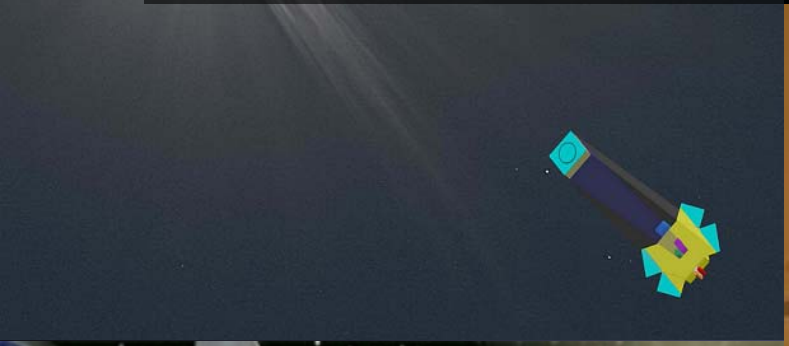
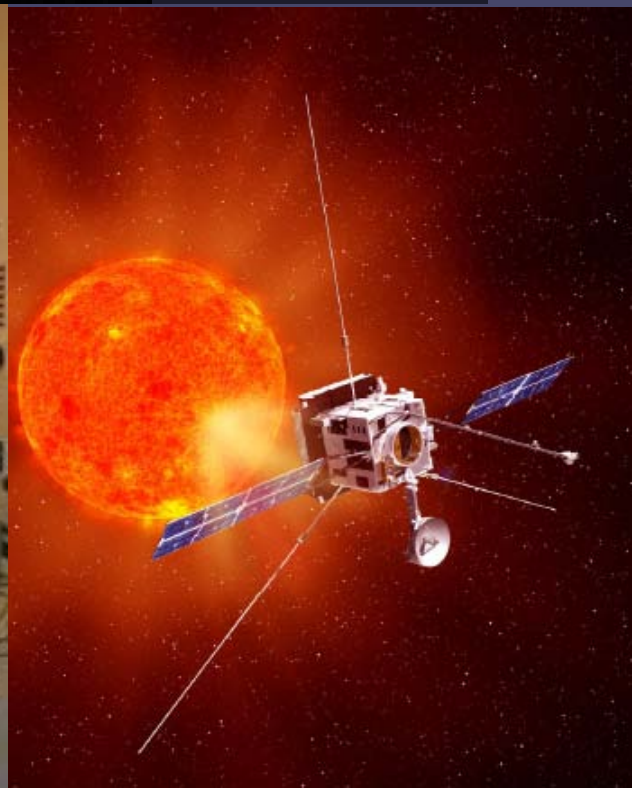
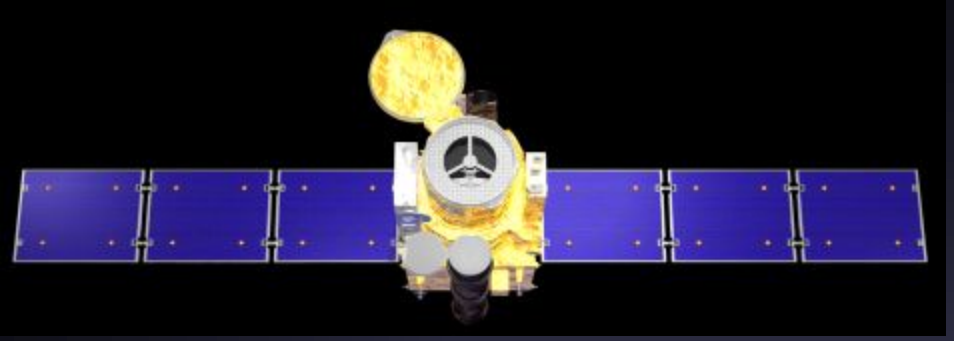
Current and Future Solar System Space Missions



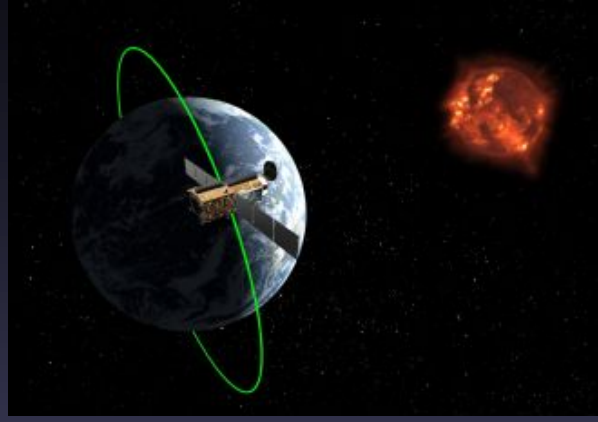


Some Key Future Missions I: Solar and Sun – Earth Connection

MISSION	LAUNCH
Hinode (Solar B) - The Solar Hubble	Sep 22, 2006
STEREO - The Sun in 3D (Solar TErrestrial RElations Observatory)	Oct 25, 2006
Sunrise - High-resolution balloon mission	June 8, 2009
SDO - The telemetry giant, Solar activity & Space Weather (Solar Dynamics Explorer - First Mission in NASA's Living with a Star Program)	Feb 11, 2010
Proba 3 – Coronagraphy down to the limb; ESA technology mission	2013 ?
Solar Orbiter - Getting close to the Sun & out-of-ecliptic (ESA's next Solar Mission)	Jan 2017 (?)
Solar C – Japanese solar mission	2018 – 2020 ?
Kuafu - The Chinese Space Weather Explorer	?



Hinode



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

Launched Sep 22, 2006 into polar sun-synchronous orbit

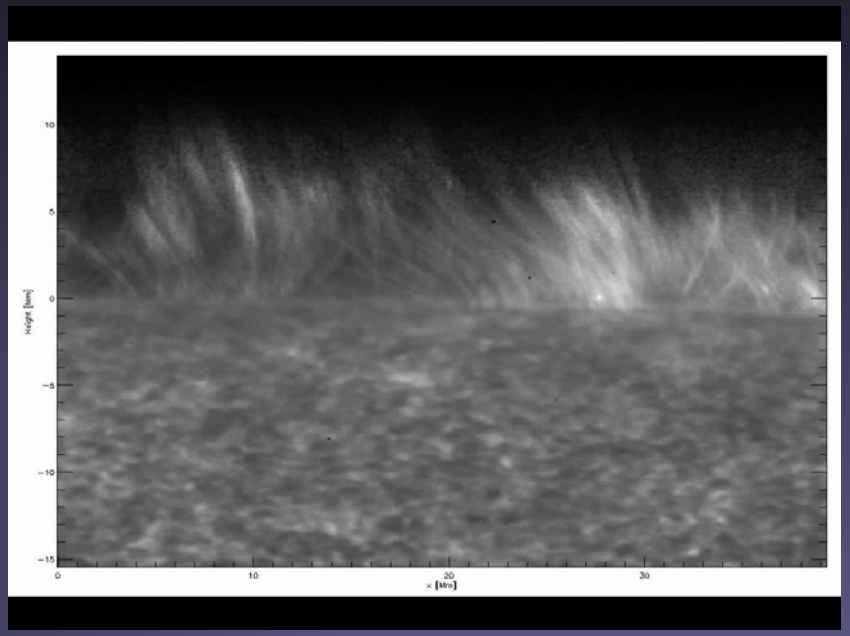
Mission Aim: Study connection between fine magnetic field elements in the photosphere and the structure and dynamics of the corona

3 science instruments

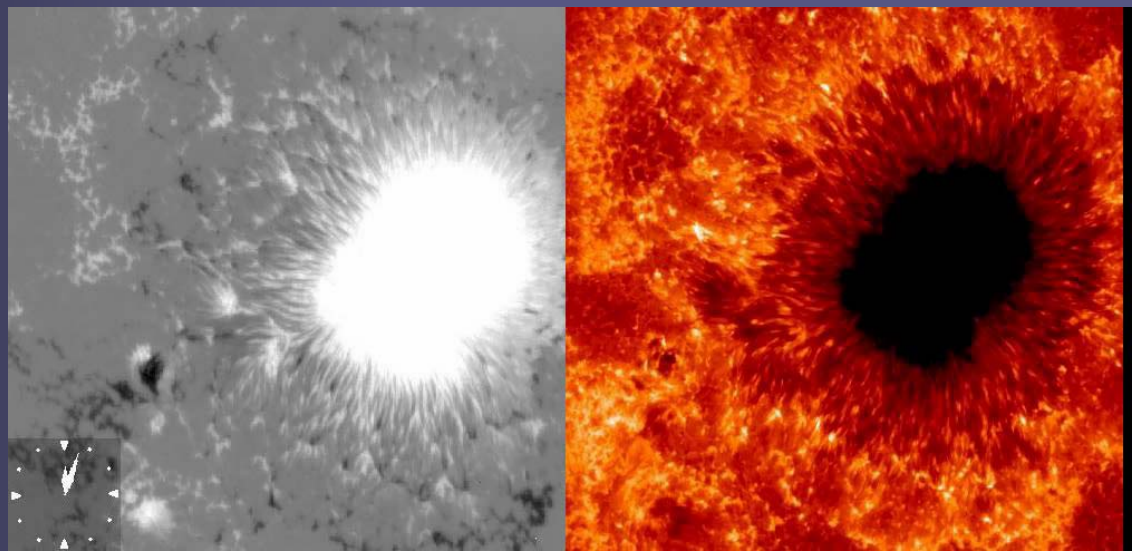
- SOT - Solar Optical Telescope: 0.2-0.3” resolution of solar magnetic fields; Focal Plane package with Spectropolarimeter (vector magn. field, FOV 164x328”), Narrowband Imager (vector magn. field, 164x264”, bubble problem) and Broadband Imager (intensity, 109x218”)
- XRT - X-Ray Telescope: resolution 3 x as high as Yohkoh
- EIS - EUV Imaging Spectrometer: higher resolution than CDS/SOHO

