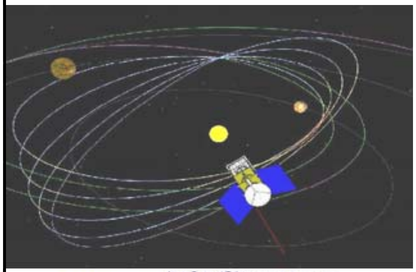
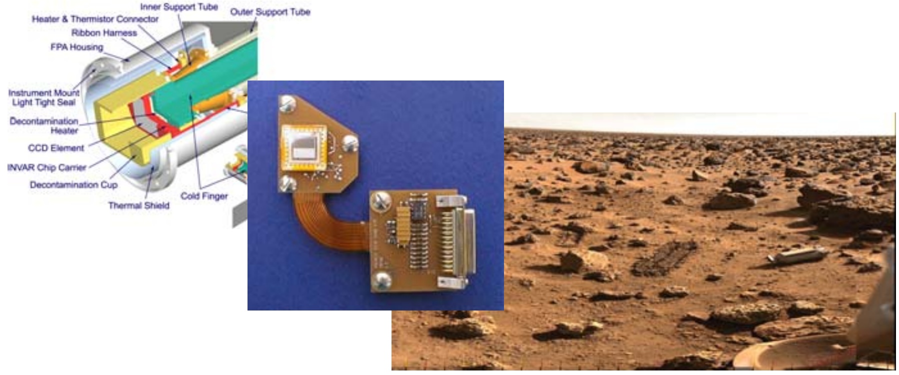


Solar System School Lecture on

Space Instrumentation

IMPRS Katlenburg-Lindau, Dec 4 – 7, 2006



Space Instrumentation - Outline

Introduction

- **Why we go to Space**
- **History of Space Exploration**
- **Realization of Space Projects**
- **Present and Future Space Missions**

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

IMPRS LECTURE 'Space Instrumentation' Dec 4 – 7, 2006

TIME	SPEAKER	WORKING TITLE
Mon, Dec 4th		
9:30-10:15	J. Woch	Introduction I
10:30-11:15	J. Woch	Introduction II
11:30-12:15	A. Gandorfer	Solar Telescopes I
lunch		
13:30-14:15	A. Gandorfer	Solar Telescopes II
14:30-15:15	W. Curdt	Solar Spectroscopy
15:30-16:15		Tour SUMER ?
Tue, Dec 5th		
9:30-10:15	A. Gandorfer	Instrumental Techniques for Solar Polarimetry, Magnetographs
10:30-11:15	R. Schwenn	Coronagraphs
11:30-12:15	P. Barthol	Sunrise – A Solar Balloon Mission
lunch		
13:30-14:30	J. Woch	Particle detectors
14:45-15:45	I. Richter	Magnetometer

IMPRS LECTURE 'Space Instrumentation' Dec 4 – 7, 2006

TIME	SPEAKER	WORKING TITLE
Wed, Dec 6th		
9:30-10:15	M. Hilchenbach	Rosetta – An Example for a Modern Planetary Mission
10:30-11:15	N. Hoekzema	Cameras and Altimeters
11:30-12:15	P. Hartogh	Microwave Spectroscopy
lunch		
13:30-14:15	H. Krueger	Dust Detection and Analysis
14:30-15:15	U. Mall	IR / UV Spectroscopy
15:30-16:15	F. Goesmann	Lander and Instrumentation
Thu, Dec 7th		
9:30-10:30	U. Schühle	Imaging Detectors
10:45-11:45	H. Hartwig	Space Instrument Development
lunch		
13:00-14:00		*Tour: Test Chambers, CCD lab*
14:00-15:00	T. Sakurai	*Seminar:* First Glimpse on Hinode Data

Focus is on

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

not on

astrophysical observatories

Earth observation instruments

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

space application (telecomm, navigation ...)

Why go to Space for Solar System Exploration ?

Electromagnetic Spectrum

Quantum nature of radiation:
$E_\nu = h\nu = hc/\lambda$

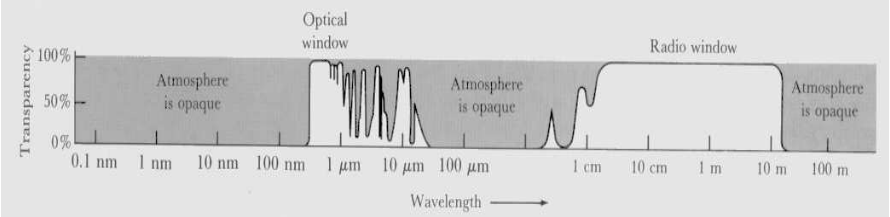
- Radio/Microwave (Frequency/Wavelength) → THz, GHz, MHz, cm, m
- Infra-red/Sub-mm (Wavelength) → µm, mm
- Visible/UV/EUV (Wavelength) → Å, nm ; <100eV
- X-ray, → <1 – >10 keV
  γ-ray,
  Cosmic Rays >1 MeV

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	$1 \times 10^{-3} – 1 \times 10^{-1}$	$3 \times 10^{9} – 3 \times 10^{11}$	$2 \times 10^{-24} – 2 \times 10^{-22}$
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	$< 1 \times 10^{-11}$	$> 3 \times 10^{19}$	$> 2 \times 10^{-14}$



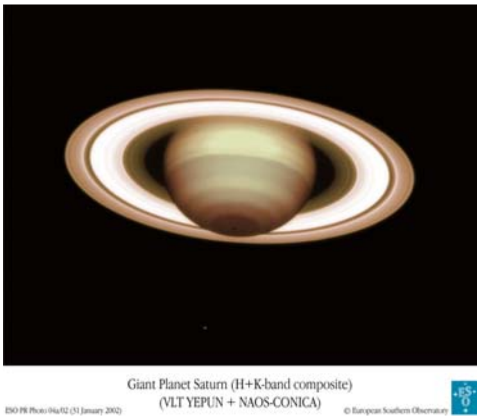
Photon absorption by the atmosphere of the Earth

Why go to Space for Solar System Exploration ?

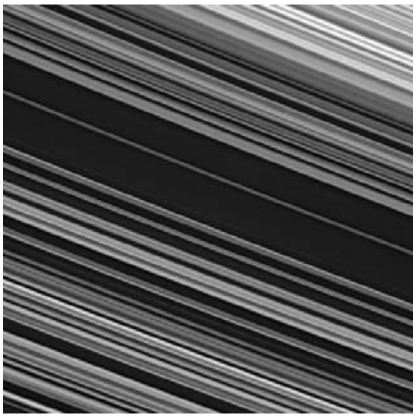
1. retrieve the information carried by em radiation not reaching Earth

   (same argument as for astrophysical applications)

Why go to Space for Solar System Exploration ?



Saturn and Rings
from Earth

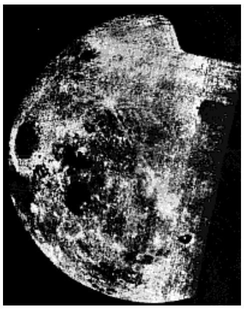


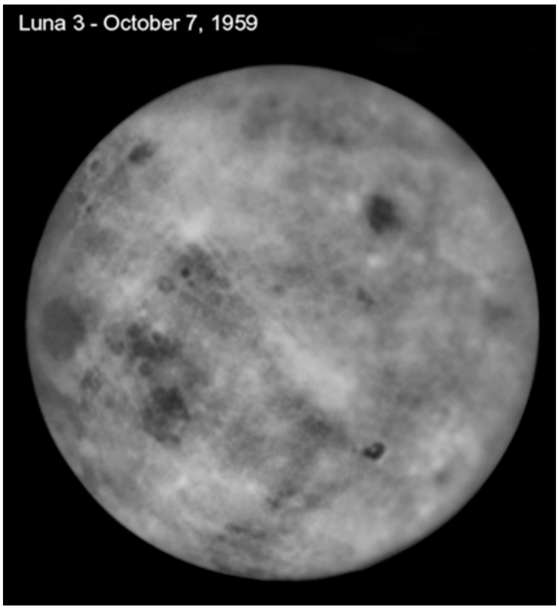
Spokes Zone in the B Ring of Saturn
from Cassini

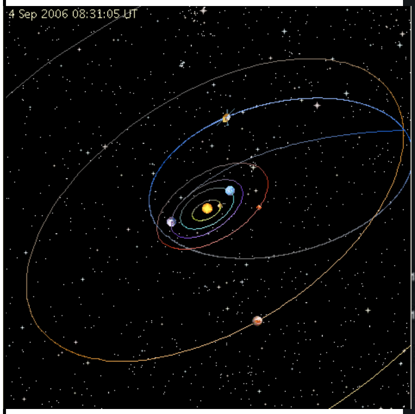
Why go to Space for Solar System Exploration ?

