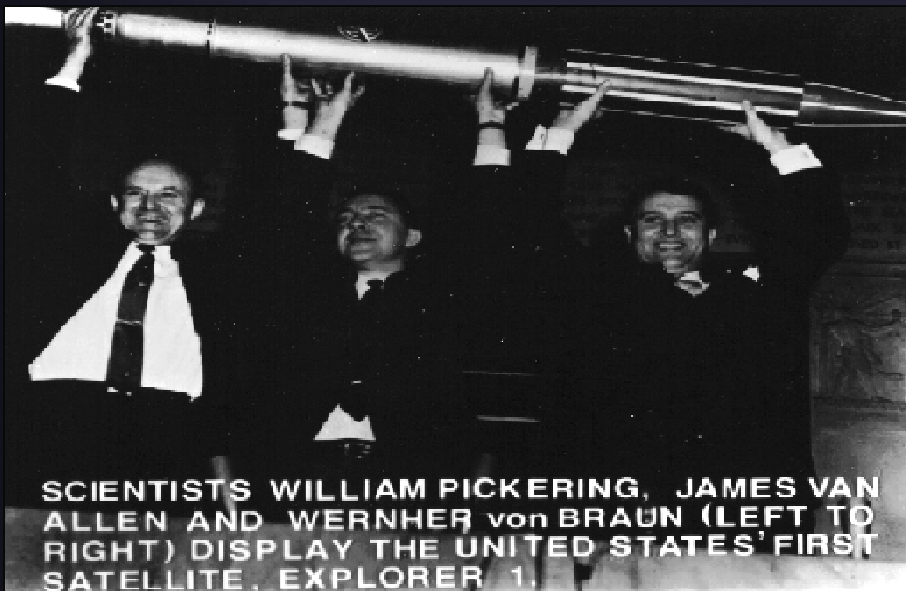
Before that, SSS was solely based on

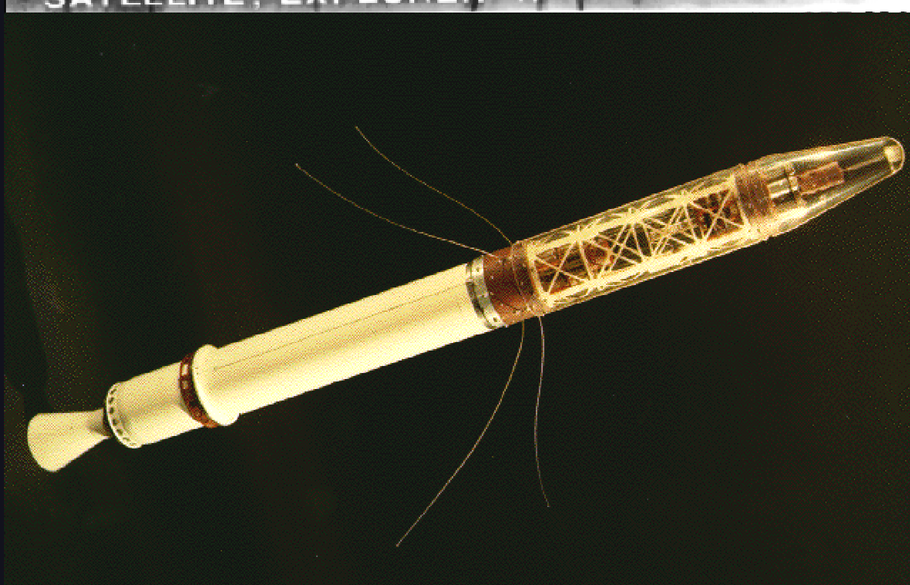
- Astrophysical methods (optical & radio observations)
- Some limited indirect methods (e.g. aurora observations, ground based magnetic field observations, cosmic ray detection which allowed some educated guesses on the interplanetary environment)

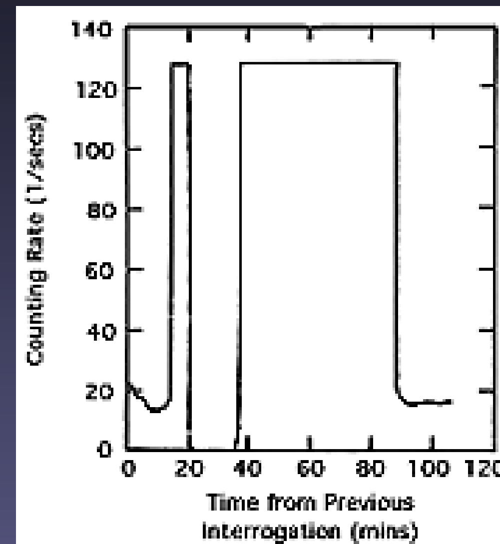
➔ SSS was severely restricted (with solar physics as a bit of an exception)

The possibility of in-situ observations introduced a new scientific quality to the field which justified that it became a self standing research field