SOT data

- Not as high resolution as many observations from the ground (0.3” vs. 0.15”) , but of constant quality, allowing unique time series ➔ very productive, with many discoveries



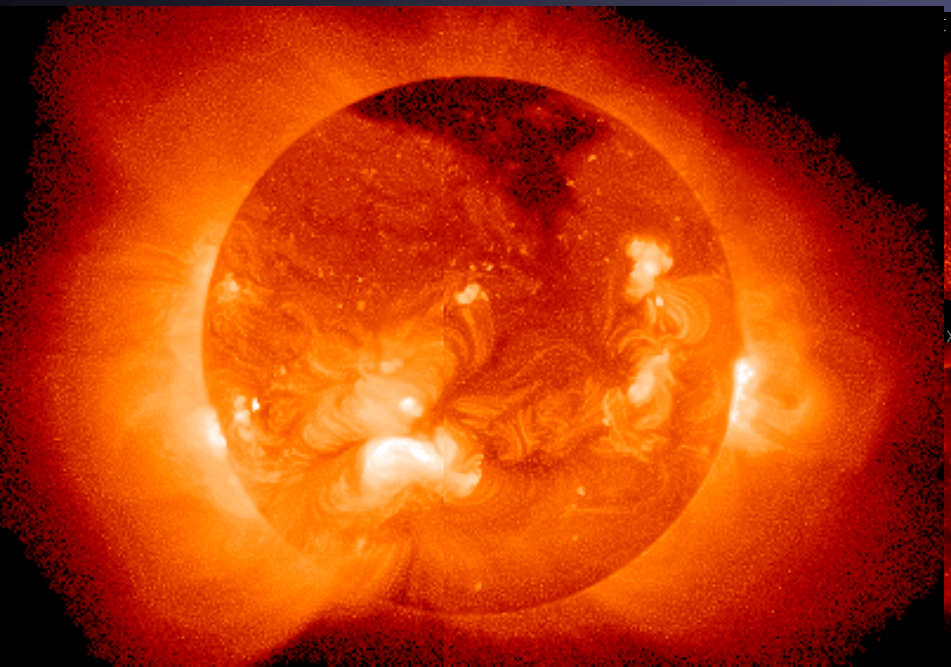
- Availability of simultaneous magnetic, velocity and intensity data of equal quality and high resolution has been revolutionary

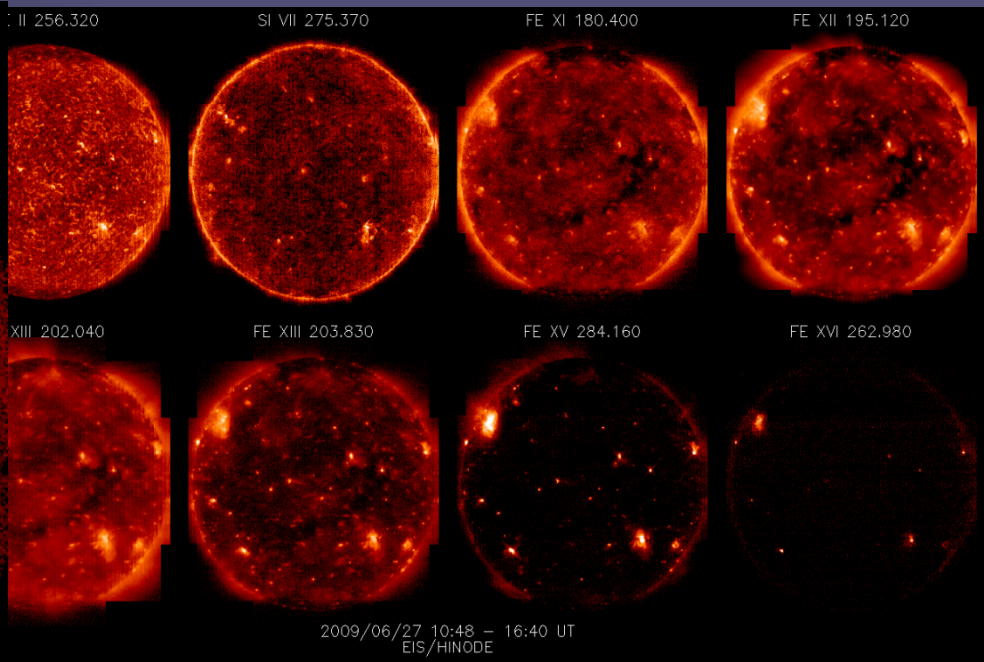


HINODE – XRT & EIS

- **X-Ray Telescope**
- Direct successor to the SXT on *Yohkoh*
- Key features:
  - 2 arcsec resolution (1” pixels)
  - Sensitive to cool corona:1-2 MK
  - 34x34 arcmin² FOV (full 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

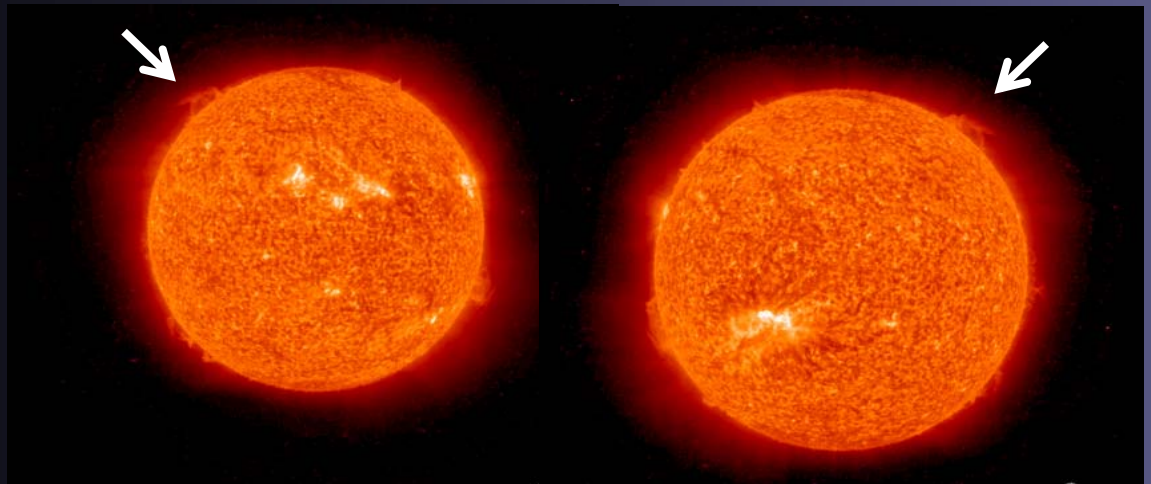
2 identical spacecraft leading & following Earth: diff. orbits due to lunar swing-by. Separate by ~44^{o} /yr

Launched Oct 25, 2006

Four instrument packages

- SECCHI imaging + coronagraphy
- PLASTIC plasmas
- SWAVES waves
- IMPACT particles

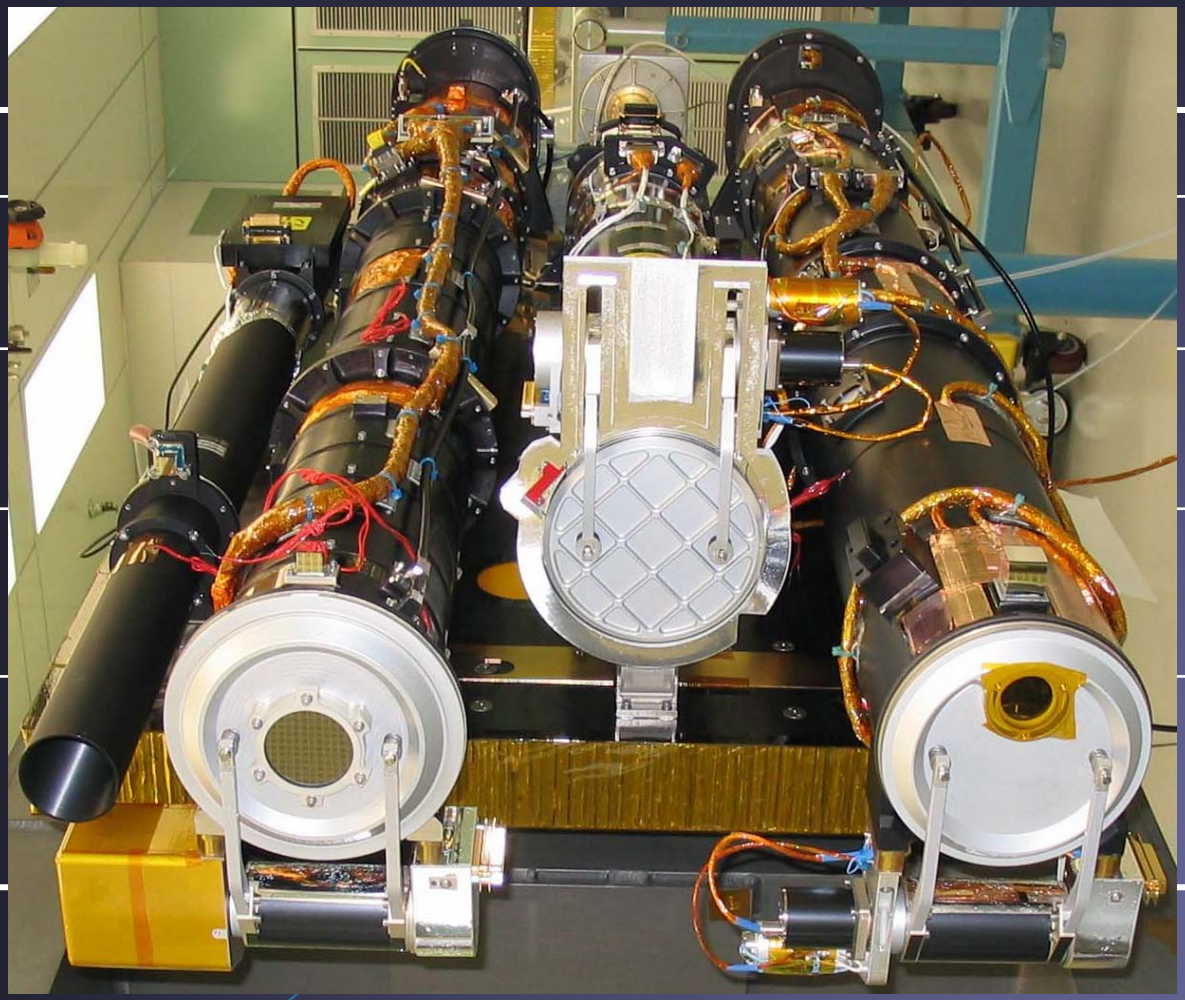
Mission Aim: Origins & consequences of CMEs