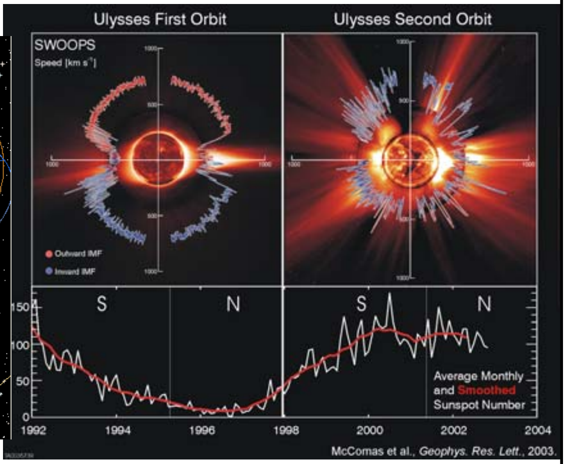
1. retrieve the information carried by em radiation not reaching Earth
2. increase resolution

The far side of the Moon




Luna 3 - October 7, 1959



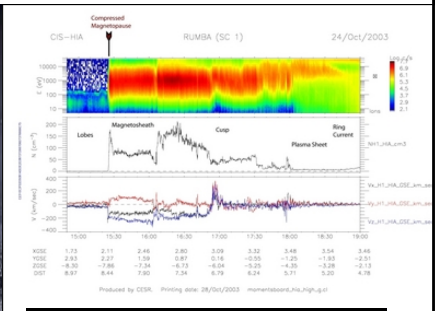


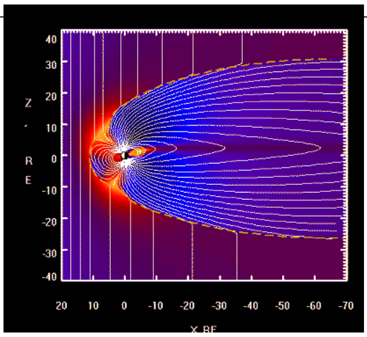
McComas et al., *Geophys. Res. Lett.*, 2003.

Ulysses polar orbit around the Sun

Why go to Space for Solar System Exploration ?

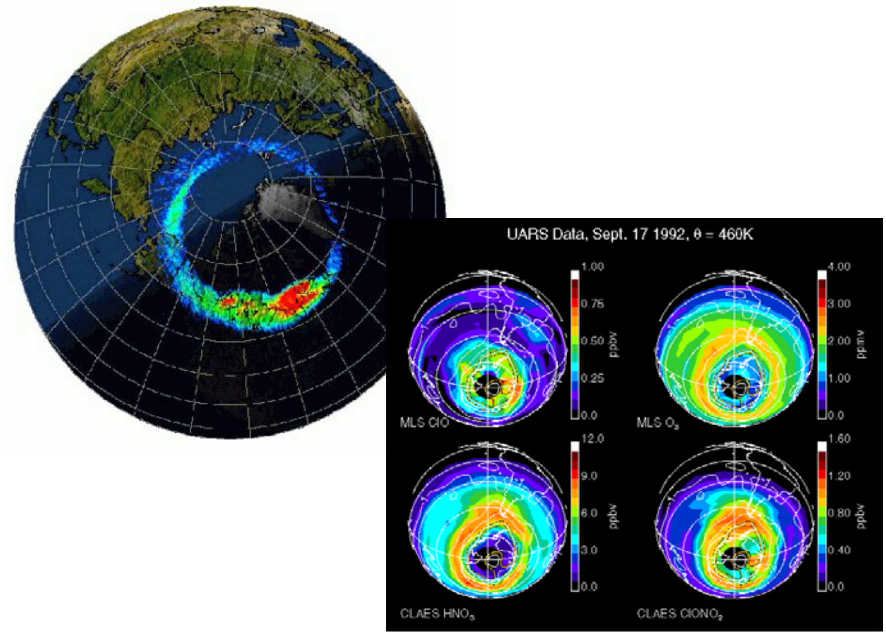
1. retrieve the information carried by em radiation not reaching Earth
2. increase resolution
3. observe regions ‘invisible’ from Earth





Why go to Space for Solar System Exploration ?

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



Why go to Space for Solar System Exploration ?

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

Brief History

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

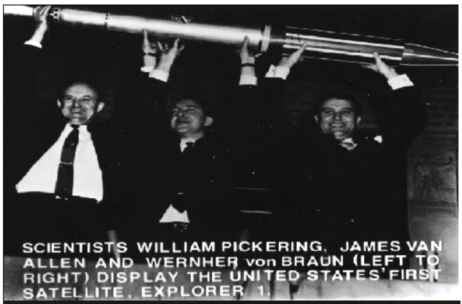
- **astrophysical methods** (optical & radio observations)
- **and some limited indirect methods** (e.g. aurora observations, ground based magnetic field observations, cosmic ray detection which allowed some educated guesses on the interplanetary environment)

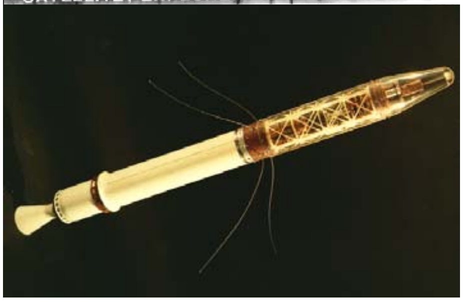
⇒ thus SSS was severely restricted (with solar physics as a bit of an exception)

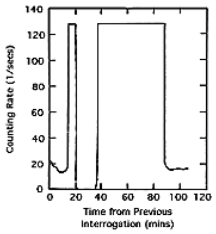
the possibility of in-situ observations introduced a new scientific quality to the field which justified that it became a self standing research field

---

Brief History







tape recorder read-out from Explorer 3

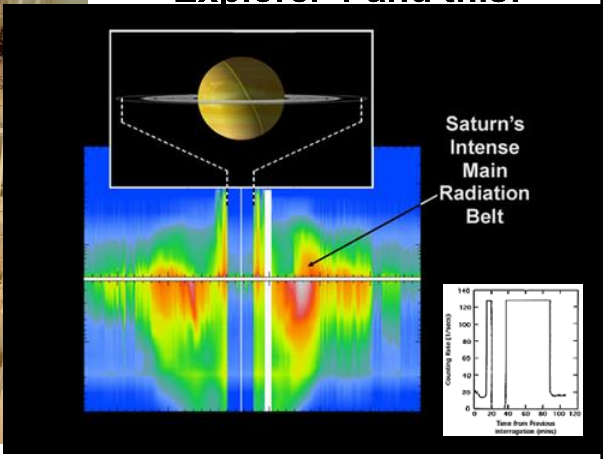
Explorer 1 (Jan 31, 1958) carried a Geiger Counter to study the latitudinal distribution of low-energy cosmic ray it failed in that

instead it discovered Earth’s radiation belts (saturation of counters)

Lesson 1: Solar System Science is full of Surprises

If you build an instrument and you are convinced you know what it will observe - you don't have to build it !

< 50 years between Explorer 1 and this:

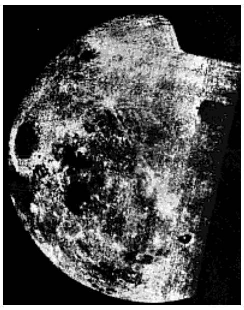


Cassini pre-launch 1997

Cassini at Saturn 2004

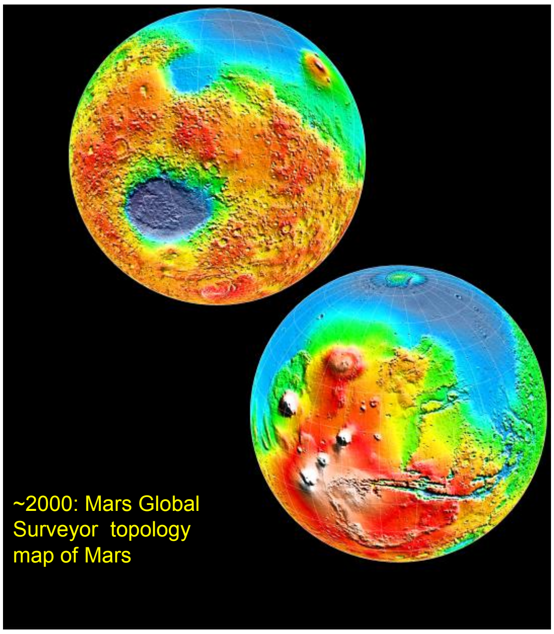
---

and < 40 years between Luna 3 and this:



1959: Luna 3 image of the far side of the Moon

Lesson 2: Solar System Science is a young field which has seen very rapid progress !



~2000: Mars Global Surveyor topology map of Mars

Solar System Science is just past the ‘Columbus’ Stage in some areas possibly still in it

Columbus Stage:

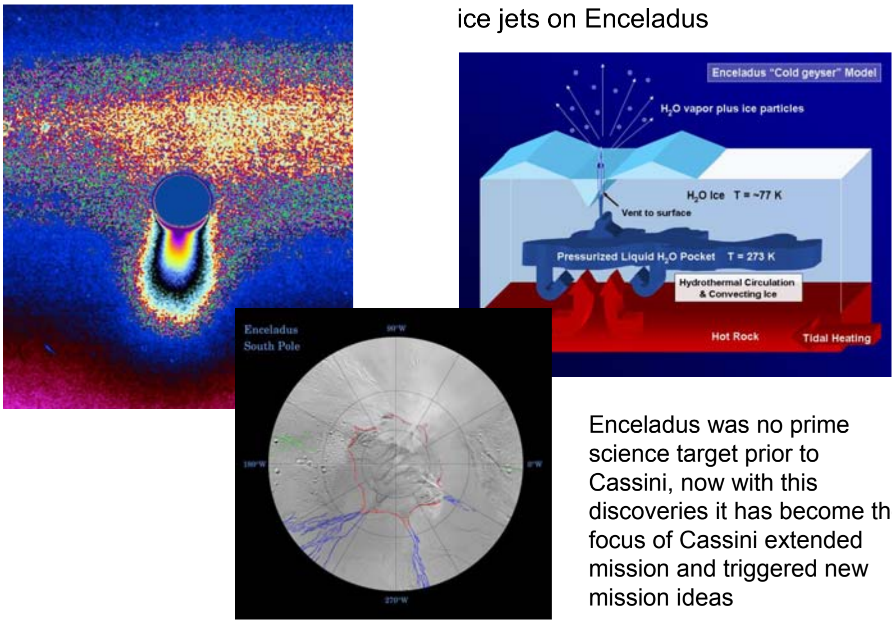
- Explorers with a great idea are given the opportunity to test this (made possible due to the availability of new techniques and sponsors with ‘higher’ interests, e.g. economic interests, ‘cold war’)
- a mission leads to new discoveries (sometimes not even identified as such) → new concepts and new ideas → calls for new observational methods → new missions → cycle starts again

nowadays: not every mission brings new discoveries, some ‘just’ confirm models and theories

not saying that there are no new discoveries possible
A recent example: Cassini and Enceladus