Early Space-based Research





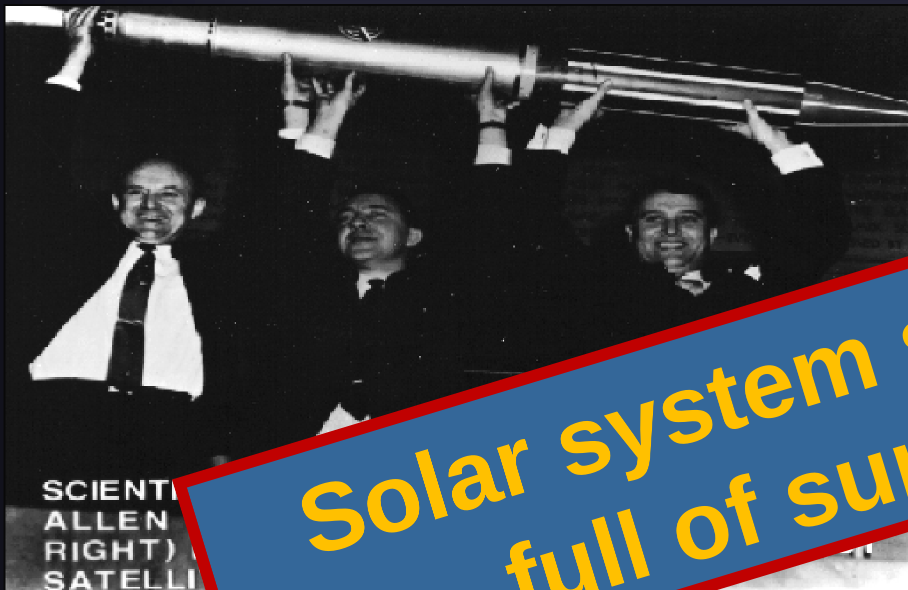


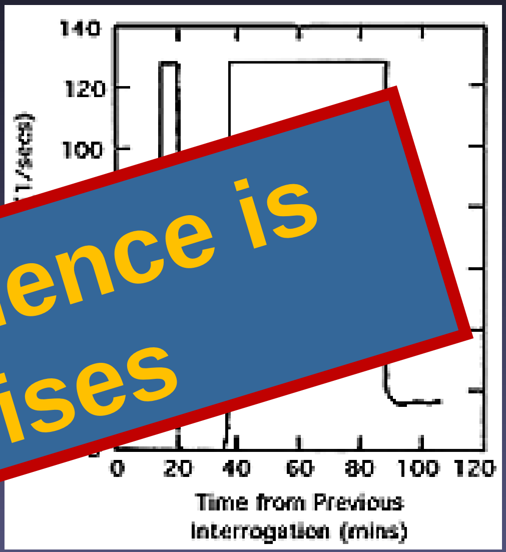
tape recorder read-out from Explorer 3

Explorer 1 (Jan 31, 1958) carried a Geiger Counter to study the latitudinal distribution of low-energy cosmic rays. It failed miserably in that

Instead, it discovered Earth's radiation belts (saturation of counters)

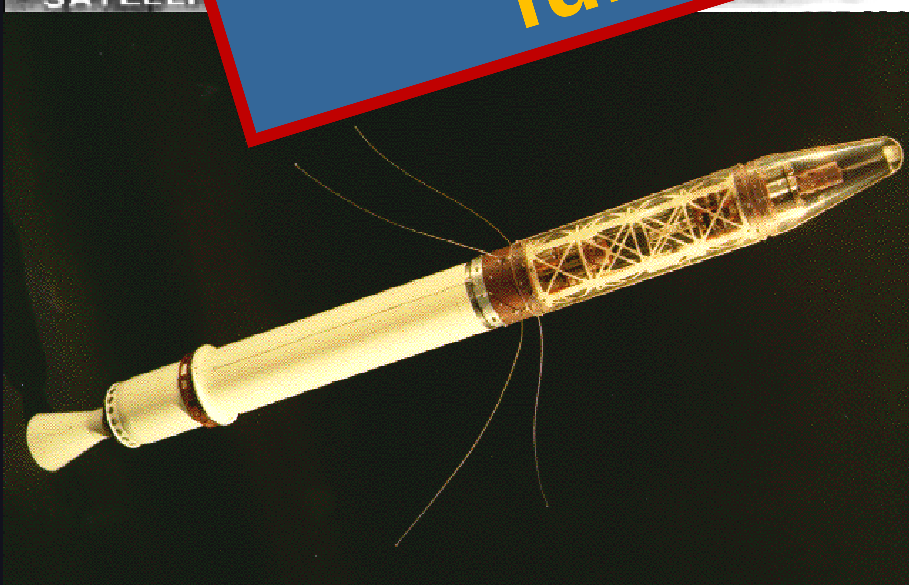