SECCHI Instrument Parameters

Sun Earth Connection Coronagraphic & Heliospheric Investigation

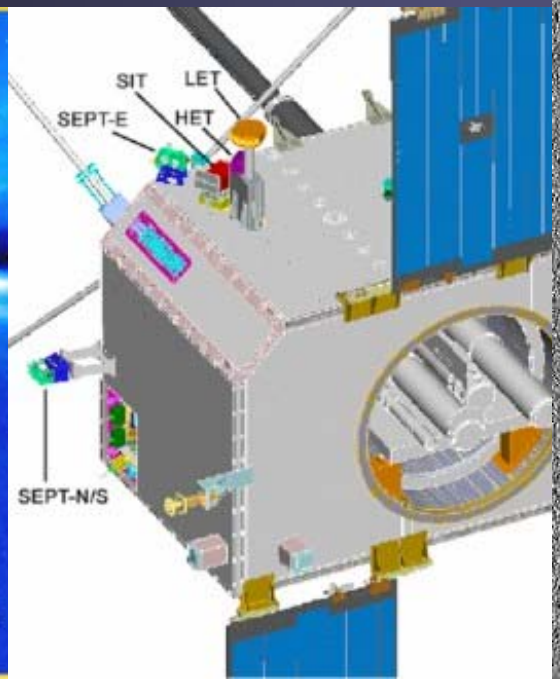
Instrument	FOV (R_S)
COR1	1.3-4
COR2	2-15
HI1 & HI2	HI-1: 12-84 HI-2: 66-318
EUVI	<1.7



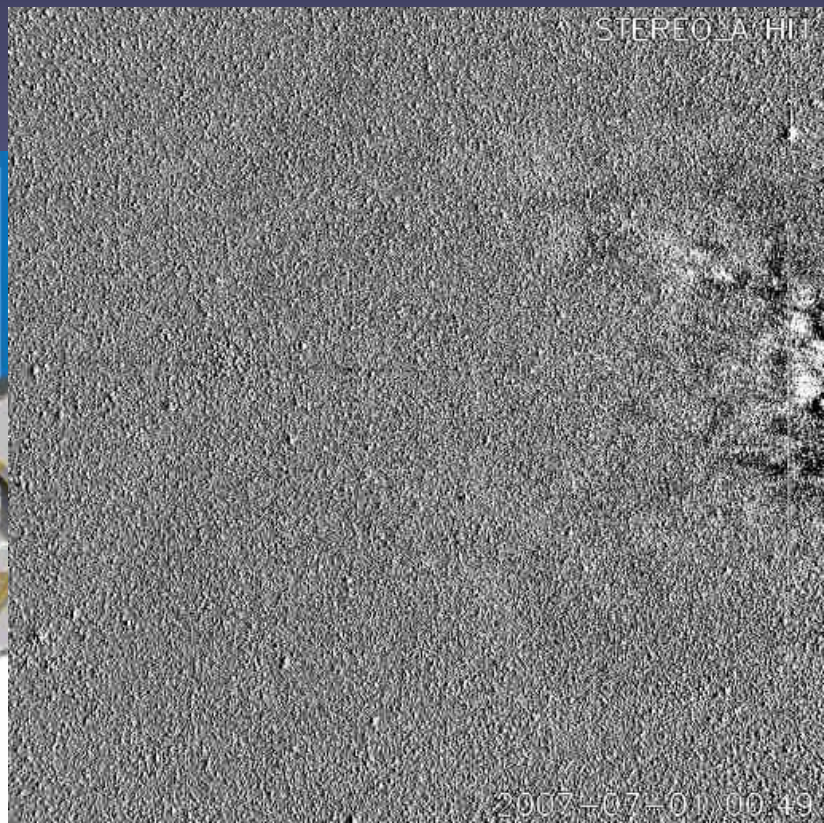
GT COR 1 EUVI COR 2

IMPACT

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

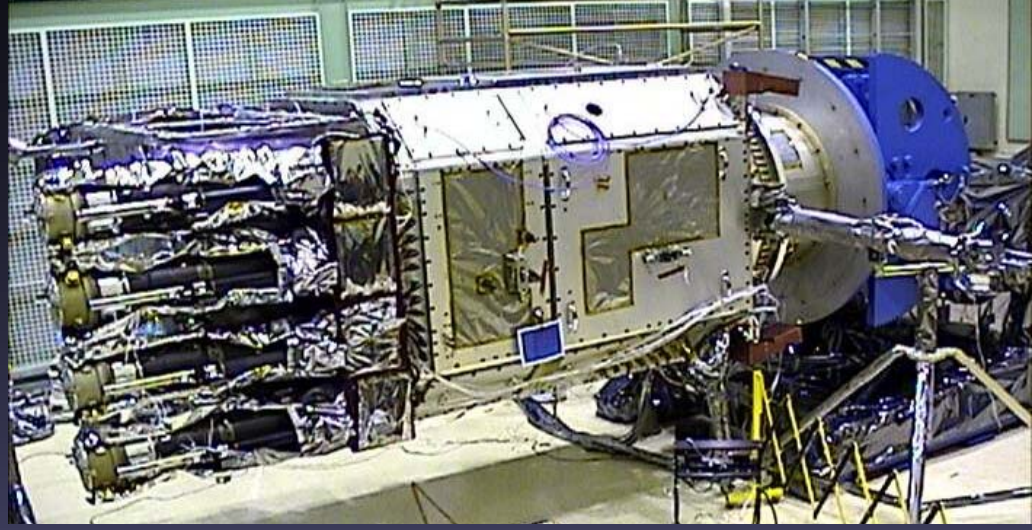


HI difference movie

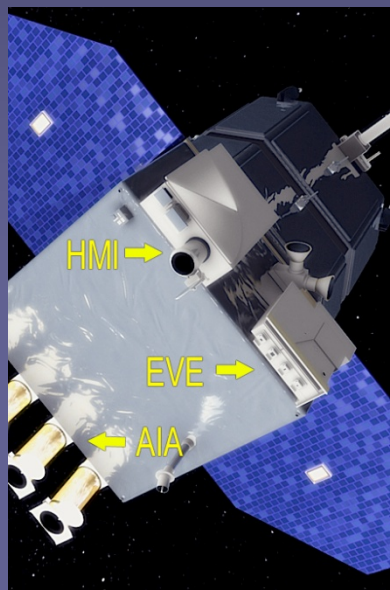


SDO: Solar Dynamics Observatory

NASA mission
Launched 11 Feb 2010 into geosynchronous orbit

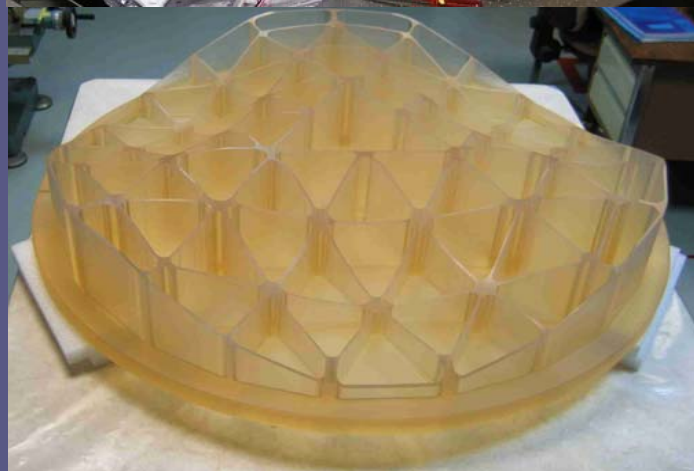


- Mission aims: study how solar activity is created and how it produces Space Weather. Probe solar interior, photospheric magn. field & coronal dynamics & EUV irradiance that creates ionospheres of planets
- 3 instruments view full solar disk with 4kx4k detectors
  - HMI: helioseismology and magnetography every 45 s
  - AIA: atmospheric imaging in 8 wavelengths every 10 s
  - EVE: EUV spectroscopy of the Sun as a star
- Immense flood of data: 130 MB/s → over 1 TB/day
- MPS contribution: German data centre