---

ice jets on Enceladus



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

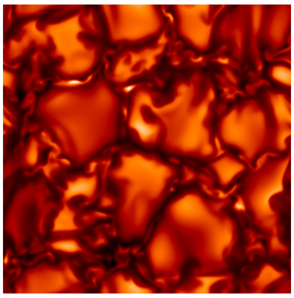
Solar Physics is a somewhat more mature field (the standard astrophysical methods (ground based observatories) were quite adequate to give some insight even before the space age (provided a head start)

Theoretical models, simulation have made tremendous progress (great ideas, advanced techniques and powerful computer hardware)

Simulations down to scales not yet accessible by existing observatories (order of 10 km)

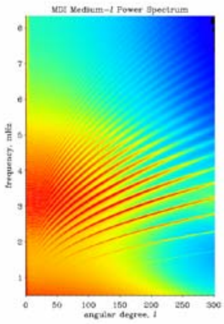
for testing these and the underlying physical concept new projects are designed (e.g. Sunrise)

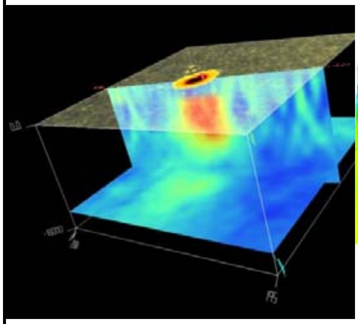
But surely beside proving or disproving the models Sunrise will bring new discoveries by opening a new spatial domain

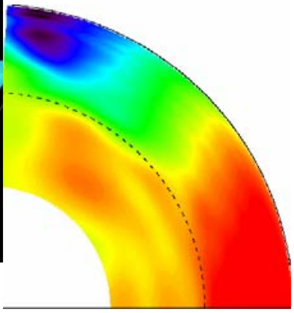


Magneto-convection in the solar photosphere by means of realistic 3D MHD. The figure shows snapshots of (frequency integrated) brightness from a simulated plage region with an average field strength of 200 G. (Resolution ~ 10 km)

A recent example how new instrumentation have revived a seemingly ‘dead’ field is MDI on SOHO which gave a tremendous boost to helioseismology







Tones of the Oscillating Sun Sound waves resonate deep within the Sun, producing surface oscillations with periods near five minutes. Only waves with specific combinations of period and horizontal wavelength resonated within the Sun. The precise combinations are related to the Sun's interior structure; they produce the fine-tuned "ridges" of greater power shown in this period versus wavelength diagram obtained from 2 months of the SOHO/MDI Doppler measurements. They allow to infer the structure, composition and dynamics inside the Sun

In essence you are in a comparatively young research field which is still good for surprises and thus highly interesting

But now down to Earth:
How does a Space Mission comes to Life

Implementation of a Space Science Project

it is no longer like this

it is like this

Space Projects have become increasingly complex

- **targets are much more difficult to reach**
- **instrumentation has become more advanced and thus demanding**

⇒ tremendous increase in costs

⇒ most missions are handled by the big space agencies (NASA, ESA, JAXA, ...) and often run as multi-national projects

⇒ opportunities are comparatively rare, approval phase is long and troublesome and depends on political and economical factors (not science alone is the driver) (e.g. The Mars/Moon man landing program of Bush and its implication on the NASA and consequently ESA science program)

A look at a Space Agency (ESA) – The Science Program

ESA's Cosmic Vision Program

OPERATIONS	IMPLEMENTATION	DEFINITION	ASSESSMENT
Venus Express [2005]	COROT [2006]	**BepiColombo**	Darwin
Rosetta [2004]	Herschel [2007]	Gaia	Hyper
Double Star [2003]	Planck [2007]	JWST	**Solar Orbiter**
SMART-1 [2003]	LISA Pathfinder [2009]	LISA	XEUS
Mars Express [2003]			
INTEGRAL [2002]			
Cluster [2000]			
XMM-Newton [1999]			
Cassini-Huygens [1997]			
SOHO [1995]			
Hubble [1990]			
Ulysses [1990]			

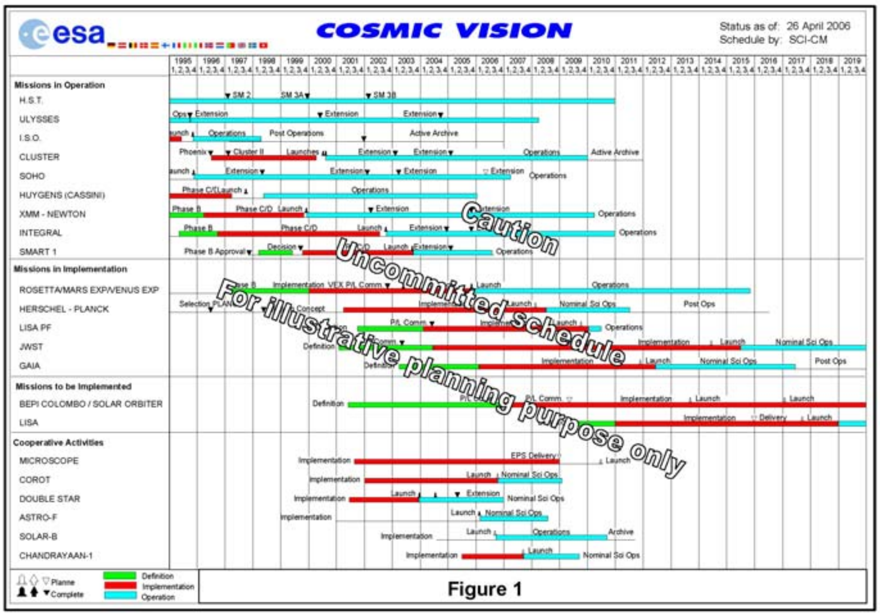
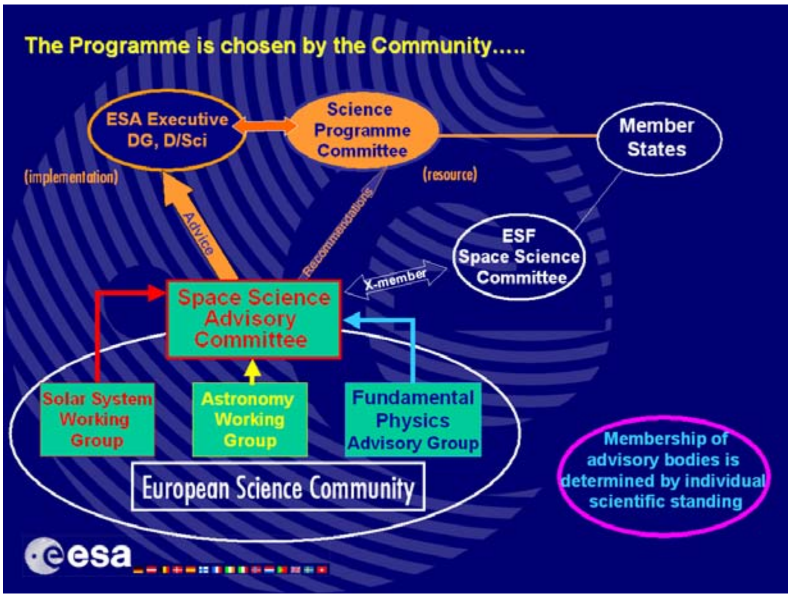