Early Space-based Research





tape recorder read-out from Explorer 3

Solar system science is full of surprises



Explorer 1 (Jan 31, 1958) carried a Geiger Counter to study the latitudinal distribution of low-energy cosmic rays. It failed miserably in that

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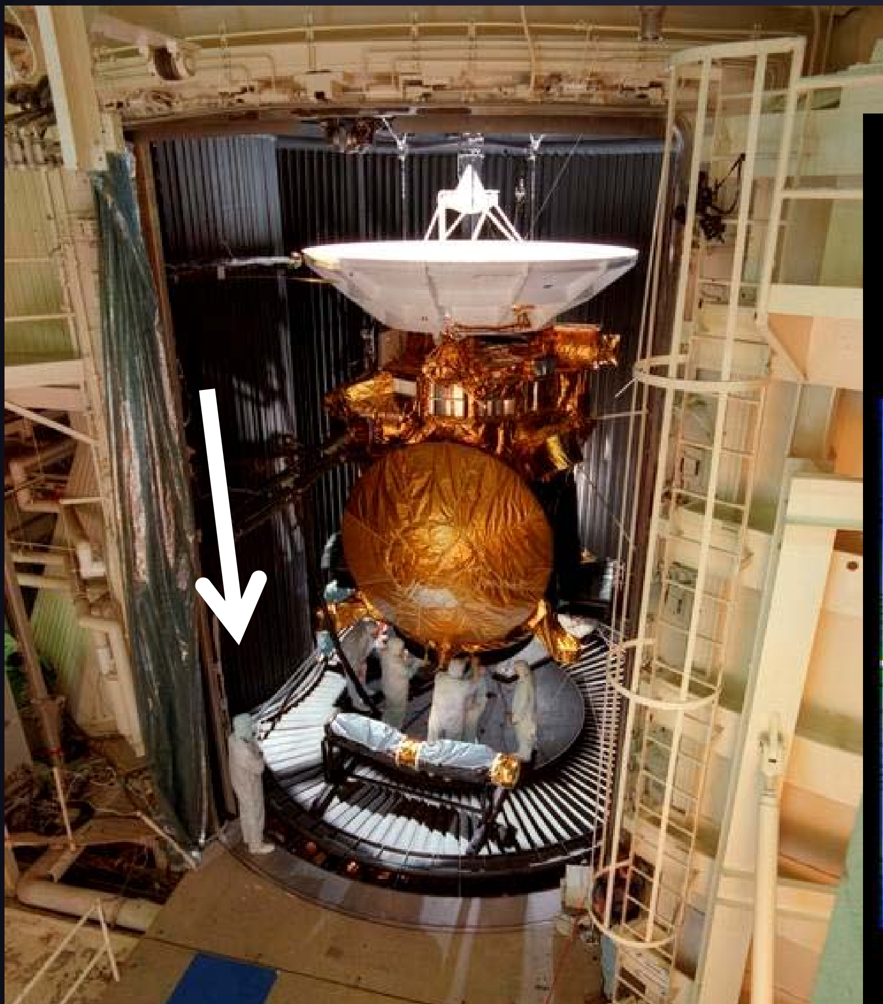
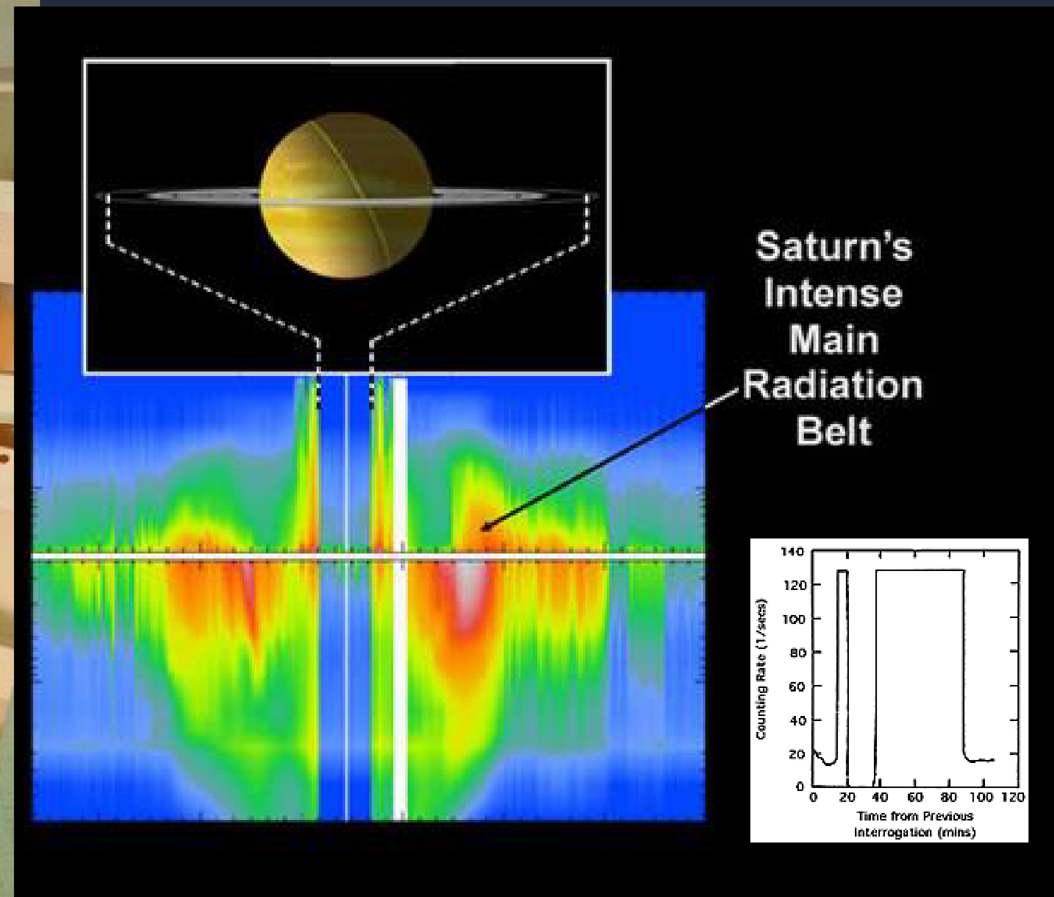
Solar system science has developed