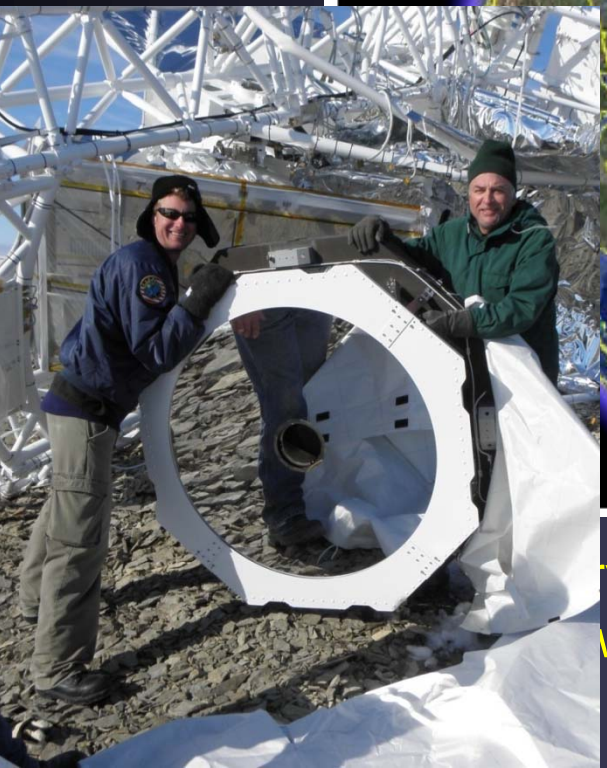


Sunrise balloon-borne solar observatory

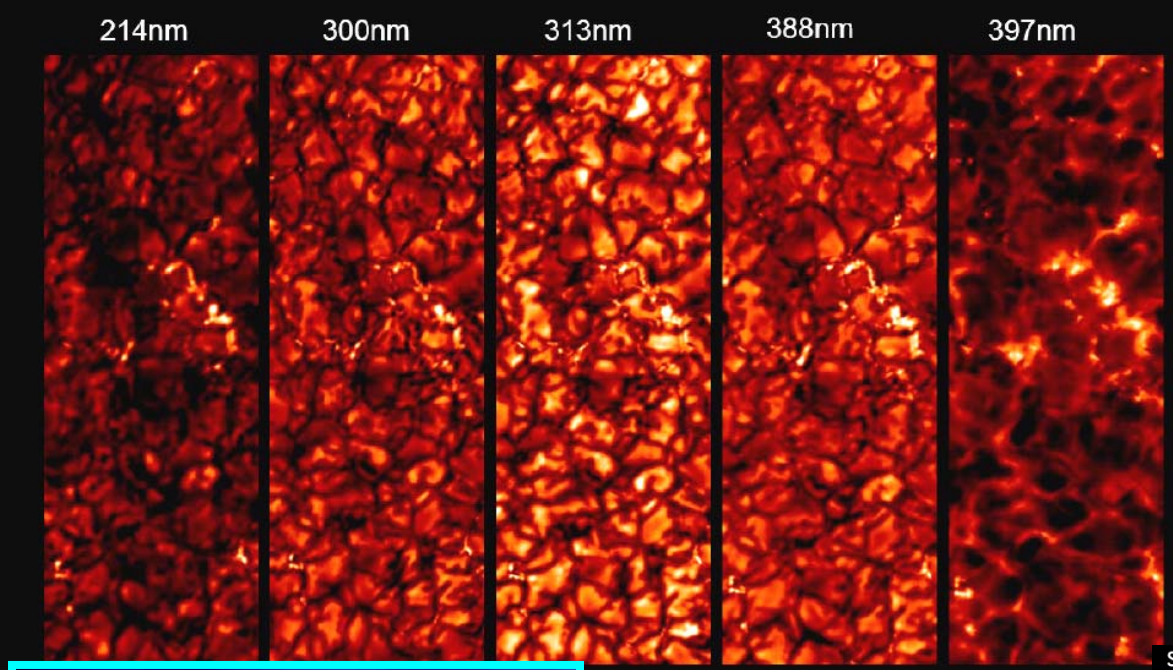
- Science aims: understand structure and dynamics of magnetic field in solar atmosphere, driven by magnetoconvection. In particular resolve kG FTs
- Gregory telescope, 1-m aperture (biggest solar telescope to leave ground)
- 2 science instruments:
  - SUFI, UV filter imager: 214nm, 300nm, 312nm, CN, Ca II H (397 nm)
  - IMAX, Imaging Magnetograph Experiment: vectormagnetograms in Fe I 525.02 nm (Landé g=3)
  - Both instruments observe simultaneously
- Correlating wavefront sensor
- Protective and stabilizing gondola



2009 flight path (duration ~6 days)

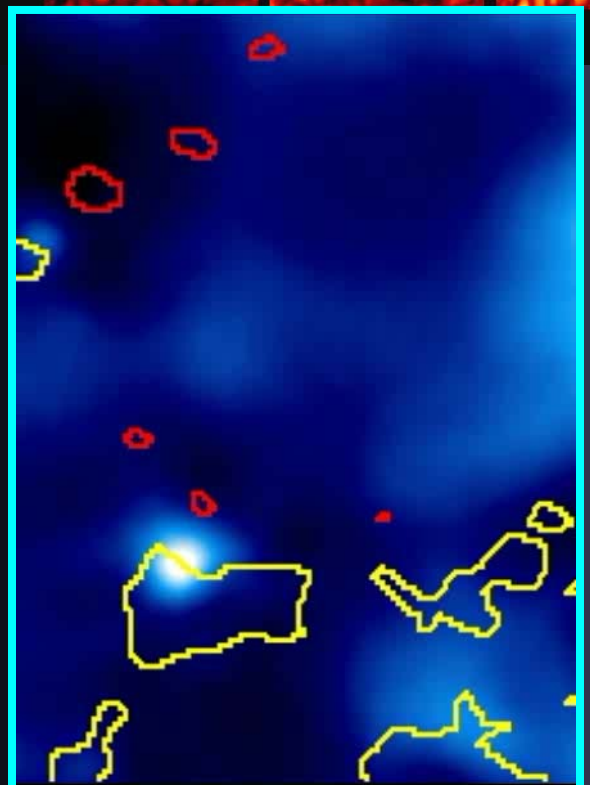


y lost hours after launch. No images until recovery
was recovered with all major systems intact