Figure 1

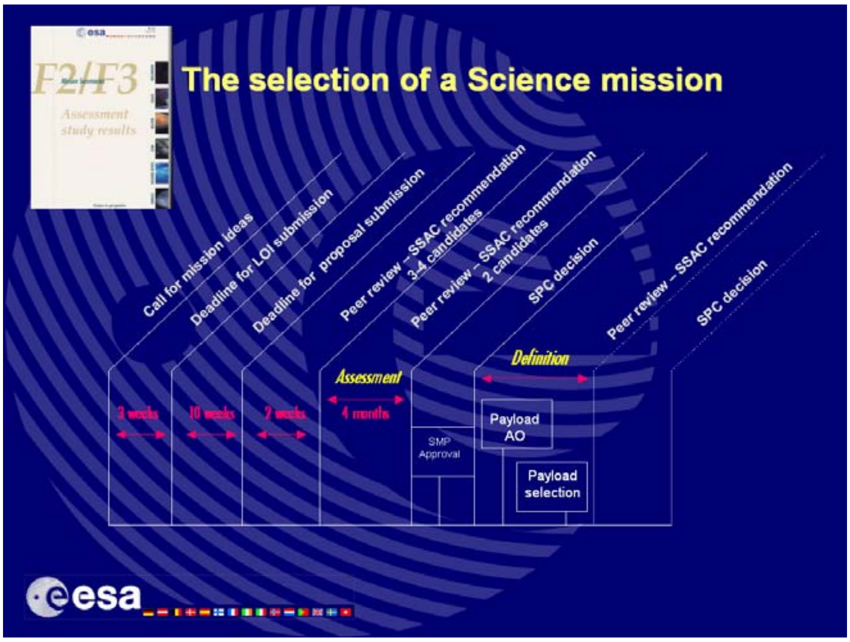
The Selection Process of a Mission

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)***

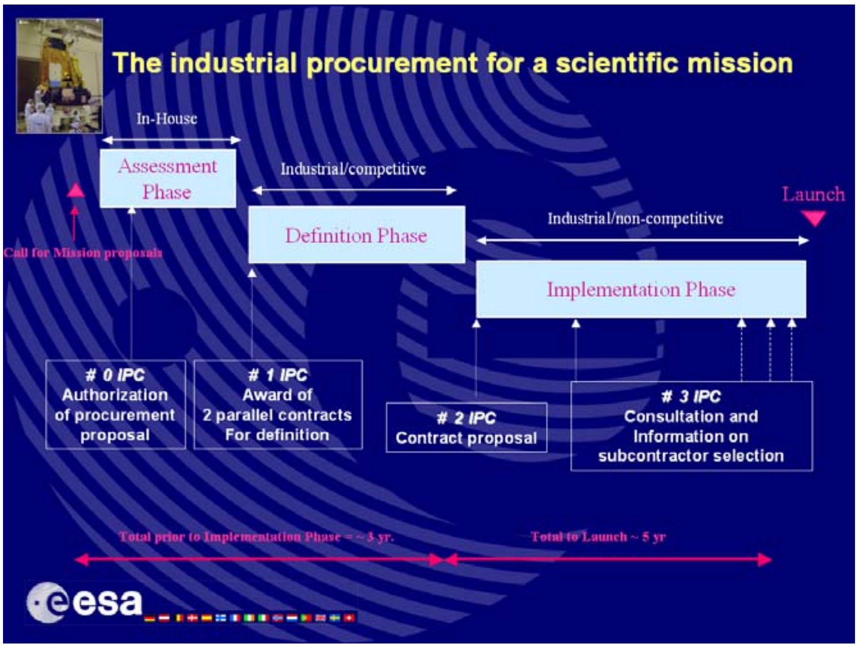
The Advisory Structure of ESA



The Programme is chosen by the Community.....



The selection of a Science mission



The industrial procurement for a scientific mission

In-House

Assessment Phase

Industrial/competitive

Definition Phase

Industrial/non-competitive

Launch

Implementation Phase

Call for Mission proposals

 # 0 IPC
Authorization of procurement proposal

 # 1 IPC
Award of 2 parallel contracts For definition

 # 2 IPC
Contract proposal

 # 3 IPC
Consultation and Information on subcontractor selection

Total prior to Implementation Phase = ~ 3 yr.

Total to Launch ~ 5 yr

esa

Selection of a Mission – The Different Phases

Call for Ideas Phase: mission proposals are solicited from the wide scientific community. These proposals are evaluated by Peer review committees (the AWG, SSWG and the FPAG) and the Executive, following which a recommendation is made as to which of the proposals should be selected for an assessment phase.
Assessment Phase: a maximum of four missions are selected by the SPC, each mission supported by a Science Team, which includes the mission proposer. The Science Mission Team defines a model payload and ESA engineering teams undertake the technical assessment. The aim of the Assessment Phase is to define of the mission to a sufficient level to show the scientific value and technical feasibility. The phase lasts approximately three months and culminates in the submission of a report on each mission to the Working Groups and the SSAC. Following this, the SSAC recommends normally one mission to be studied further in the Definition Phase.
Definition Phase: Aim is to establish the cost and implementation schedule for the project. At the end of the definition phase, the Prime Contractor for the Implementation Phase is selected. Competition between potential Prime Contractors is necessary. It is also essential that the design and costing is based on the actual mission, i.e. with the selected PI (Principal Investigator) funded instruments and selected new technologies. The definition phase has 3 stages.

Selection of a Mission – The Different Phases *(cont.)*

Definition Phase Stages

1. Stage: The Invitation to Tender for the Definition Phase and the selection of potential Prime Contractors takes place. Two competing Contractors are selected on the basis of industrial proposals. Industry commences the study of the mission defined during the Assessment Phase and assists ESA in the technical preparation of the **Announcement of Opportunity (AO) for the PI provided payload.** The AO is issued. The potential prime contractors incorporate the technology developments already underway and planned in the ESA Science Core and Technology Research Programmes (CTP and TRP) for the particular mission into the system design. This is accomplished by the already selected technology providers being incorporated directly into the team by the potential prime contractors.

2. Stage: The payload is selected via a Peer Group procedure. During this activity industry:

- supports the Peer Group through technical assessment of the consequences of incorporating the different instruments in the baseline mission design,
- advises ESA as to the likely impacts of alternative payload options on programmatics and costs.

Extensive dialogue between the potential PIs, industry and ESA takes place in this period. At the end of this phase, the instruments to be flown are selected. Industry incorporates the selected payload and the viable technologies into their mission study.

Selection of a Mission – The Different Phases *(cont.)*

Definition Phase Stages (cont.):

3. (final stage):

Industry continues with detailed studies of the actual mission including the technologies and the selected payload. In this activity, they are supported by the PIs who are required to agree firm interface specifications with the contractors.
ESA discusses with Delegations to secure the funding of the payload
ESA prepares and issues the ITT (Invitation To Tender)**.**

After confirmation of the mission by SPC and selection of the prime contractor we enter the

Implementation Phase

We now have a mission comprising a selected suite of instruments.

This is Theory !!!!

Timeline:

Call for Mission Proposals – End of Assessment Phase	~ 1 year
Definition Phase (with the instrument selection in the 1. stage)	~ 2 years
Implementation Phase (ending with the launch)	~ 5 years

ESA’s Future Science Programme

A new round for defining a new ESA programme is about to come in the near future: Cosmic Vision 2015 – 2025

Tentative schedule for the Call for Proposals "Cosmic Vision 2015-2025“

Release of the Call	February 2007
Letters of Intent	March 2007
Proposals due	June 2007
Selection of mission concepts	October 2007

Watch Out !!!! This might have great impact on your carreer

up to 3 *class M* and 3 *class L* mission proposals will be selected for the assessment study phase to be carried out by ESA and subsequently by industry.

Class M cost of mission to ESA ≤ 300 Meuros (2006 e.c.)
launch (most tentatively) earliest 2017

Class L cost of mission to ESA ≤ 650 Meuros (2006 e.c.)
launch (most tentatively) earliest 2021

Some Things to Remember

Space Missions usually are:

Precious
- they offer discoveries of new frontiers,
- they have an outstanding 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 has to be designed more carefully than usual,
- proper tests have to be conducted,
- the agencies require considerable management efforts,
- safety aspects are major cost drivers

Rare
- because of the cost, they are carefully selected and often delayed,
- other discplines are in competition.

Space Missions usually are:

Long-term efforts, because of

• long approvement 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 2003...

Ambitious

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

Extremely conservative

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

Basic rules for developing instruments and missions:

No mass,
No power,
No cost.

Launching

- The primary driver for cost of the launch is the mass.
- This will then restrict the size of the spacecraft
- The instruments will be subject to severe vibration and acoustic noise from the rocket motors. Mechanical shocks will also be present caused by e.g. the first stage separation.

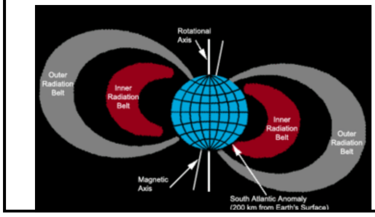
Some Challenges in Orbit

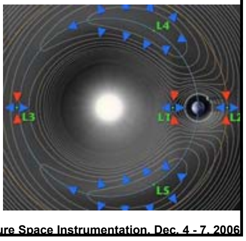
- Vacuum of space: contaminants can readily move from one part of an instrument to another, high voltage discharge is an issue.
- Sun’s thermal radiation: typically a satellite will be illuminated by the Sun on one side (T~6000K) and the Earth (T~300K) or space (~4K) on the other.
- Ionising radiation - 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 of imaging instruments, and reducing the quantity of spectral information produced, data transmission has to be minimized without loss of information, intelligent observation modes have to be invented, powerful data compression algorithms have to be applied

Choice of Orbit

E.g. for a Solar Observatory there might be different choices

- Low Earth Orbit (LEO) - orbit between the atmosphere and the Van-Allen radiation belts. This minimises the damaging effect of high energy particles. They are 200-1200km above the Earth with an orbital period of 90-100 mins. Can be prepared by the space shuttle (e.g. HST)
- High Earth Orbit (HEO) - is above the radiation belts - more expensive to launch (e.g. XMM-Newton). Apogee > 30,000km.
- Geosynchronous orbit - has the same orbital period as the sidereal period of the Earth. It has an altitude of 42,164km. SDO will be operated this way - it means full time contact – high telemetry rates
- The Lagrangian points (the 5 points in IP space where a spacecraft can be stationary relative to the Sun and the Earth, for example). SOHO flies at the Lagrangian point L1 of the Earth’s orbit about the Sun, in the same orbit as the Earth.