- Nowadays not every mission brings new discoveries, some ‘just’ test (and confirm or reject) current models and theories
- A new mission/instrument therefore in general needs to be significantly better in some way than earlier missions/instruments that did the same thing

< 50 years between Explorer 1 and this

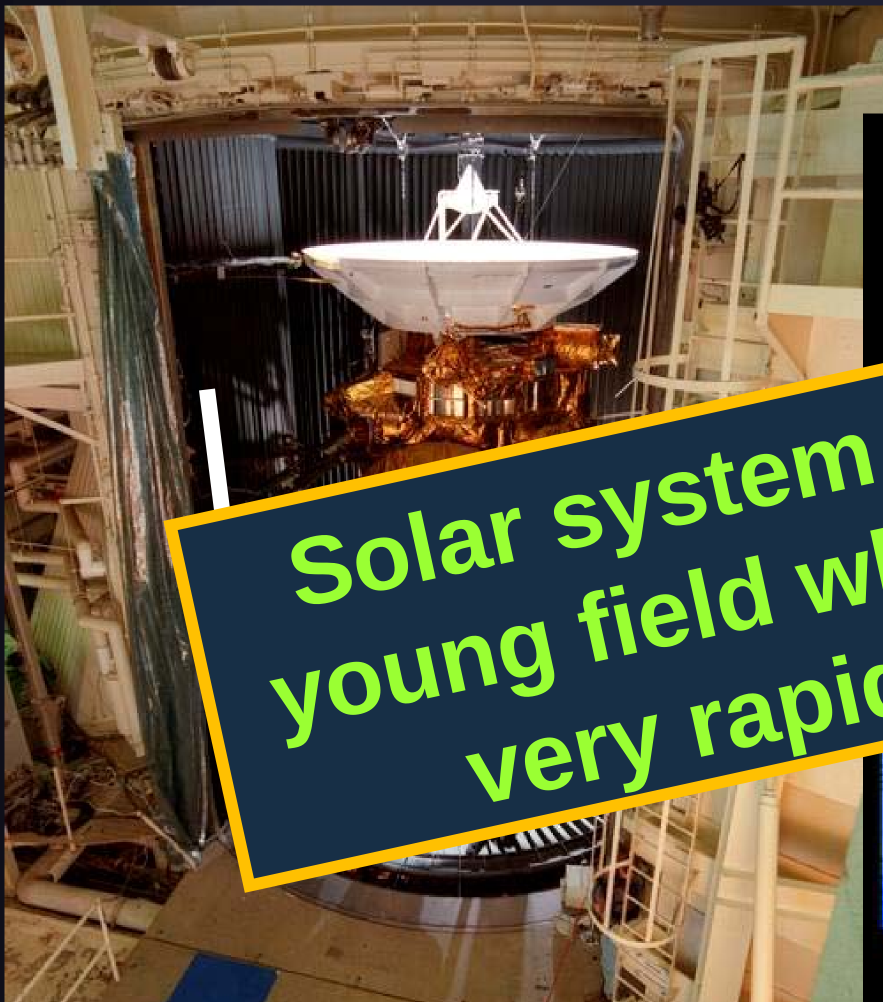


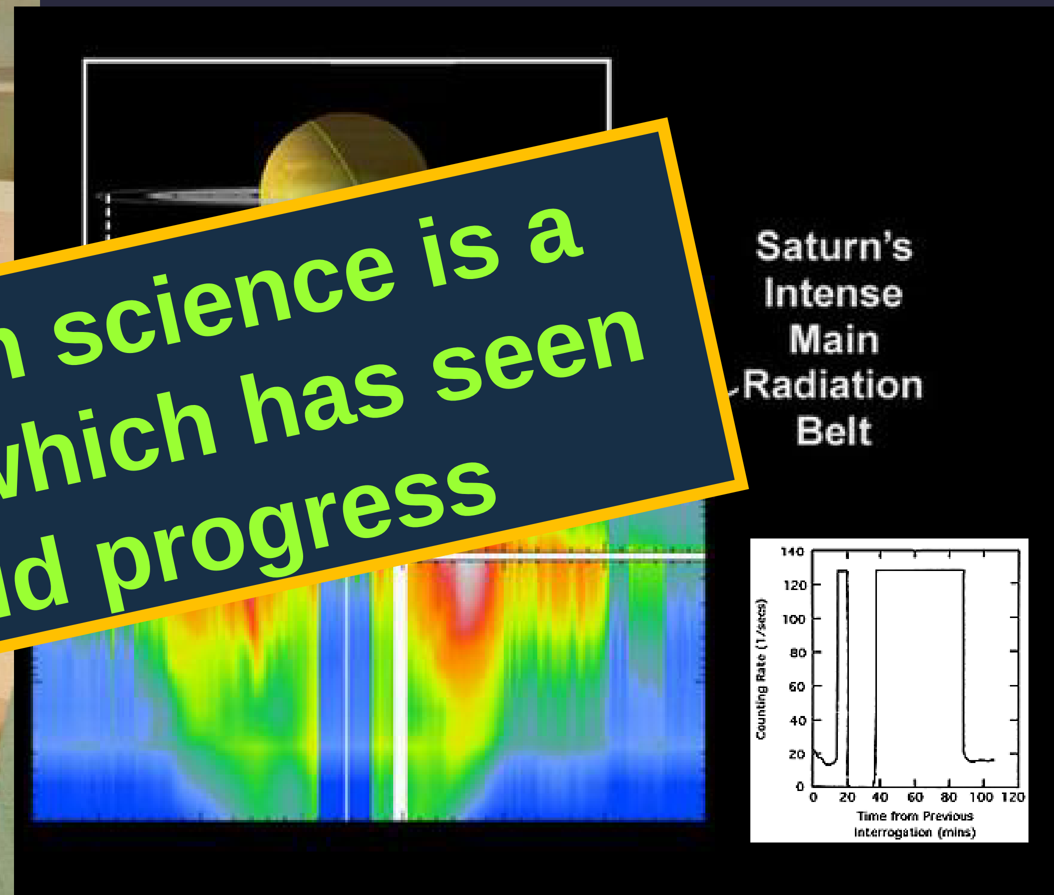


Cassini pre-launch 1997

Cassini at Saturn 2004

< 50 years between Explorer 1 and this





Solar system science is a young field which has seen very rapid progress

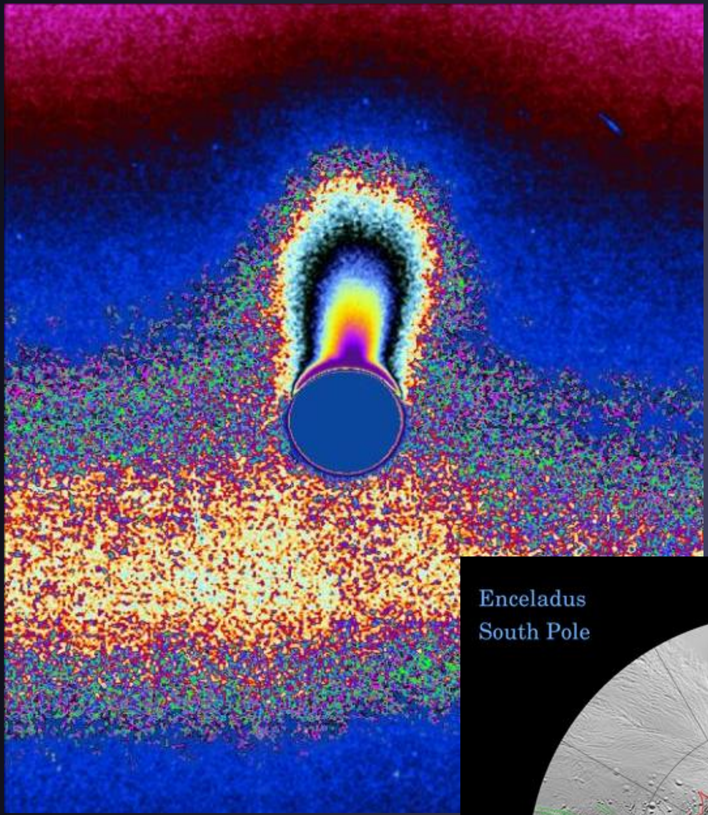
Cassini pre-launch 1997

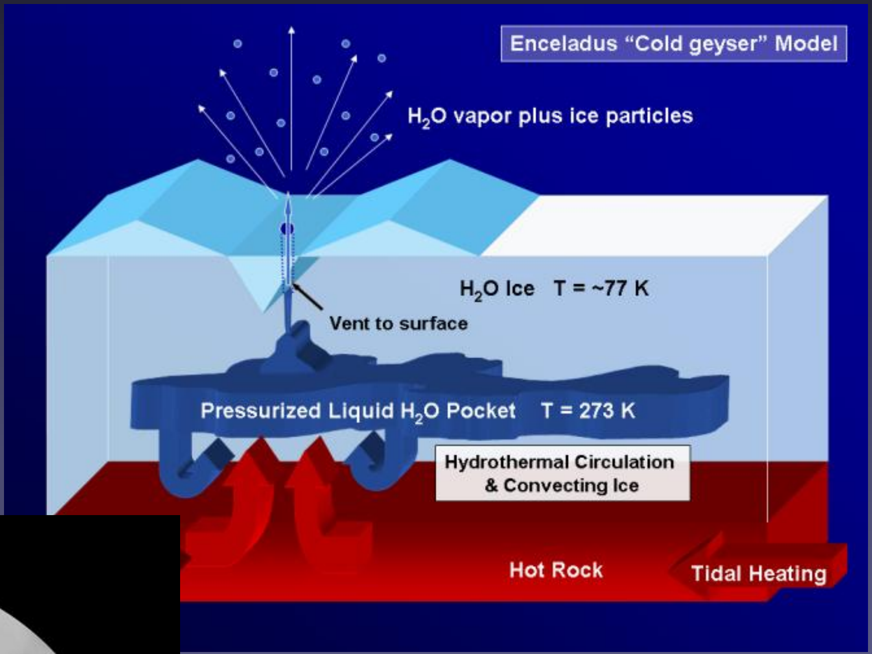
Cassini at Saturn 2004

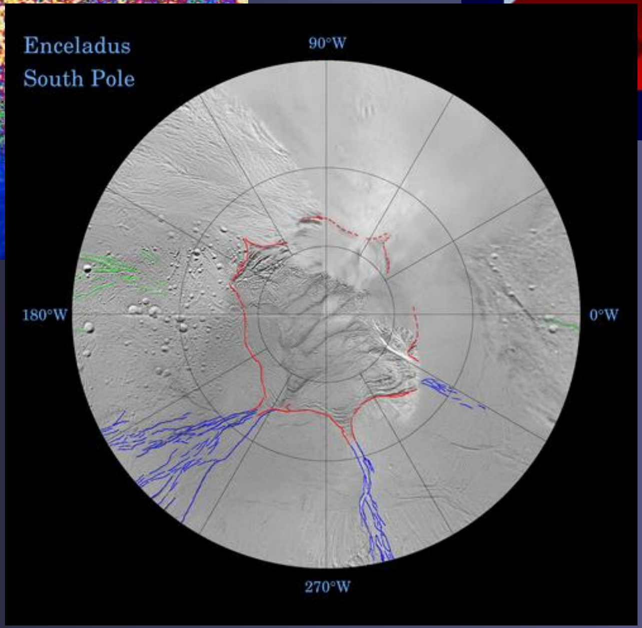