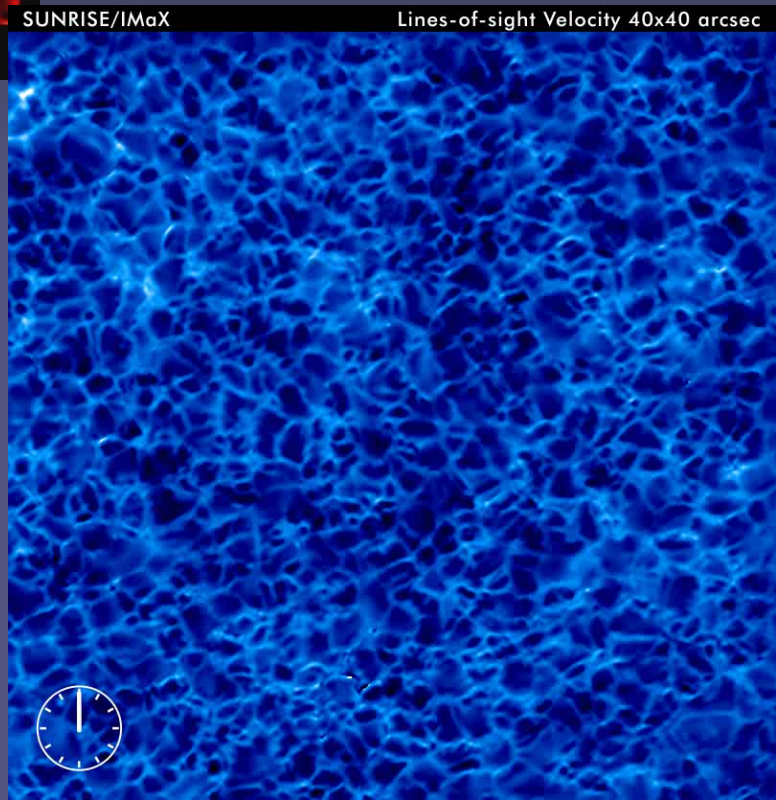


SUFI: highest granulation contrasts ever measured: magnetic elements resolved

IMAX LOS velocity

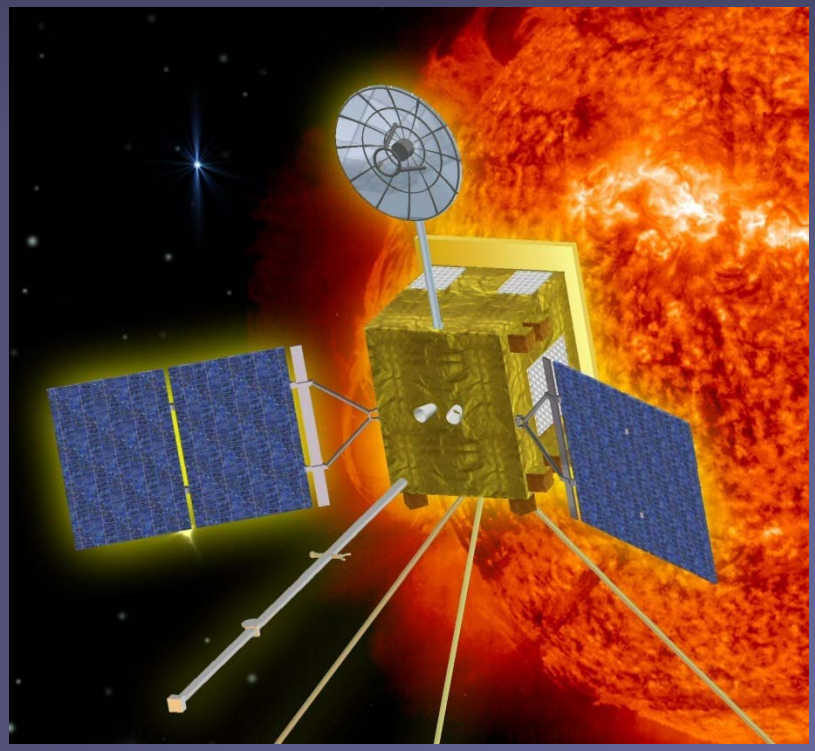


Combined SUFI (chromosphere) + IMAX (photospheric magnetic field) movie



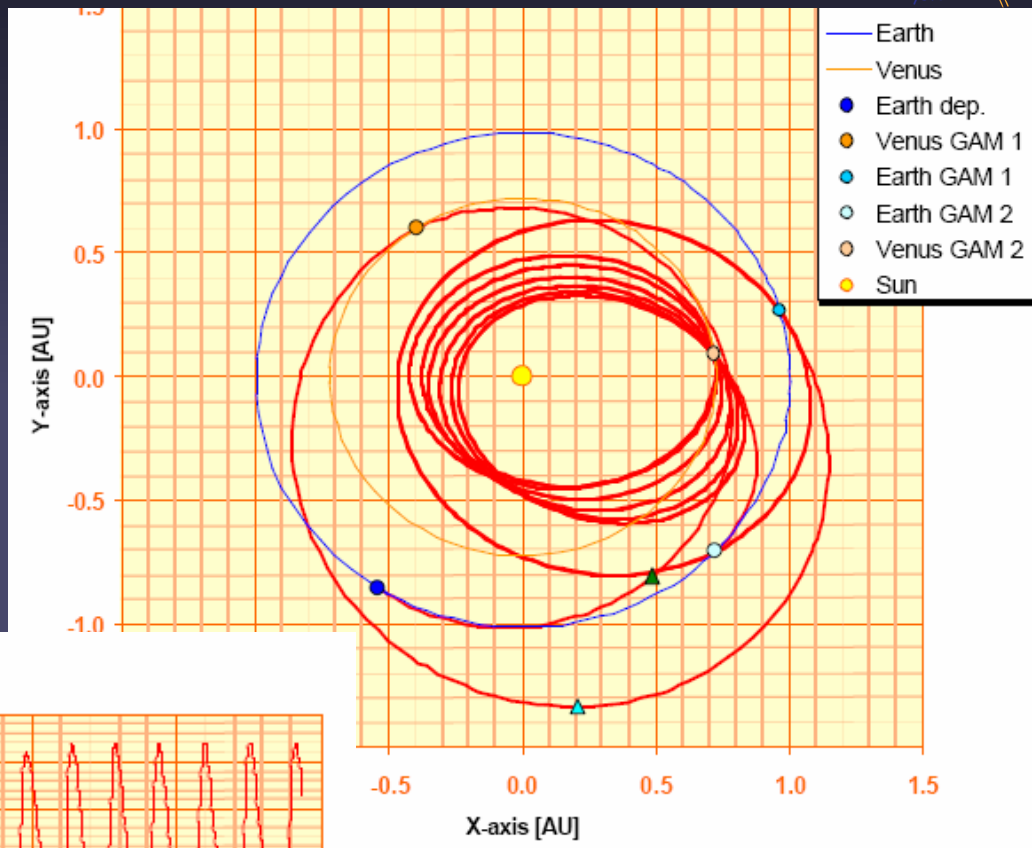
Solar Orbiter

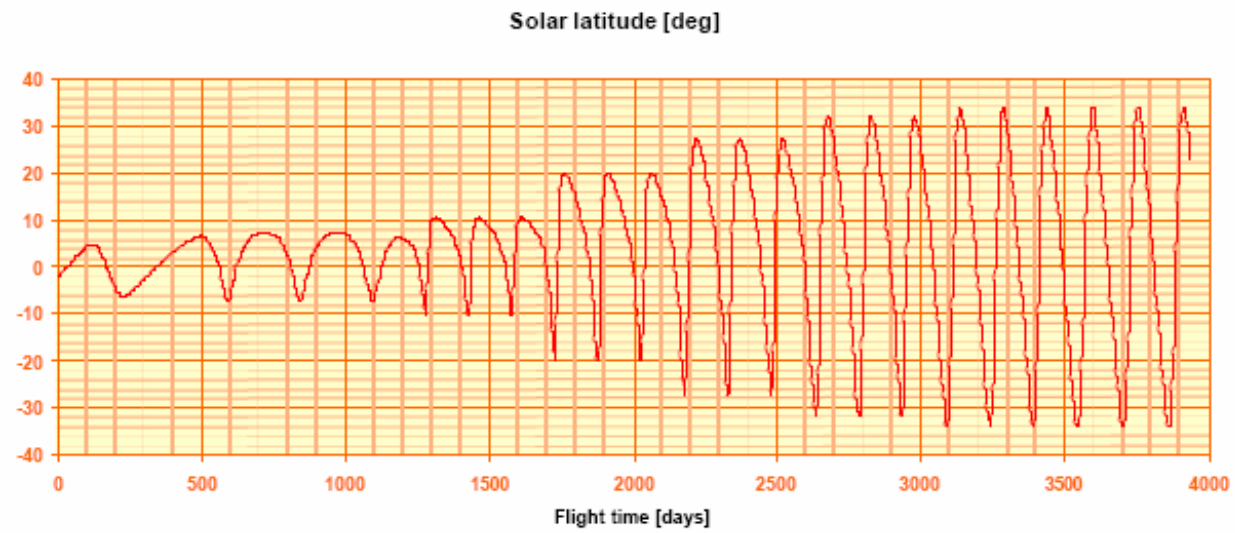
- ESA mission in definition phase
- Launch Jan 2017
- Will get as close as 0.28 AU and will leave the ecliptic plane (solar latitudes of ~ 35deg)
- In-situ and remote sensing instrument packages
- Mission aims:
  - Determine properties, dynamics & interactions of plasma, fields & particles in near-Sun heliosphere
  - Investigate links betw. solar surface, corona & heliosphere
  - Explore, at all latitudes, energetics, dynamics & fine-scale structure of Sun's magnetized atmosphere
  - Probe solar dynamo: observe high-latitude field, flows & waves



Solar Orbiter - Orbit

- Each orbit is ~150 days
- Every 3rd orbit a fly-by of Venus gives an out of the ecliptic kick to spacecraft
- Orbit reaches latitudes of ~35° during extended mission (> 4 years)