Choice of Orbit

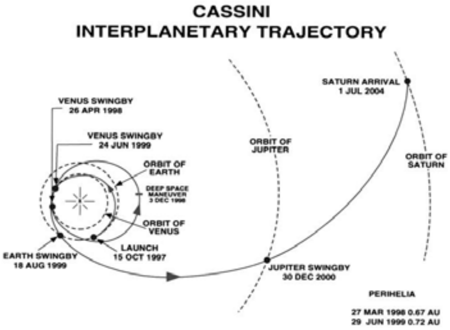
For many interplanetary and planetary missions the target prescribes the orbit

However, often there is the choice between a direct trajectory and a trajectory with (multiple) gravitational assist manoeuvres

Direct: short travel time, large ΔV → high fuel consumption → less scientific payload

GAMs: long travel times,
less ΔV → less fuel consumption →
more mass for scientific payload

advantages/disadvantages have to be carefully considered



Some Key Future Missions I: Solar and Sun – Earth Connection

MISSION	LAUNCH
Hinode (Solar B) - The Solar Hubble	**Sep 22, 2006**
STEREO - The Sun in 3D (Solar TErrestrial RElations Observatory)	**Oct 25, 2006**
SDO - The telemetry giant, Solar activity & Space Weather (Solar Dynamics Explorer - First Mission in NASA’s Living with a Star Program)	**Aug 2008**
Sunrise - A high-resolution balloon mission	**> 2009**
Solar Orbiter - Getting close to the Sun and out-of-ecliptic (ESA’s next Solar Mission)	**2015 ?**
Kuafu - The Chinese Space Weather Explorer	**2012 ?**

Solar Missions: Hinode – Sunrise (Solar B)

Japan/USA/UK mission
Follow-up to *Yohkoh*

successful launch Sep 22, 2006

polar sun-synchronous orbit

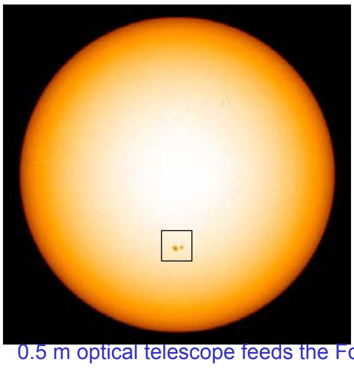
3 scientific instruments

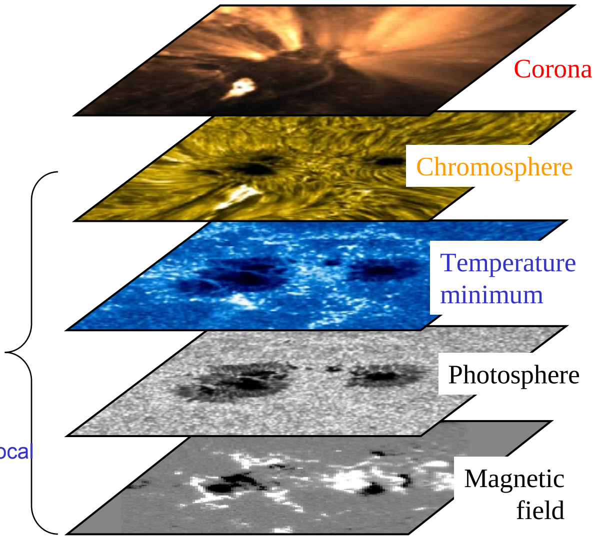
- SOT - Solar Optical Telescope
  0.25 arcsec resolution of solar magnetic fields
  (~ 140 km on the Sun)
- XRT - X-Ray Telescope resolution 3 x as high as Yohkoh
- EIS - EUV Imaging Spectrometer sensivity 10x that of EIT/SOHO

Mission Aim:

Solar-B will study the connections between fine magnetic field elements in the photosphere and the structure and dynamics of the entire solar atmosphere.

The Solar Optical Telescope (SOT) on Hinode observes photosphere and chromosphere





0.5 m optical telescope feeds the Foca Plane Package (FPP); Telescope diffraction-limited to ~0.25 arcsec resolution; Maximum field-of-view: 2.75x2.75 arcmin²

SOT

0.5 m optical telescope feeds the Focal Plane Package

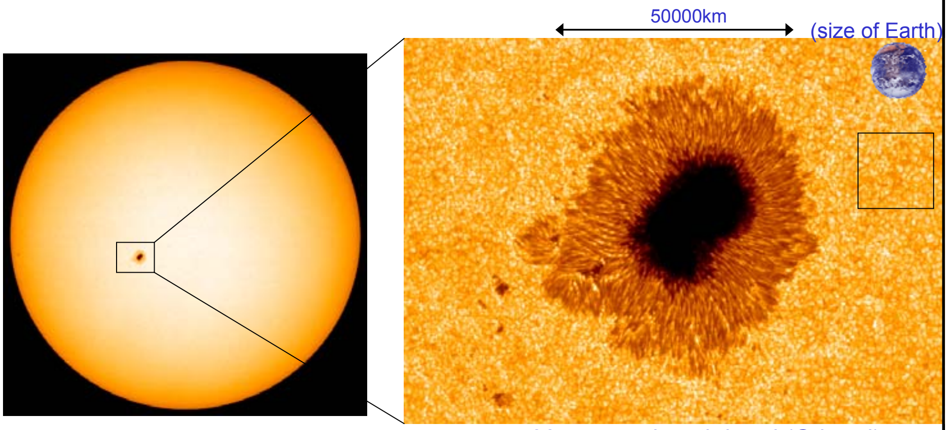
Telescope diffraction-limited to ~0.25 arcsec resolution

- Maximum field-of-view: 2.75x2.75 arcmin²

Focal Plane Package

- Spectro-Polarimeter
  - Based on successful HAO Advanced Stokes Polarimeter
  - Takes spectra at different polarisations to allow vector magnetic field to be determined
  - Raster images produced; pixel size 0.16 arcsec; 164x328 arcsec² field-of-view
- Narrowband Filter Imager
  - 0.08 arcsec pixels; 164x328 arcsec² field-of-view
  - Vector magnetograms obtained by rapidly taking images at different wavelengths and polarizations
- Broadband Filter Imager
  - 0.05 arcsec pixels; 100x200 arcsec² field-of-view
  - White light images; velocitygrams; magnetograms

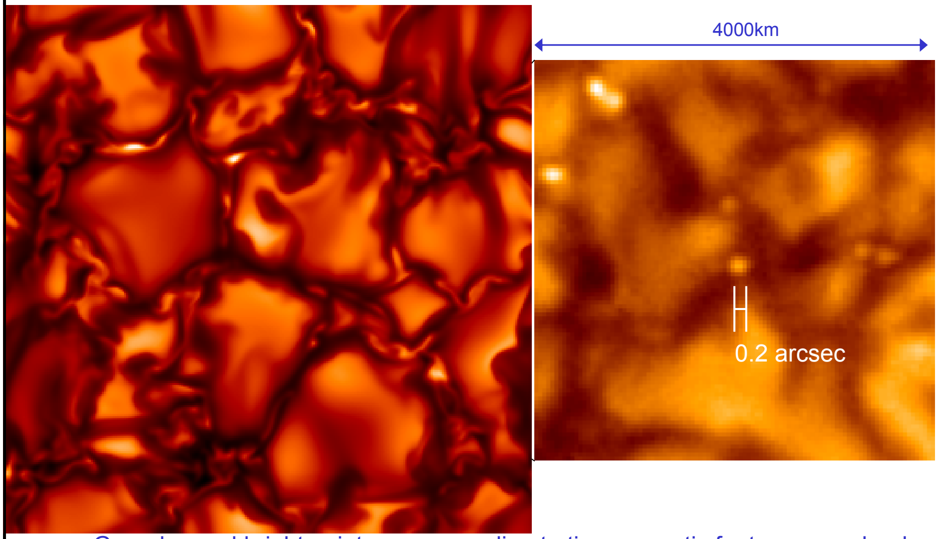
"Microscopic" observation by SOT



430nm wavelength band (G-band)

Solar Optical Telescope (SOT) on *Hinode* is the largest solar telescope flown in space, which provides the best spatial resolution. Its "microscopic" observation allows to observe fine structures in a Sun spot.

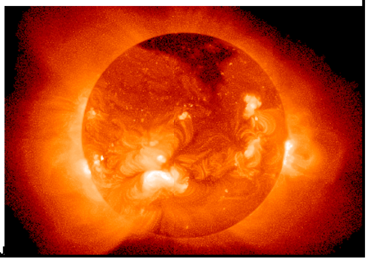
Close-up of granules



Granules and bright points corresponding to tiny magnetic features are clearly seen. Obtained data proves that SOT achieves the diffraction limit resolution of 50cm-aperture telescope, 2 arcsec in the wavelength of 430 nm.

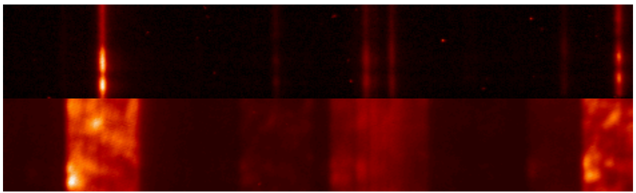
HINODE (Solar-B) – XRT

- X-Ray Telescope
- Direct successor to the SXT on *Yohkoh*
- Key features:
  - 2 arcsec resolution (1 arcsec pixels)
  - Greater sensitivity to cool corona (1-2 MK)
  - 34x34 arcmin² field-of-view (full solar disk)



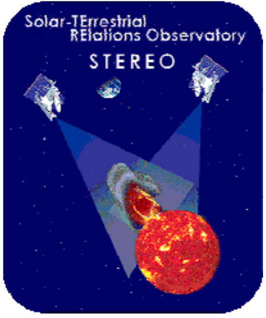
EUV Imaging Spectrometer

- Spectra in 170-210Å and 250-290Å wavelength ranges
- Field-of-view 6 x 8 arcmin²
- Spatial scale: 1 arcsec pixels
- Spectral scale: 0.02Å pixels
  - Line centroids ~3 km/s; line widths ~20 km/s



STEREO
Solar-Terrestrial Relations Observatory

Two identical spacecraft leading and following Earth. The two spacecraft have different orbits due to Swing-by at moon. They separate by about 44 degree every year.