Solar system science has developed

- Nowadays not every mission brings new discoveries, some ‘just’ test (and confirm or reject) current models and theories
- A new mission/instrument therefore in general needs to be better in some way than earlier missions/instruments doing the same thing
- This does not mean that there are no new discoveries possible!   Recent examples: Cassini and Enceladus; Hinode and polar X-ray jets

Ice jets on Enceladus

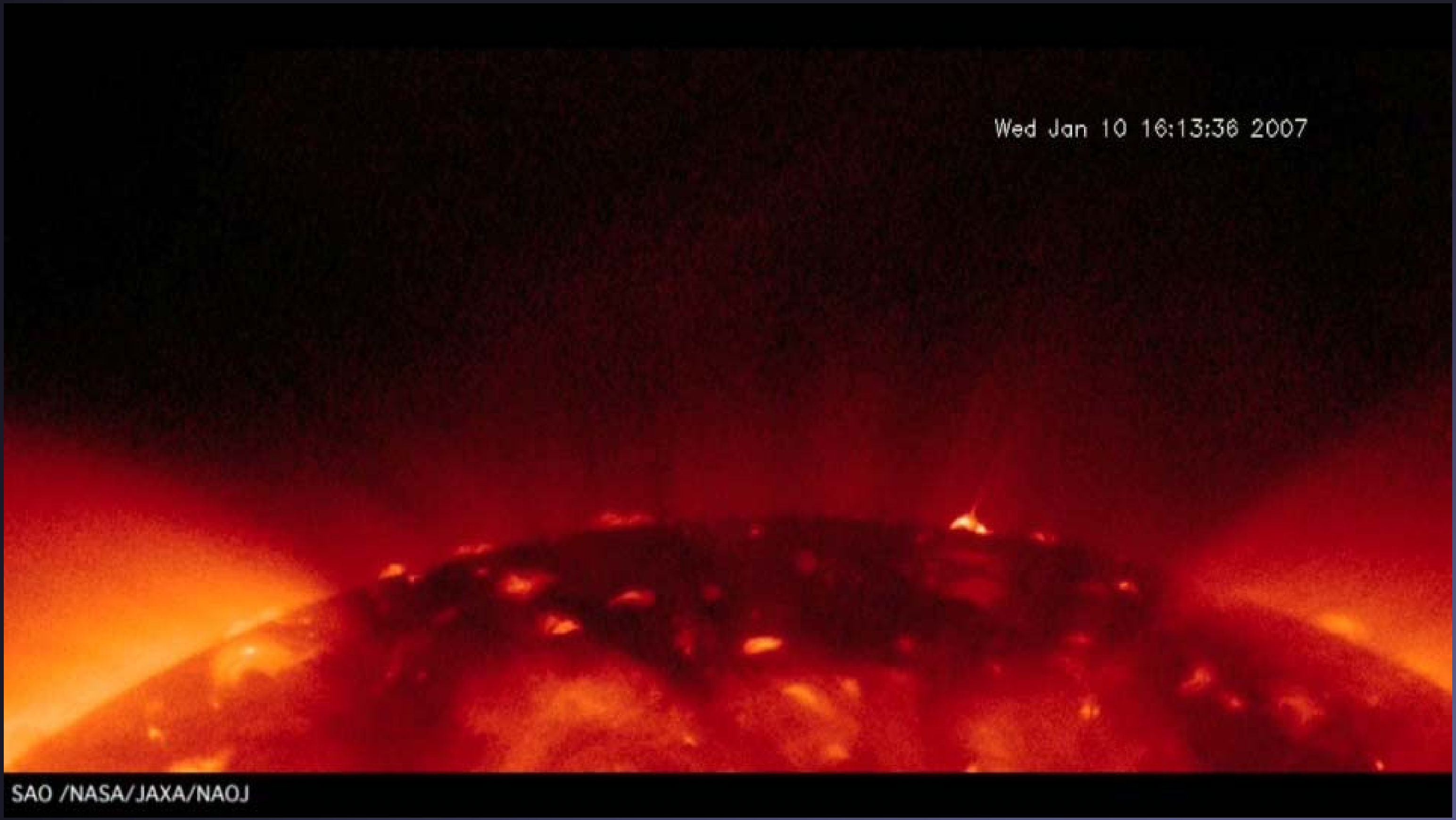






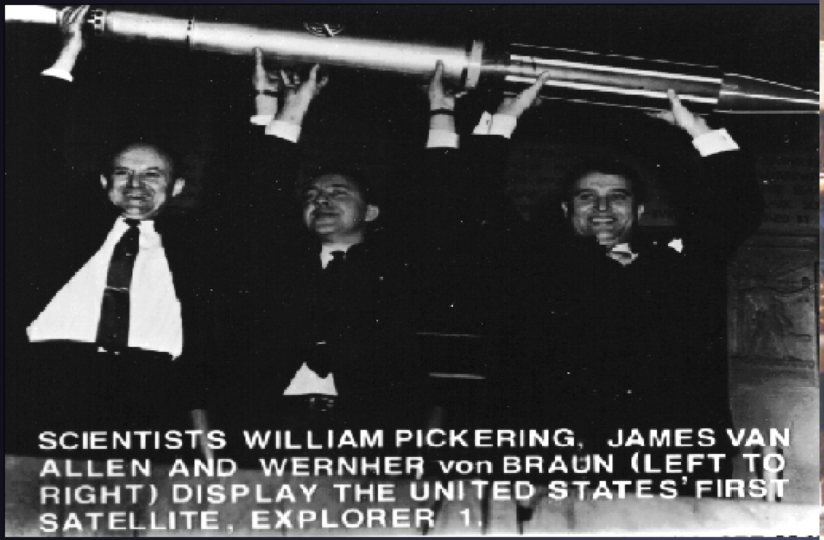
Enceladus was no prime science target prior to Cassini, now with this discoveries it has become the focus of the Cassini extended mission and triggered new mission ideas