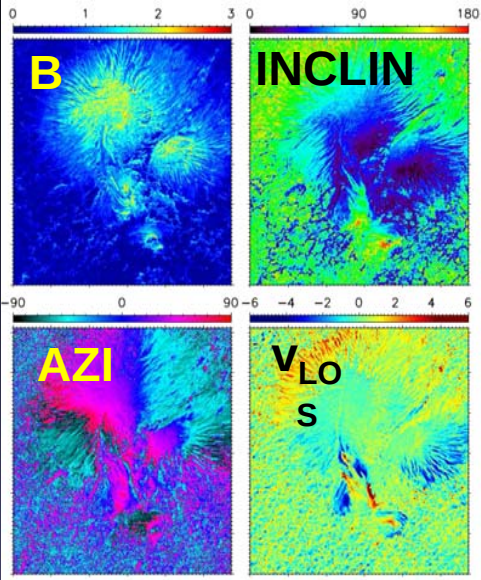


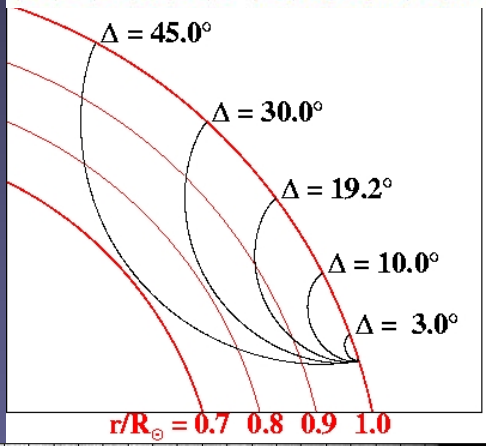
Selected instruments

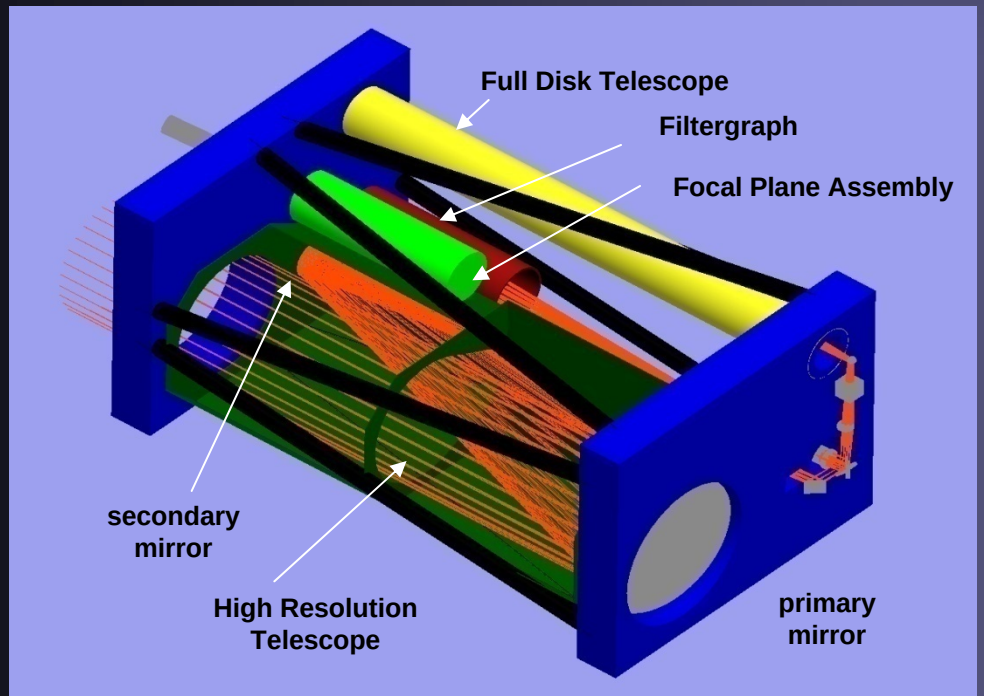
Instruments	Mass kg	Power W	Rate kbps
Plasma Package (SWA)	15.9	14.2	14
Fields Package (MAG + RPW)	15.7	13.4	11.8
Particles Package (EPD: neutrons, γ-rays, dust)	13.8	16.1	3.1
Polarimetric & Helioseismic Imager (SO/PHI)	29.1	31	20
Extreme Ultraviolet Imager (EUI)	18.1	24	20
EUV Spectrometer (SPICE)	18.4	28.8	17
Visible & VUV Coronagraph (METIS)	20.6	26	10
X-ray Spectrometer Telescope (STIX)	4.4	4.4	0.2
HI: Heliospheric Imager	11.2	10	20
Total	**147.2**	**167.9**	**116.1**

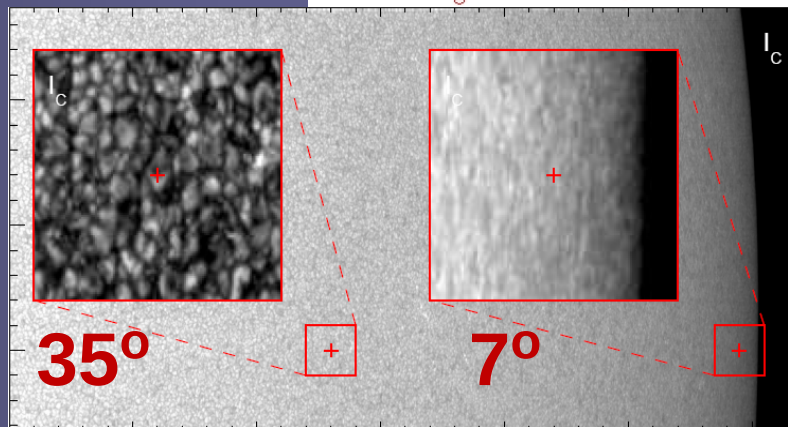
SO/PHI: Polarimetric and Helioseismic Imager

- High-resolution and full-disk telescopes provide: magnetic vector, velocity & intensity
  - input for helioseismology
  - magnetic driver for coronal dynamics







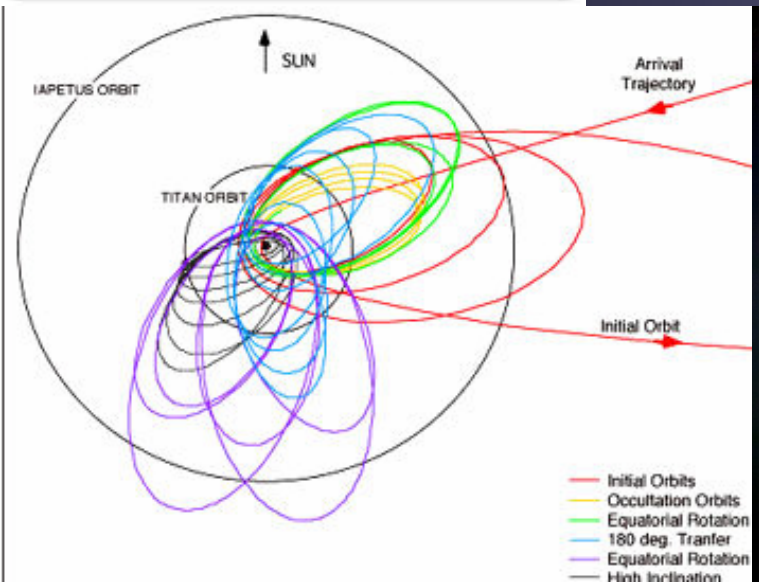


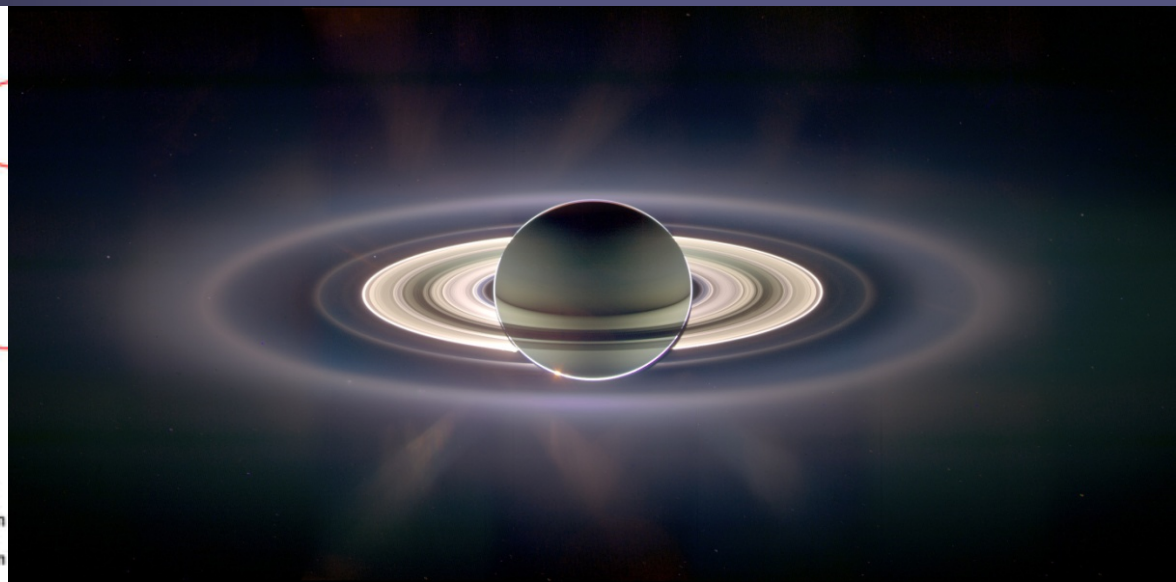
Key Planetary Missions

MISSION	LAUNCH
Cassini-Huygens - Saturn and Titan (NASA/ESA)	Oct 15, 1997
MarsExpress – Mars (ESA)	June 2, 2003
Rosetta - ESA's Cometary Mission (ESA)	Mar 2, 2004
Messenger - Mercury (NASA)	Aug 3, 2004
VenusExpress - Venus (ESA)	Nov 9, 2005
New Horizons - A Pluto – Kuiper Belt mission (NASA)	Jan 19, 2006
Dawn - An Asteroid mission to Vesta & Ceres (NASA)	Sep 27, 2007
Chandrayaan 1 – Lunar orbiter (ISRO)	June 22, 2008
BepiColombo - Mercury (ESA/JAXA)	Jul- Aug, 2013
Exomars – Mars orbiter + lander + 2 rovers (ESA/NASA)	2016 + 2018

Cassini-Huygens

- **NASA / ESA Mission**
- **Launch:** 15 Oct 1997 - in orbit around Saturn since 1 July 2004
- **Duration:** possibly up to 2017
- **Mission Highlights:** numerous moon flybys (44 of Titan alone). Release of the Huygens probe that landed 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

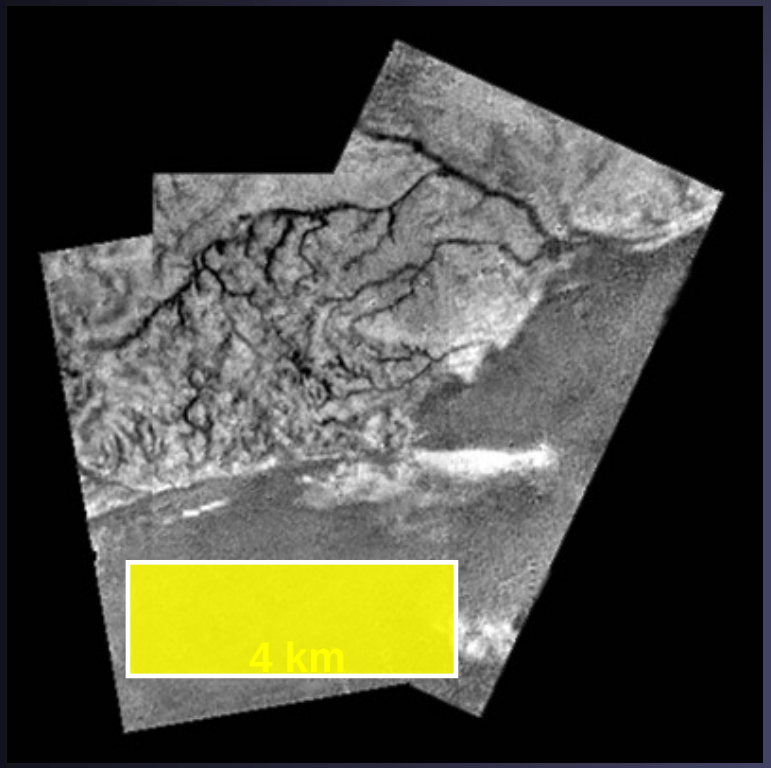
to map atmospheres, determine the mass of moons, collect data on ring particle size, and unveil the surface of Titan.