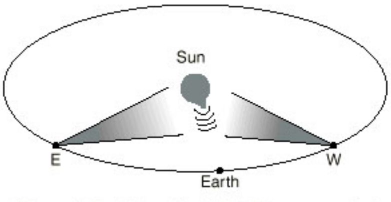


Successful launch Oct 25, 2006
Four instrument packages

• **SECCHI**	**imaging**
• **PLASTIC**	**plasmas**
• **SWAVES**	**waves**
• **IMPACT**	**particles**

Mission Goal: Understand the origin and consequences of CMEs

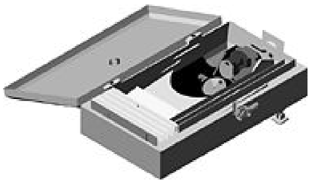
STEREO Mission Phases



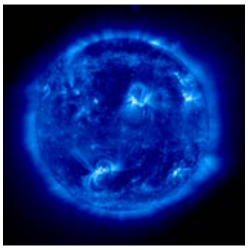
- **Phase 1 (first 400 days; α ▪ 50°)**
  - **3-D structure of the corona**
- **Phase 2 (days 400 to 800; 50° ▪ α ▪ 110°)**
  - **Physics of CMEs**
- **Phase 3 (days 800 to 1100; 110° ▪ α ▪ 180°)**
  - **Earth-directed CMEs**
- **Phase 4 (after day 1100; α > 180°)**
  - **Global solar evolution and space weather**

STEREO – SECCHI

- Instruments
  - EUVI (EUV imager)
  - COR1 & COR2 (white light coronagraphs)
  - HI (heliospheric imager)
- EUVI and CORs are direct follow-ons to EIT and LASCO

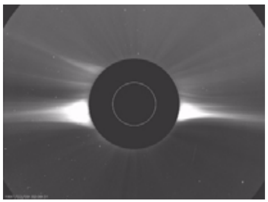


SECCHI – EUVI



- **Successor to EIT**
- **Image channels: Fe IX 171, Fe XII 195, Fe XIV 211, He II 304**
- **Larger detector (2048x2048 pixels) leads to**
  - **Higher spatial resolution (1.6 arcsec vs. 2.5 arcsec)**
  - **Larger field-of-view (1.7 Rsun vs. 1.4 Rsun)**
- **Higher telemetry ensures higher image cadence**

SECCHI – COR1 & COR2



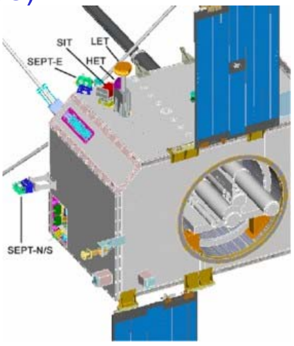
- Two coronagraphs do a similar job to the three coronagraphs of LASCO
- COR1
  - 1.1-3.0 Rsun; 7.5 arcsec pixels
  - Measures polarization
- COR2
  - 2-15 Rsun; 14 arcsec pixels
  - Higher spatial resolution and time cadence than LASCO C3

Heliospheric Imager (HI)

- Will obtain a new type of solar data: imaging of CMEs out to 1 a.u.
- Images not Sun-centred (unlike coronagraphs)
- Two independent telescopes (HI-1, HI-2) with half-angle fields-of-view of 10º and 35º

IMPACT

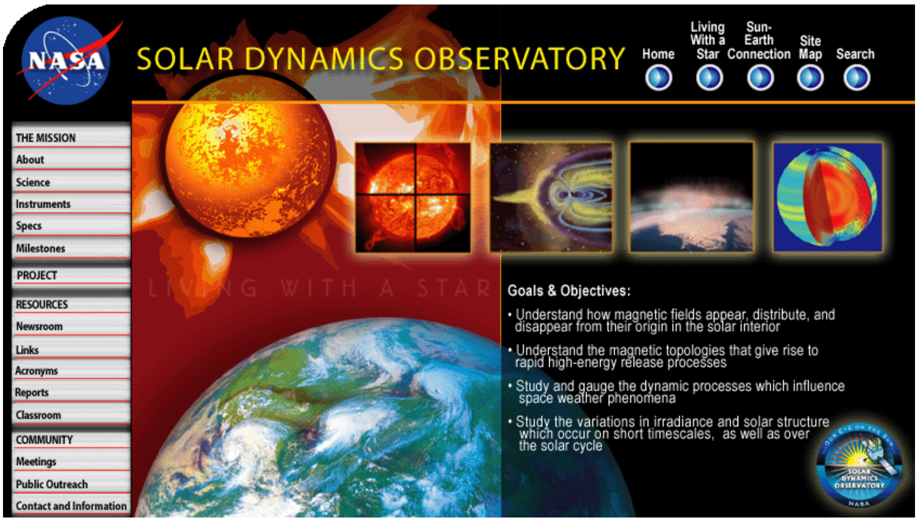
- SWEA (Solar Wind Electron Analyzer)
- STE (Suprathermal Electron Telescope)
- MAG (Magnetometer)
- SEPT (Solar Electron Proton Telescope)
- SIT (Suprathermal Ion Telescope)
- LET (Low Energy Telescope)
- HET (High Energy Telescope)



Solar Dynamics Observatory

- **Launch Aug 2008 as Part of International Living with a Star Program**
- **Duration > half a solar cycle**
- **Geosynchronous orbit**
  - **Very high telemetry rate (130 Mb/s)**
- **3 instrument packages selected by NASA:**
  - **AIA (imaging and coronagraph)**
  - **HMI (magnetograph)**
  - **EVE (extreme ultraviolet irradiance monitoring)**
- **Mission Goal: to understand, driving towards a predictive capability, the solar variations that influence life on Earth and technological systems**

  SDO will study how solar activity is created and how Space Weather comes from that activity. Measurements of the interior of the Sun, the Sun's magnetic field, the hot plasma of the solar corona, and the irradiance that creates the ionospheres of the planets are primary data products.



Goals & Objectives:

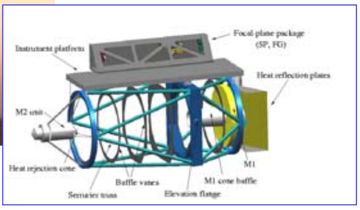
- Understand how magnetic fields appear, distribute, and disappear from their origin in the solar interior
- Understand the magnetic topologies that give rise to rapid high-energy release processes
- Study and gauge the dynamic processes which influence space weather phenomena
- Study the variations in irradiance and solar structure which occur on short timescales, as well as over the solar cycle

---

SDO

- HMI: The Helioseismic and Magnetic Imager will extend the capabilities of the SOHO/MDI instrument with continuous full-disk coverage at higher spatial resolution. Provide a link between internal processes and dynamics of the corona. PI: Phil Scherrer, PI Institution: Stanford University
- AIA: The Atmospheric Imaging Assembly will image the solar atmosphere in multiple wavelengths to provide 3D images on the coronal structure and dynamics and to link changes in the surface to changes of the irradiance. Data will include images of the Sun in 10 wavelengths every 10 seconds. PI: Alan Title, PI Institution: Lockheed Martin Solar Astrophysics Laboratory.
- EVE: The Extreme Ultraviolet Variability Experiment will measure the solar extreme-ultraviolet (EUV) irradiance with unprecedented spectral resolution, temporal cadence, and precision. Measures the solar extreme ultraviolet (EUV) spectral irradiance to understand variations on the timescales which influence Earth's climate and near-Earth space. PI: Tom Woods, PI Institution: University of Colorado.

Sunrise



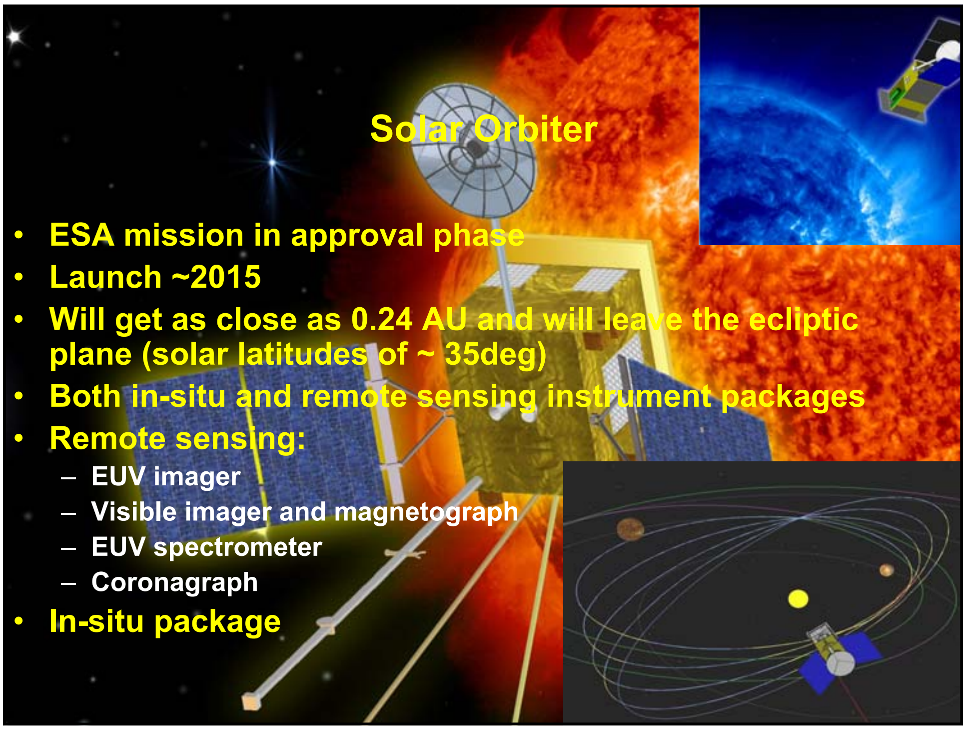
A balloon mission led by the MPS with a 1m telescope allowing highest ever achieved spatial resolution