Plasma jets at solar poles

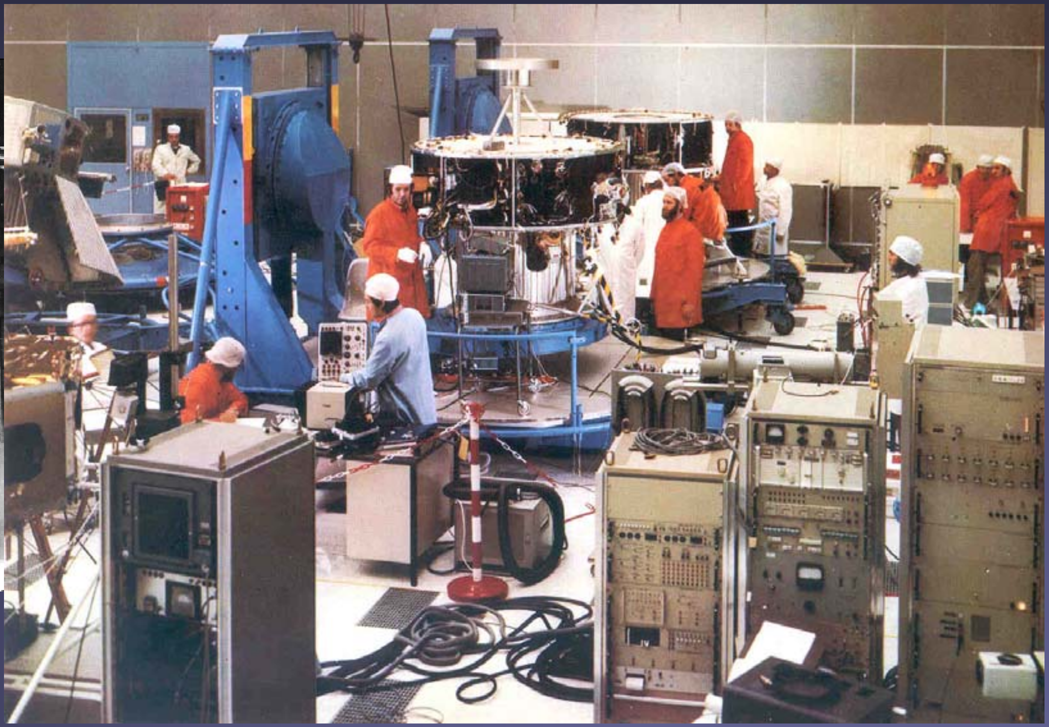


- Hinode XRT found prominent jets in solar polar coronal holes
- These hot jets imply expulsion of material into the upper corona
- Probably powered by magnetic reconnection near their footpoints
- Showed what a violent place coronal holes are

How does a Space Mission come to Life? Implementing a Space Project



it is no longer like this (with some exceptions)



it is (usually) like this

Increasing complexity of space projects

Space Projects have become increasingly complex:

Main driver: each mission needs to achieve more than the previous one:

- Targets are more difficult to reach; easy targets have all be studied in depth
- Instruments have become more advanced and thus more demanding

➔ tremendous increase in costs

➔ most missions are handled by big space agencies (NASA, ESA, JAXA, ...); often multi-national projects

➔ opportunities are comparatively rare, approval phase is long and troublesome and depends on political and economical factors (e.g. NASA manned spaceflight can easily eat up entire science budget by a slight cost overrun).

Science Program of a Space Agency (e.g. ESA)