- Radar
- Radio Science (RSS)

Huygens at Titan

DISR (Descent Imager and Spectral Radiometer)

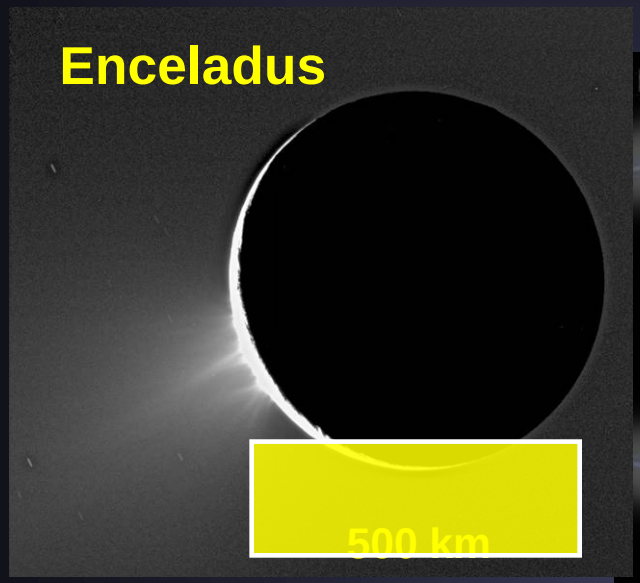
River systems and dried-up methane-lakes

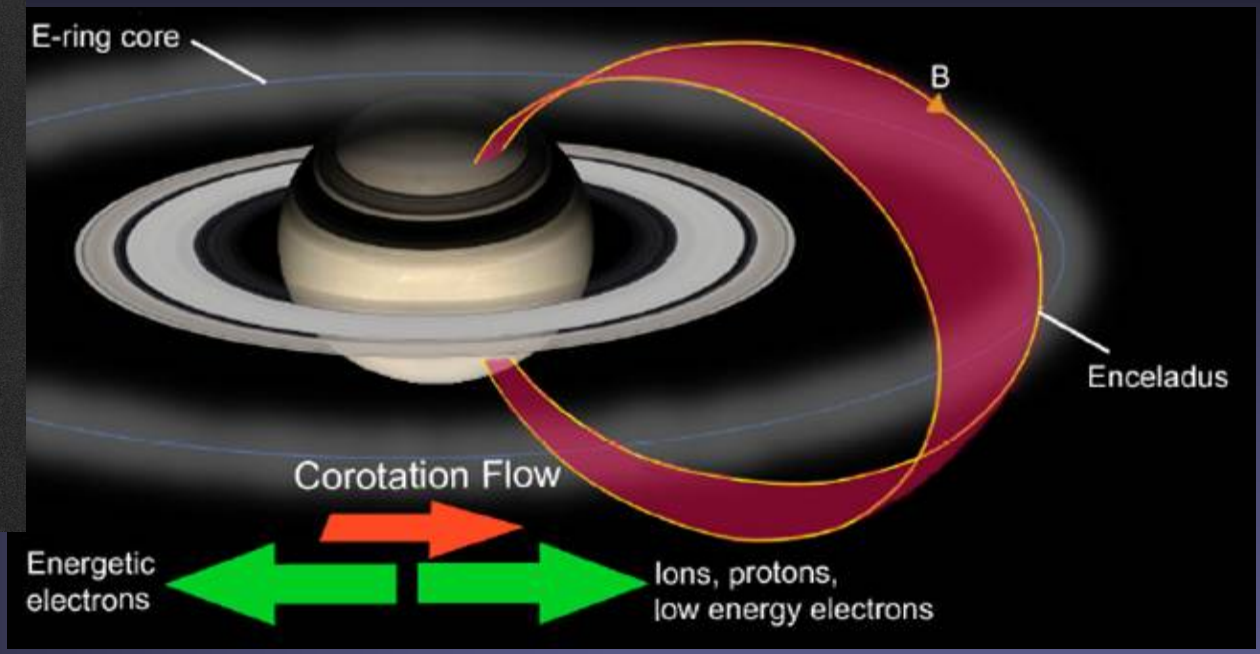


„Land“ area is brighter and redder than „Lake“ area (not clean water ice)

Landing site: Sandy plane covered with water ice (?) rounded pebbles

Saturn's Magnetosphere (Cassini)





Gas- and dust stream emanating from Enceladus' south pole.
Protons and electrons of the saturnian magnetosphere collide with the gas Remote sensing with the particle instrument MIMI.
Result: Gas jet is highly variable.

(Jones et al., Science, 2006)

Mars Express

ESA's first planetary orbiting mission

Launch: 2 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

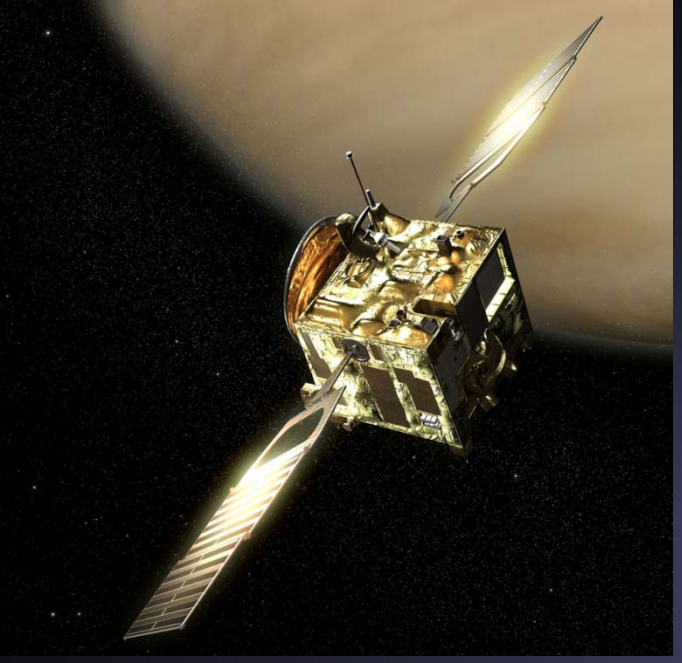
MarsExpress – Payload and Mission Goals

Mission Goal:

- image entire surface with 10 m/pixel, selected areas with 2 m/pixel
- produce map of mineral composition of surface at 100 metre resolution
- map composition of atmosphere and determine its global circulation
- determine structure of sub-surface to a depth of a few kilometres
- determine effect of atmosphere on surface
- determine interaction of atmosphere with 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 Rebuild of MEX (Mars Express)

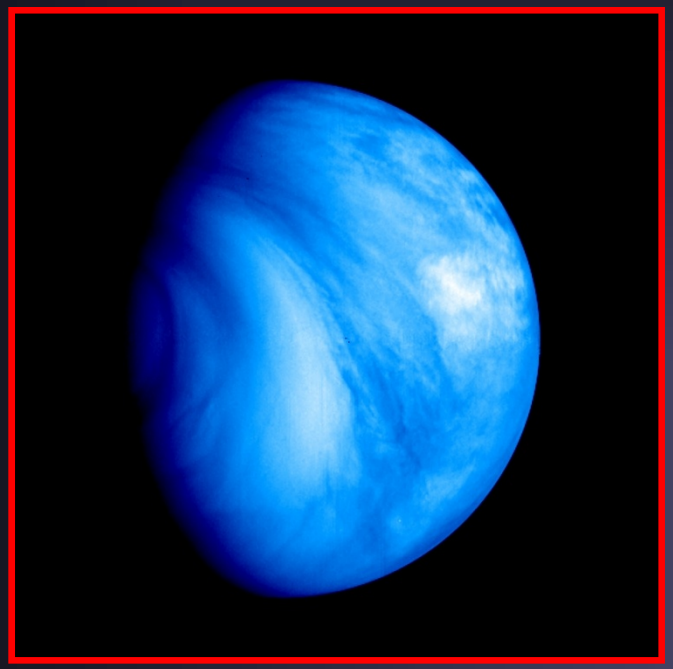
Launch: 9 Nov 2005, in orbit around Venus since April 2006