0.1″ (70 km on the Sun) in the visible

0.05″ (35 km on the Sun) in the UV (at 200 nm)

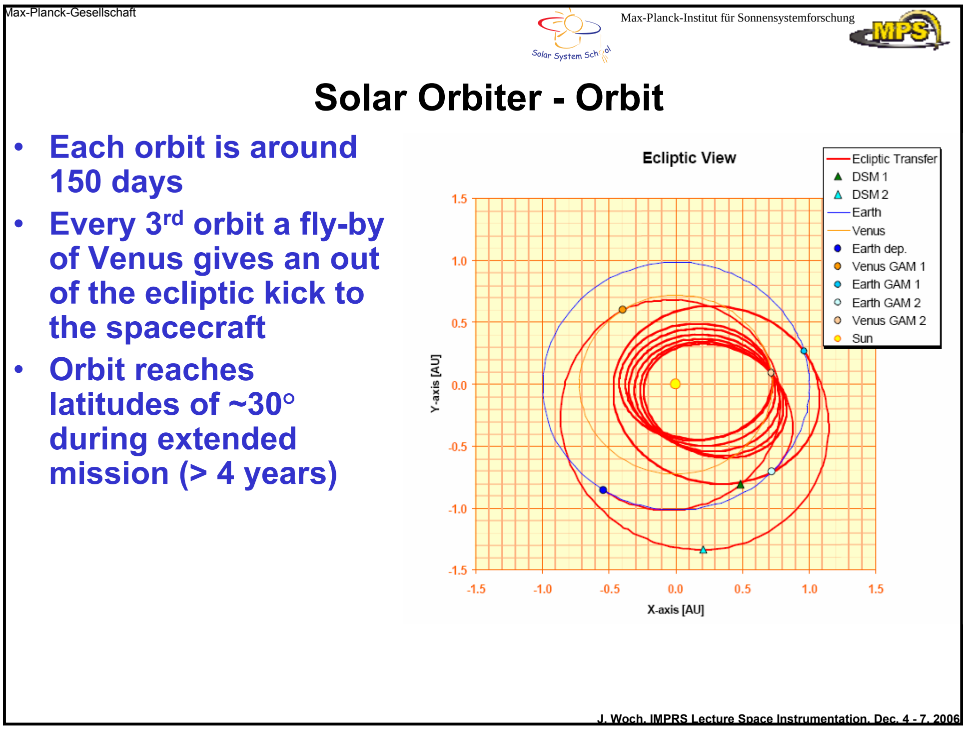
Mission goal

to understand the structure and dynamics of the magnetic field in the solar atmosphere. Interacting with the convective flow field, the magnetic field in the solar photosphere develops intense field concentrations on scales below 100 km, which are crucial for the dynamics and energetics of the whole solar atmosphere.



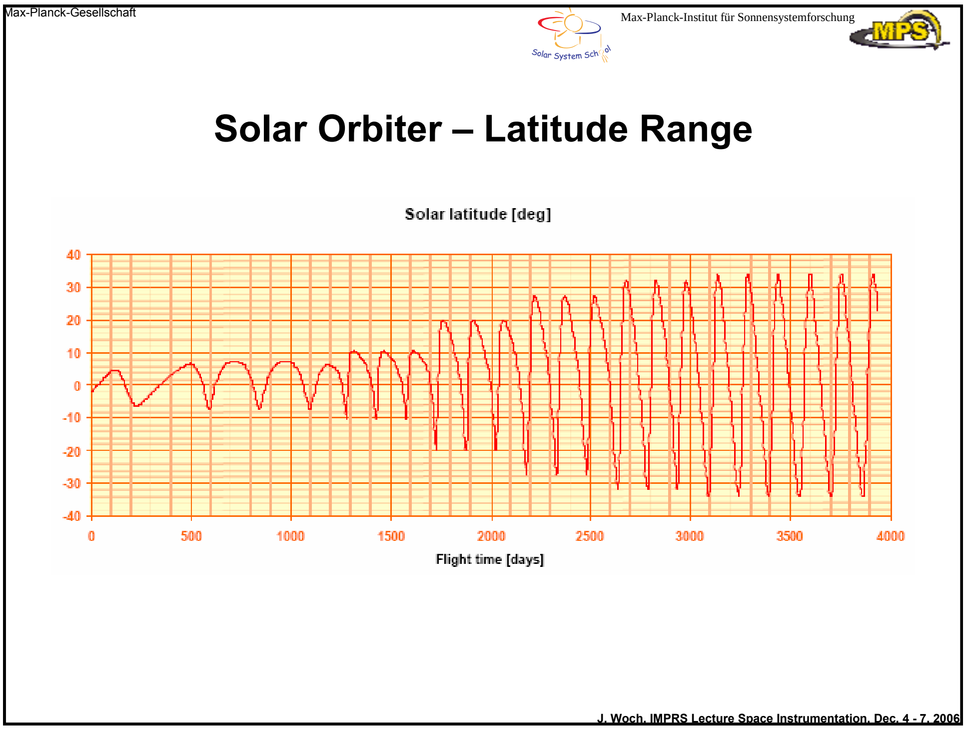
Solar Orbiter

- ESA mission in approval phase
- Launch ~2015
- Will get as close as 0.24 AU and will leave the ecliptic plane (solar latitudes of ~ 35deg)
- Both in-situ and remote sensing instrument packages
- Remote sensing:
  - EUV imager
  - Visible imager and magnetograph
  - EUV spectrometer
  - Coronagraph
- In-situ package



Solar Orbiter - Orbit

- Each orbit is around 150 days
- Every 3rd orbit a fly-by of Venus gives an out of the ecliptic kick to the spacecraft
- Orbit reaches latitudes of ~30° during extended mission (> 4 years)



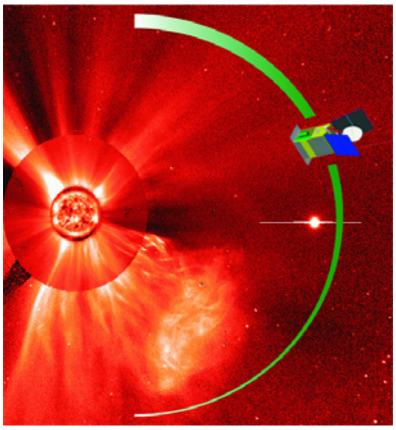
Solar Orbiter – Latitude Range

SolO - Top level scientific goals

With Solar Orbiter we will, *for the first time*:

- Determine the properties, dynamics and interactions of plasma, fields and particles in the near-Sun heliosphere
- Investigate the links between the solar surface, corona and inner heliosphere
- Explore, at all latitudes, the energetics, dynamics and fine-scale structure of the Sun's magnetized atmosphere
- Probe the solar dynamo by observing the Sun's high-latitude field, flows and seismic waves

Combination of Remote Sensing + In-Situ science



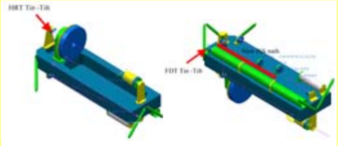
Solar Orbiter Firsts:

- Study the Sun from close-up (48 solar radii or 0.22 AU) at high resolution
- Fly by the Sun and examine the solar surface and the space above from a nearly co-rotating vantage point
- Provide images of the Sun's polar regions from heliographic latitudes as high as 35°

Reference payload

Instrument	Mass [kg]	Power [W]
a) **In-Situ instruments**		
Solar Wind Plasma Analyzer (SWA)	16.5	15.5
Radio & Plasma Wave Analyzer (RPW)	13.0	7.0
Magnetometer (MAG)	2.1	1.5
Energetic Particle Detector (EPD)	9.0	8.5
Dust Particle Detector (DPD)	1.8	6.0
Neutron Gamma-ray Detector (NGD)	5.5	5.5
SUBTOTAL	**47.9**	**44.0**

Instrument	Mass [kg]	Power [W]
b) **Remote-Sensing instruments**		
Visible Imager & Magnetograph (VIM)	30.4	35.0
EUV Spectrometer (EUS)	18.0	25.0
EUV Imager (EUI)	20.4	28.0
Coronagraph (COR)	18.3	30.0
Spectrometer Telescope Imaging X-rays (STIX)	4.4	4.0
SUBTOTAL	**91.5**	**122**
c) **Payload Support Elements (PSE)**	28.4	4.0
TOTAL (IS+RS+PSE)	**167.8**	**170.0**



Schedule - Planning assumptions

Sept 2006	Letters of Intent to Propose
to Nov 2007	\`Mission Consolidation\` Phase
Nov 2007	SPC Decision
thereafter	AO release
2008	SPC approval of payload
2008	Start of definition phase (18 months)
2010	Start of implementation phase (tbc)
May 2015	Launch

KuaFu

Chinese space weather mission

Launch next solar maximum 2012 (tbc)
Mission design
three spacecraft
KuaFu-A at the L1 liberation point for continuous monitoring of the Sun
KuaFu-B1 and KuaFu-B2 in polar orbits for continuous monitoring of the north polar aurora oval and magnetospheric environment
Instrumentation
KuaFu-A:
remote sensing instruments for observing solar extreme ultraviolet (EUV) emissions and white light Coronal Mass Ejections (CMEs),
and in-situ instruments to measure radio waves, the local plasma and magnetic field, and high-energy particles.
KuaFu-B1/B2:
magnetospheric in-situ instrument package and auroral imagers