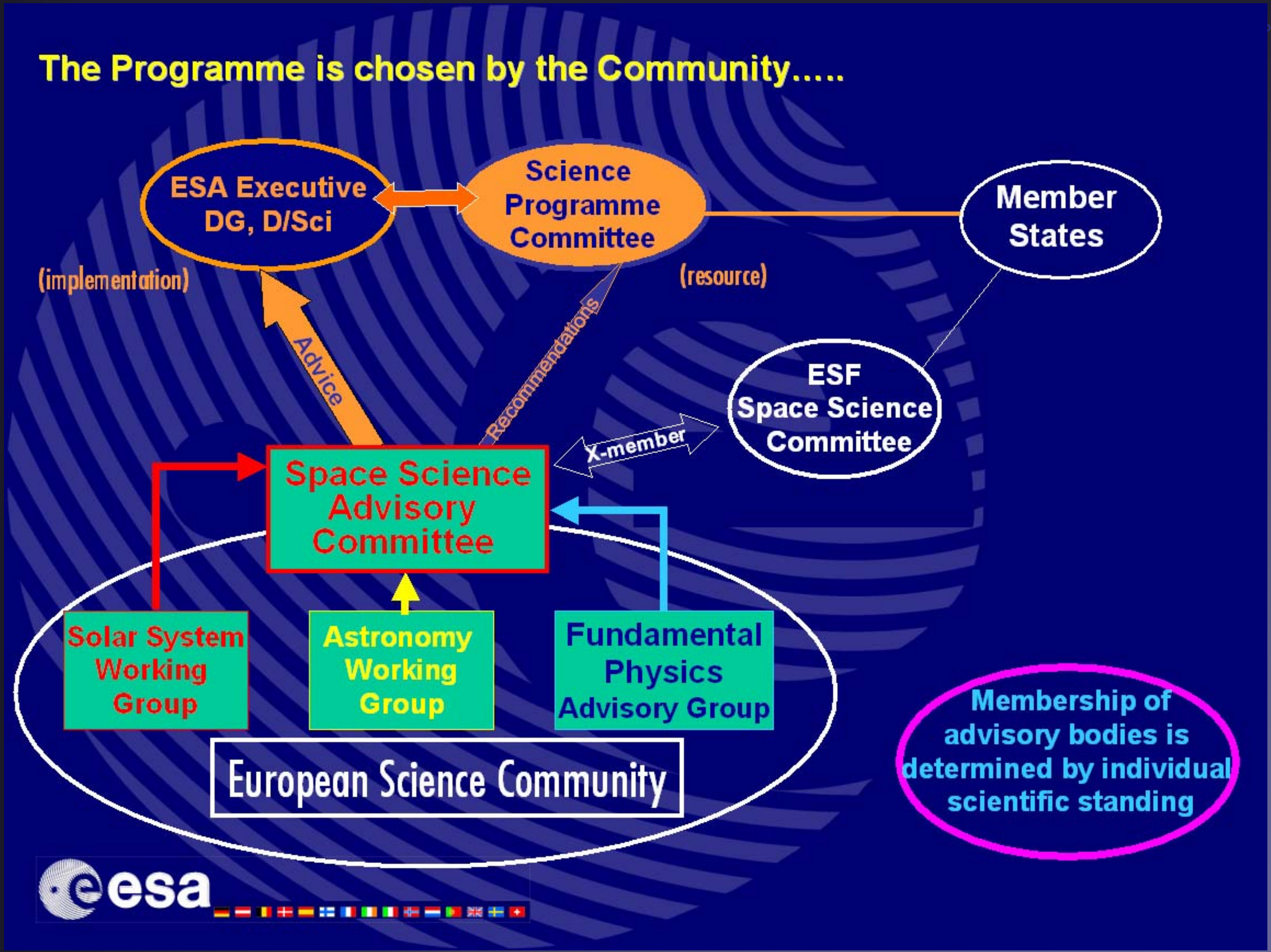
ESA's Cosmic Vision Program

OPERATIONS / DATA ANALYSIS	IMPLEMENTATION	DEFINITION	ASSESSMENT
Venus Express [2005]	GAIA [2012]	**Solar Orbiter [2017]**	**EJSM [2020-2025]**
Rosetta [2004]	LISA Pathfinder [2012]	PLATO [2018]	LISA [2020-2025]
Double Star [2003]	JWST [2014]	Euclid [2018-2019]	IXO [2020-2025]
SMART-1 [2003]	**BepiColombo [2014]**		
Mars Express [2003]			
INTEGRAL [2002]			
Cluster [2000]			
XMM-Newton [1999]			
Cassini-Huygens [1997]			
SOHO [1995]			
Hubble [1990]			
Ulysses [1990]			
COROT [2006]			
Herschel [2008]			
Planck [2008]			

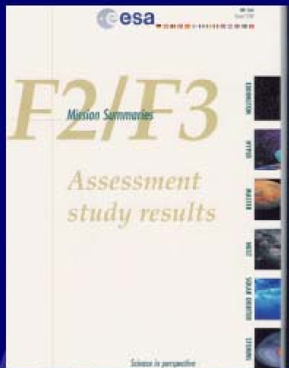
The Selection Process of a Mission

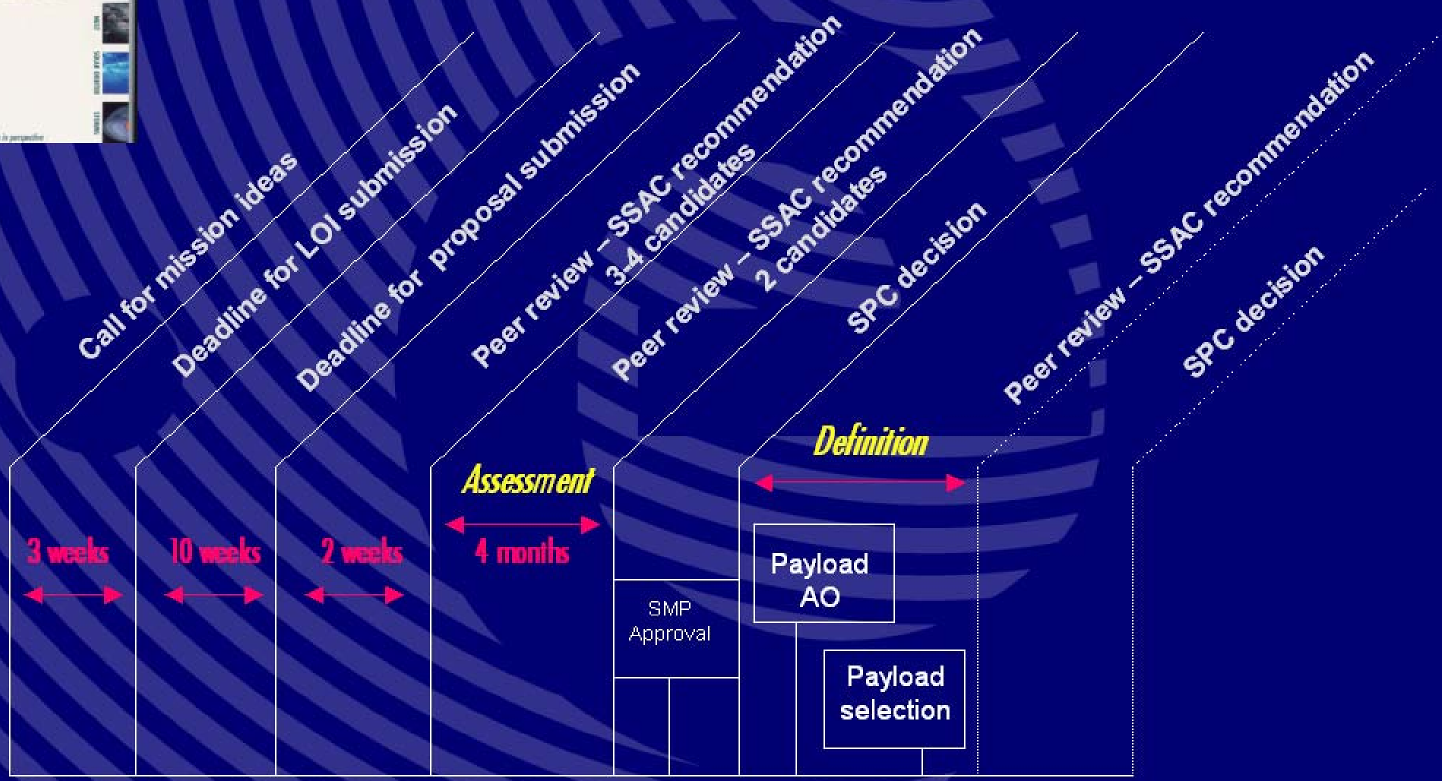
The Science Programme is a mandatory programme of the European Space Agency. This means that each member state contributes to the activities of the Science Programme with a share proportional to its GNP (Gross National Product). The missions themselves are selected in consultation with the European scientific community through the advisory structure of the Programme. Traditionally, payloads are selected by peer reviews through the advisory structure of the Programme, and are directly funded by the National Space authorities. *(Quote ESA)*