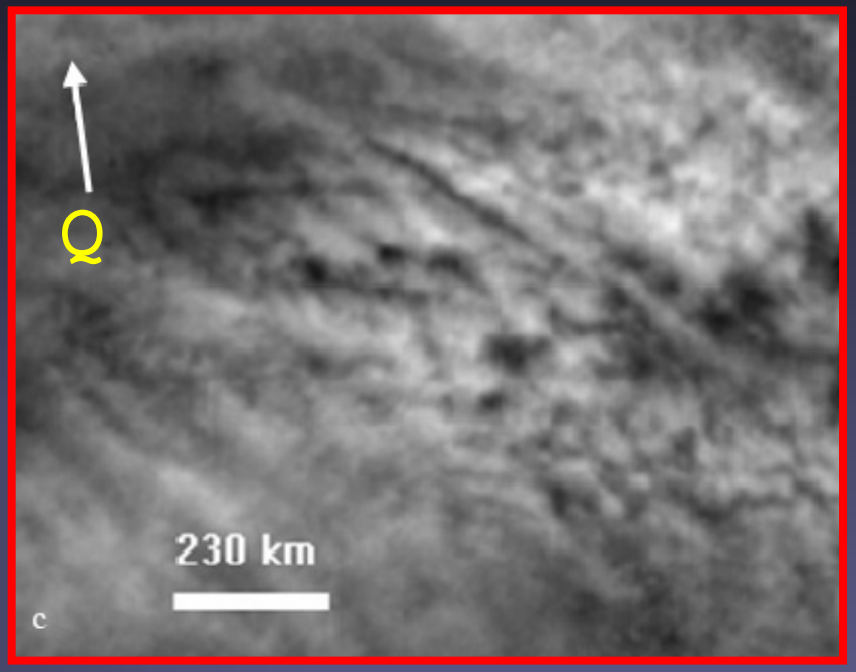
Launch mass: 1120 kg (incl. 113 kg orbiter payload and 60 kg lander)

Mission Goal: Compared to MEX stronger focus on atmosphere

- Study its complex dynamics and chemistry, and the interactions between atmosphere and surface, which gives clues on surface characteristics
- Study the interactions between the atmosphere and the interplanetary environment (solar wind) to better understand evolution of planet

Venus Express: VMC-Camera





Venus is covered by a global cloud deck in ~ 60 km altitude

Cloud structure is most obvious in the ultraviolet

Small scale convection cells close to the subsolar point suggest that convection is restricted to the top cloud layer (10 km thick)

Rosetta - the first spacecraft to orbit a comet's nucleus

ESA Mission to Comet 67P/Churyumov-Gerasimenko

Launch: 2 Mar 2004, in orbit around comet starting 2014 for ~2 yrs

Mission Design: Orbiter(165 kg payload) and 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 activity develops
- the first controlled touchdown on a comet nucleus

Rosetta instruments

Selection

Orbiter instruments

OSIRIS Camera system

MIRO Microwave spectrometer

ROSINA Mass spectrometer (gas)

CONSERT Radio wave probe

COSIMA Mass spectrometer (dust)

VIRTIS Visible & IR Spectrometer

ALICE UV imaging spectrometer

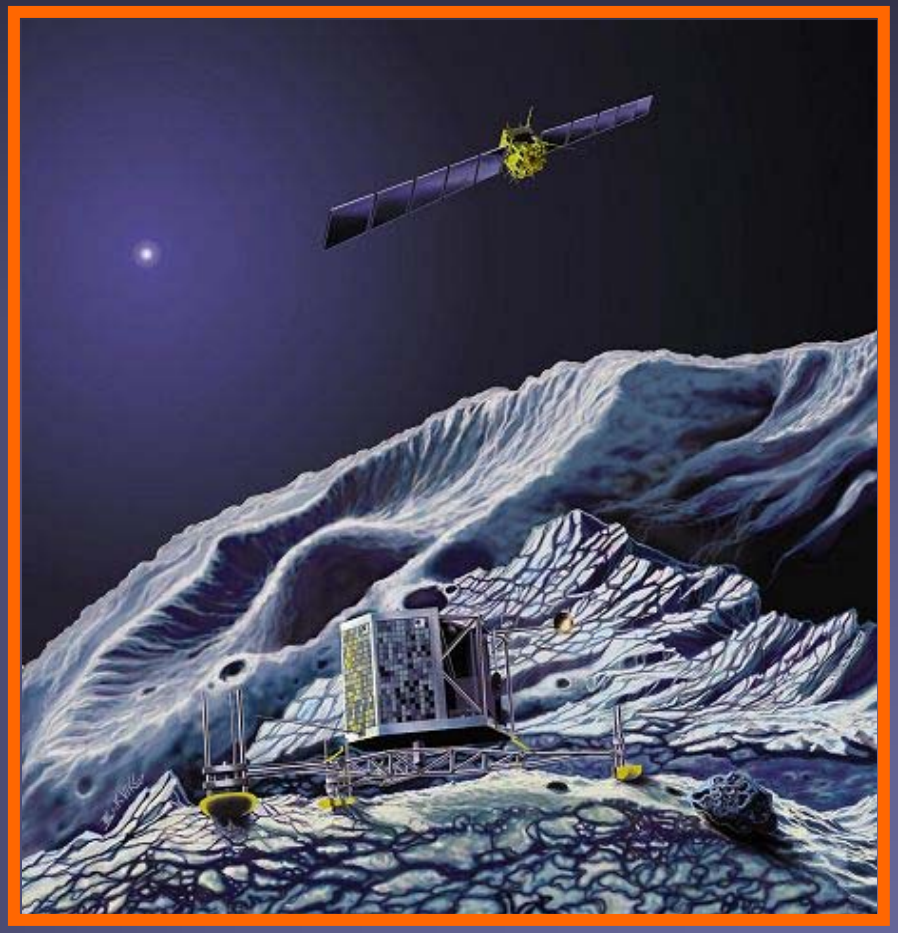
Lander Philae instruments

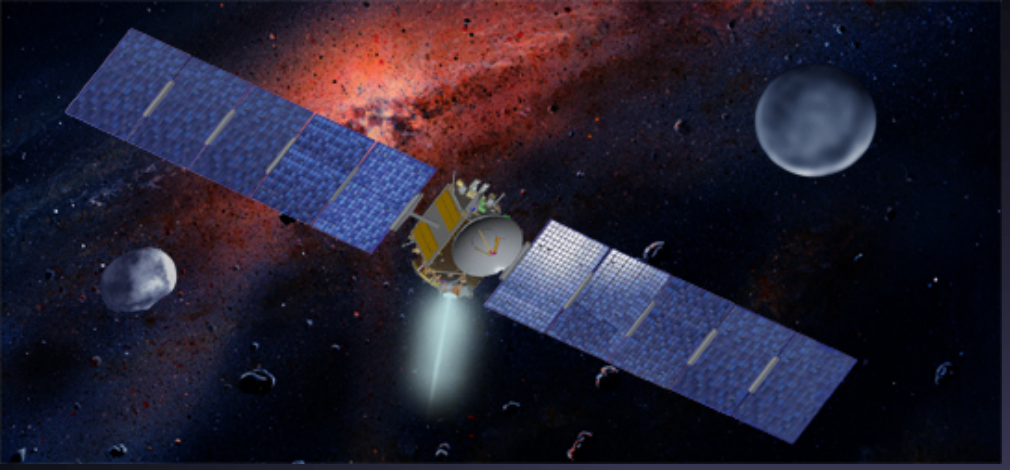
COSAC Chemical analysis

MUPUS Drilling experiment

ROMAP Magnetometer / Dust

ROLIS Lander imagers



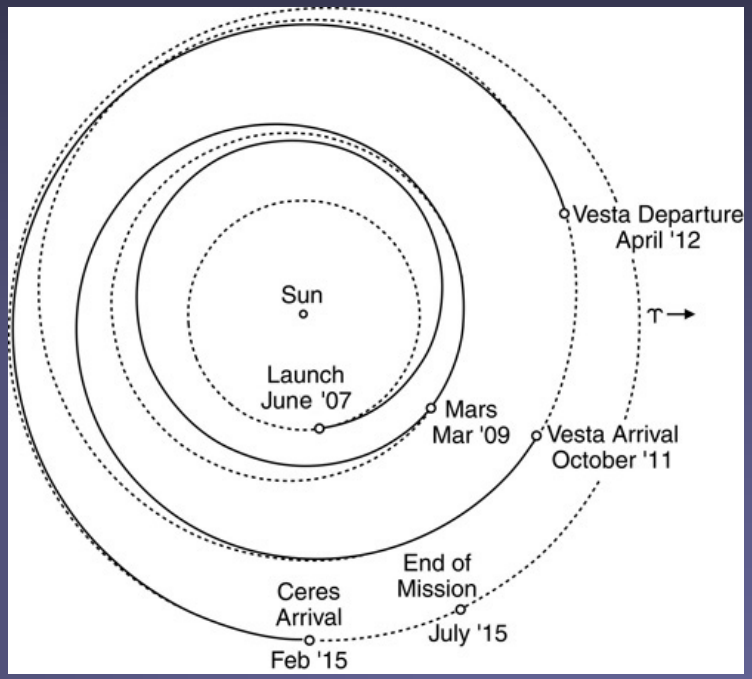


Dawn

NASA Discovery
Mission to two Asteroids
(Ceres and Vesta)

Dawn Mission Timeline (SEP)

Launch	27 Sept 2007
Mars gravity assist	Feb 2009
Vesta arrival	July 2011
Vesta departure	July 2012
Ceres arrival	February 2015
End of primary mission	July 2015



Instrumentation:

VIR – Visual & IR Mapping Spectrometer

FC – Framing Camera

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 formation

BepiColombo

ESA/JAXA Mission to Mercury

Launch: Aug 2014, in orbit around Mercury in 2020

Mission Design: Two orbiting spacecraft.

Mercury Planetary Orbiter (MPO) will map the planet

Mercury Magnetospheric Orbiter (MMO) will study its magnetosphere

Journey+ orbit: Both orbiters to be launched on single Soyuz-Fregat rocket by ESA in Kourou. BepiColombo will exploit gravity of Moon, Earth, Venus and Mercury + solar-electric propulsion (SEP). Near Mercury MMO and MPO separate to different orbits (polar orbit for MPO)

Mission Goal: A Cornerstone mission of ESA, it will study the composition, geophysics, atmosphere, magnetosphere and history of Mercury, the least explored planet in the inner Solar System