---

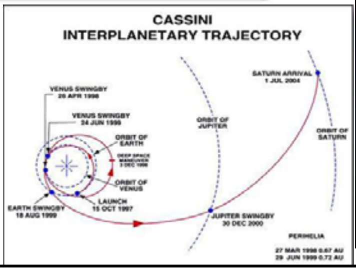
Some Key Future Missions II: Planetary Missions

MISSION	**LAUNCH**
Cassini-Huygens - Saturn and Titan	**Oct 15, 1997**
MarsExpress - Mars	**June 2, 2003**
VenusExpress - Venus	**Nov 9, 2005**
Rosetta - ESA’s Cometary Mission	**Mar 2, 2004**
Messenger - Mercury	**Aug 3, 2004**
BepiColombo - Mercury	**Aug, 2013**
New Horizons - A Pluto – Kuiper Belt mission	**Jan 19, 2006**
Dawn - An Asteroid mission (Vesta, Ceres)	**June, 2007**

Several NASA (Constellation Program) and ESA (Aurora Program) Mars Missions

Cassini-Huygens

- **NASA / ESA Mission**
- **Launch:** 15 Oct 1997 - in orbit around Saturn since 1 July 2004
- **Duration:** 2008
- **Mission Highlights:** numerous moon flybys (among those 44 of Titan) release of the Huygens probe landing on Titan (entry on 14 Jan 2005)



Cassini-Huygens - Scientific Payload

Optical Remote Sensing Instruments

to study Saturn and its rings and moons in the electromagnetic spectrum

- Composite Infrared Spectrometer (CIRS)
- Imaging Science Subsystem (ISS)
- Ultraviolet Imaging Spectrograph (UVIS)
- Visible and Infrared Mapping Spectrometer (VIMS)

Fields, Particles and Waves Instruments

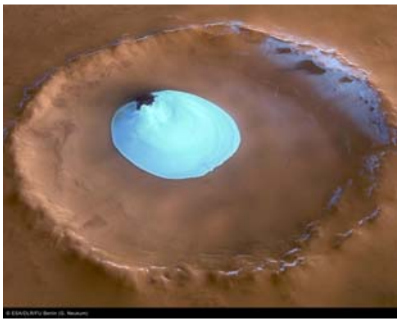
to study the dust, plasma and magnetic fields around Saturn

- Plasma Spectrometer (CAPS)
- Cosmic Dust Analyzer (CDA)
- Ion and Neutral Mass Spectrometer (INMS)
- Magnetometer (MAG)
- Magnetospheric Imaging Instrument (MIMI)
- Radio and Plasma Wave Science (RPWS)

Microwave Remote Sensing with radio waves

to map atmospheres, determine the mass of moons, collect data on ring particle size, and unveil the surface of Titan.

- Radar
- Radio Science (RSS)



Mars Express

ESA's first planetary orbiting mission

Launch: June 2003 in orbit around Mars since Dec 2003

Launch mass: 1120 kg (incl. 113 kg orbiter payload and 60 kg lander

Orbit:

inclination	86°
apocentre (furthest point from Mars)	11 560 km - 10 107 km
Pericentre (closest point to Mars)	259 km - 298 km
Period	7.5 h - 6.7 h

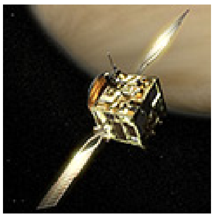
MarsExpress – Payload and Mission Goals

Mission Goal:

- image the entire surface with 10 m/pixel and selected areas at with 2 m/pixel
- produce a map of the mineral composition of the surface at 100 metre resolution
- map the composition of the atmosphere and determine its global circulation
- determine the structure of the sub-surface to a depth of a few kilometres
- determine the effect of the atmosphere on the surface
- determine the interaction of the atmosphere with the solar wind

Orbiter instruments (primarily a remote sensing package):

- High Resolution Stereo Camera (HRSC)
- Energetic Neutral Atoms Analyser (ASPERA)
- Planetary Fourier Spectrometer (PFS)
- Visible and Infra Red Mineralogical Mapping Spectrometer (OMEGA)
- Sub-Surface Sounding Radar Altimeter (MARSIS)
- Mars Radio Science Experiment (MaRS)
- Ultraviolet and Infrared Atmospheric Spectrometer (SPICAM)



Venus Express

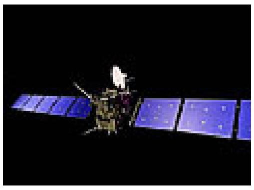
A MEX ‘Rebuilt’

Launch: 9 Nov 2005 in orbit around Venus since April 2006

Launch mass: 1120 kg (incl. 113 kg orbiter payload and 60 kg lander)

Mission Goal: compared to MEX stronger focus on atmosphere

- study its complex dynamics and chemistry, and the interactions between the atmosphere and the surface, which will give clues about surface’s characteristics
- study the interactions between the atmosphere and the interplanetary environment (solar wind) to better understand the evolution of the planet.



Rosetta - the first spacecraft to orbit a comet’s nucleus.

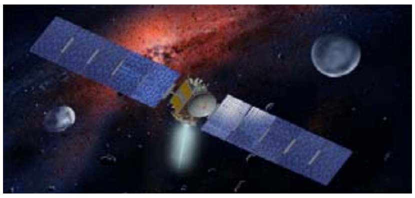
ESA Mission to Comet 67P/Churyumov-Gerasimenko

Launch: 2 March 2004 in orbit around the comet starting 2014 for ~2 years

Mission Design: An orbiting spacecraft (165 kg paylaod) and a 100 kg lander

Rosetta’s Firsts:

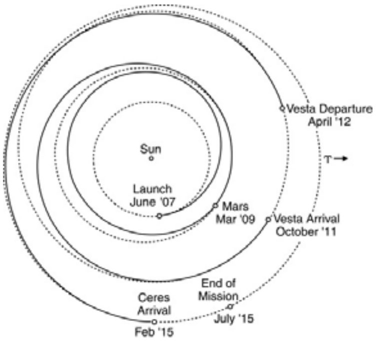
- the first spacecraft to orbit a comet's nucleus.
- the first spacecraft to fly alongside a comet as it heads towards the inner Solar System.
- first spacecraft to examine from close proximity how cometary activities develops
- the first controlled touchdown on a comet nucleus.



DAWN

NASA Discovery Mission to two Asteroids (Ceres and Vesta)

Dawn Mission Timeline (SEP)



Launch	Summer 2007
Mars gravity assist	March 2009
Vesta arrival	September 2011
Vesta departure	April 2012
Ceres arrival	February 2015
End of primary mission	July 2015

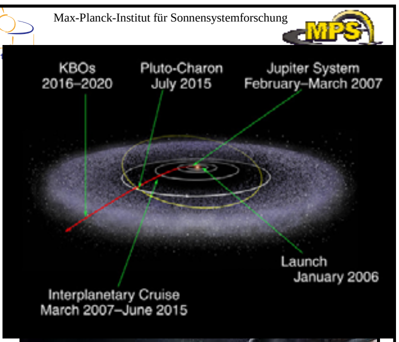
Mission Goal: to characterize the conditions and processes of the solar system's earliest epoch by investigating in detail two of the largest protoplanets remaining intact since their formations.

Measurements Objectives:

- Internal structure, density and homogeneity of two complementary protoplanets, 1 Ceres and 4 Vesta, one wet and one dry
- Determine shape, size, composition and mass
- Surface morphology, cratering
- Determine thermal history and size of core
- Understand role of water in controlling asteroid evolution
- Test the current paradigm of Vesta as the howardite, eucrite, and diogenite (HED) parent body and determine which, if any, meteorites come from Ceres
- Provide a geologic context for HEDs

Instrumentation:

VIR – Visual and Infrared Mapping Spectrometer
FC – Framing Camera



New Horizons

NASA Pluto-Kuiper Belt Mission

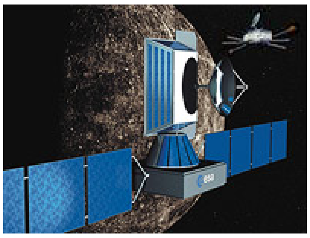
Dawn Mission Timeline (SEP)

Launch	19 Jan 2006
Jupiter gravity assist	Feb 2007
Pluto-Charon encounter	July 2015
Kuiper belt object encounters	2016-2020

Mission Goal:

- Map surface composition of Pluto and Charon
- Characterize geology and morphology ("the look") of Pluto and Charon
- Characterize the neutral atmosphere of Pluto and its escape rate
- Search for an atmosphere around Charon
- Map surface temperatures on Pluto and Charon
- Search for rings and additional satellites around Pluto
- PLUS... conduct similar investigations of one or more Kuiper Belt Objects

---



BepiColombo

ESA/JAXA Mission to Mercury

Launch: Aug 2013 in orbit around Mercury Aug/Sept 2019

Mission Design: Two orbiting spacecraft. The Mercury Planetary Orbiter (MPO) will map the planet, while the Mercury Magnetospheric Orbiter (MMO) will investigate its magnetosphere.
Journey: Both orbiters will be launched together on a single Soyuz-Fregat rocket from ESA's Spaceport in Kourou, French Guiana. For its journey, BepiColombo will exploit the gravity of the Moon, Earth, Venus and Mercury itself in combination with solar-electric propulsion (SEP).

Mission Goal: One of ESA’s Cornerstone missions, it will study and help to understand the composition, geophysics, atmosphere, magnetosphere and history of Mercury, the least explored planet in the inner Solar System.