The Advisory Structure of ESA



The selection of a Science mission





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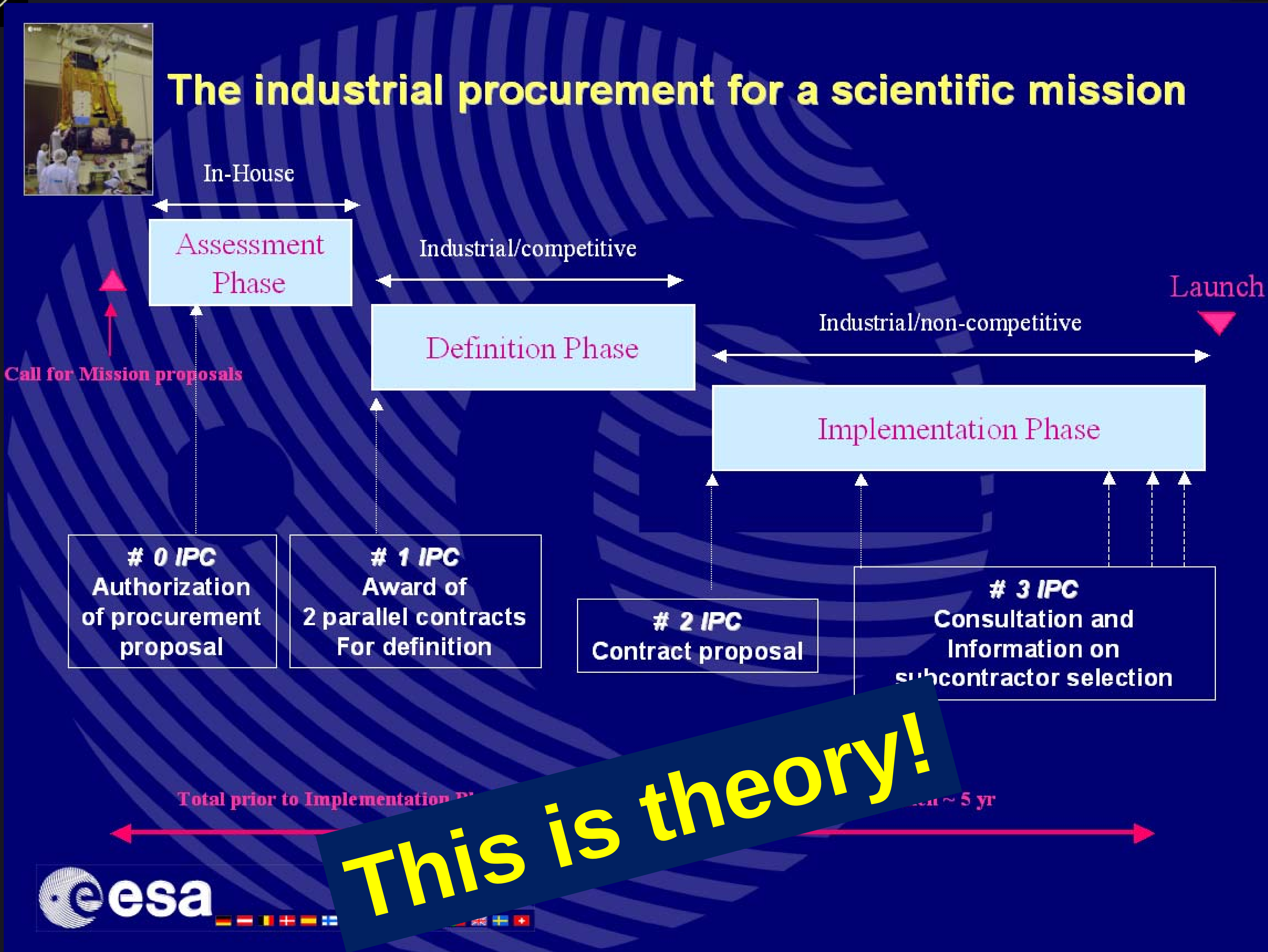

This is theory!

Some Things to Remember

Space Missions usually are:

Precious

- they offer discoveries of new frontiers,
- they have a large visibility to the public,
- data are often spectacular,
- data are often unique.

Risky

- some missions are lost too early, (some even before launch!)
- instruments can fail, there are no possibilities for repair,

Expensive

- in order to minimize risk, everything is designed more carefully than usual,
- proper tests have to be conducted (again and again and again…)
- the agencies require considerable management efforts,
- safety aspects are major cost drivers

Some Things to Remember II

Space Missions usually are:

Rare

- because of the cost, they are carefully selected and often delayed,
- you are generally in competition with other discplines

Long-term efforts, because of

• long approval procedures,	Helios:	1965 to 1969
• long development phases,		1966 to 1976
• long mission durations,		1974 to 1986
• long travel times to their research goals		n/a
• Long scientific evaluation and re-evaluation		1974 to now...

Ambitious

- They are conquering new frontiers with unknown environment,
- They often require considerable, advanced high-tech developments,

Extremely conservative

- No avoidable risk must be taken,
- Only space-proven techniques may be applied,
- In most cases, the PIs are experienced and, thus, old...

Launching

- The primary driver for cost of the launch is the mass
- This (+ size of fairing) restricts the size of the spacecraft
- Instruments are subject to severe vibration and acoustic noise from the rocket motors. Mechanical shocks are also present caused by e.g. the first stage separation

Launch of SOHO 1995

Some Challenges in Space

- Vacuum of space: contaminants can readily move from one part of an instrument to another, outgasing can be a problem, high voltage discharge is an issue.
- Sun’s thermal radiation: typically a satellite is illuminated by Sun on one side (T~6000K) and Earth (T~300K) or space (~4K) on the other
- Ionising radiation: commercial electronics are not suitable as they are not radiation hard
- Restricted power: instruments and spacecraft system have to be tailored for low power consumption
- Restricted telemetry: telemetry is a crucial constraint for satellite observations, e.g., limiting the cadence or size of images, spectra, etc. ➔ intelligent observation modes, powerful data compression algorithms, etc. required