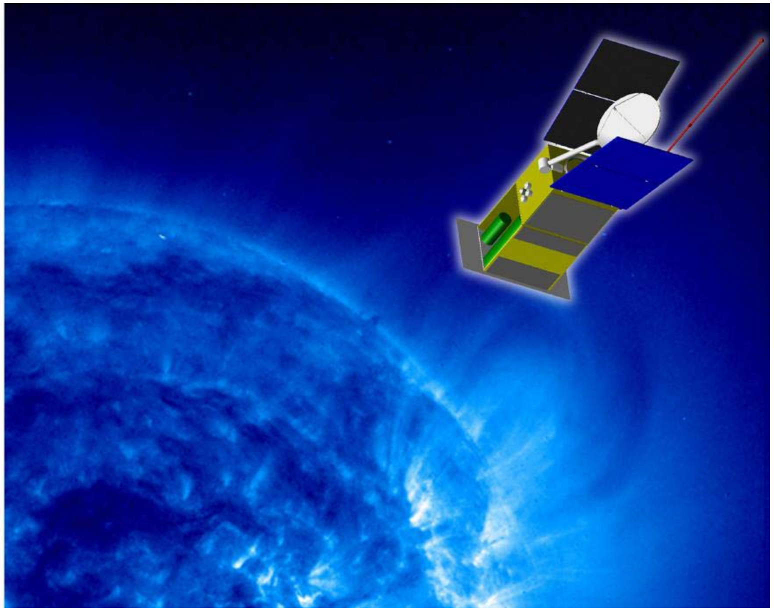
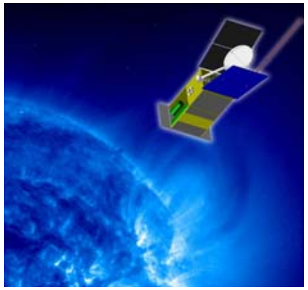
Solar Orbiter: Scientific Overview & Status

Richard Harrison, Rutherford Appleton Laboratory



A high-resolution mission to the Sun and inner heliosphere



Solar Orbiter

Study Team

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E. Antonucci	**Osservatorio Astronomico di Torino, Italy**
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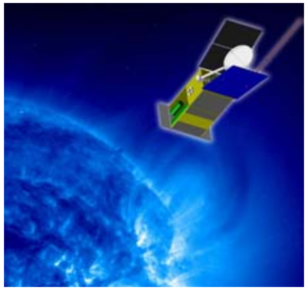
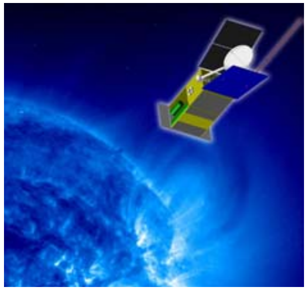
Study Scientists: B. Fleck**, ESA/GSFC and** R. Marsden**, ESA/ESTEC**
Study Manager: O. Pace**, ESA/ESTEC**
Solar System Mission Coordinator: M. Coradini**, ESA/HQ**



Solar Orbiter

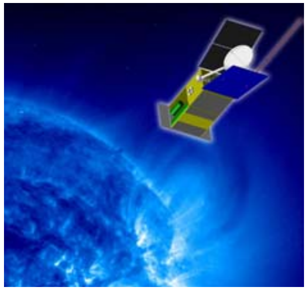
History

- European-wide meeting - Tenerife, Spring 1998
- ESA Solar Physics Planning Group - Chair: E. Priest, included O. Kjeldseth-Moe, E. Marsch & R.A. Harrison
- ‘Pre-Assessment Studies’ with ESTEC Support - proposal for F-mission study in January 2000
- Solar Orbiter selected for assessment (delta) study
- Study phase culminated in Paris presentation in September
- Selected! - October 2000
- First Solar Orbiter meeting - Tenerife, May 2001 (150 attendees)



Solar Orbiter

1. Rationale of mission
2. Mission Concept
3. Scientific Goals and Mission Firsts
4. The Four New Scientific Aspects
5. Mission Overview
6. Mission Status
7. Conclusions

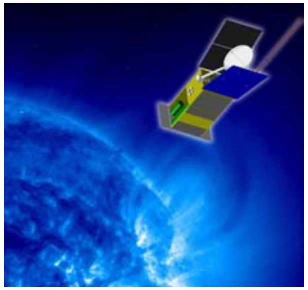


1. Rationale of Mission

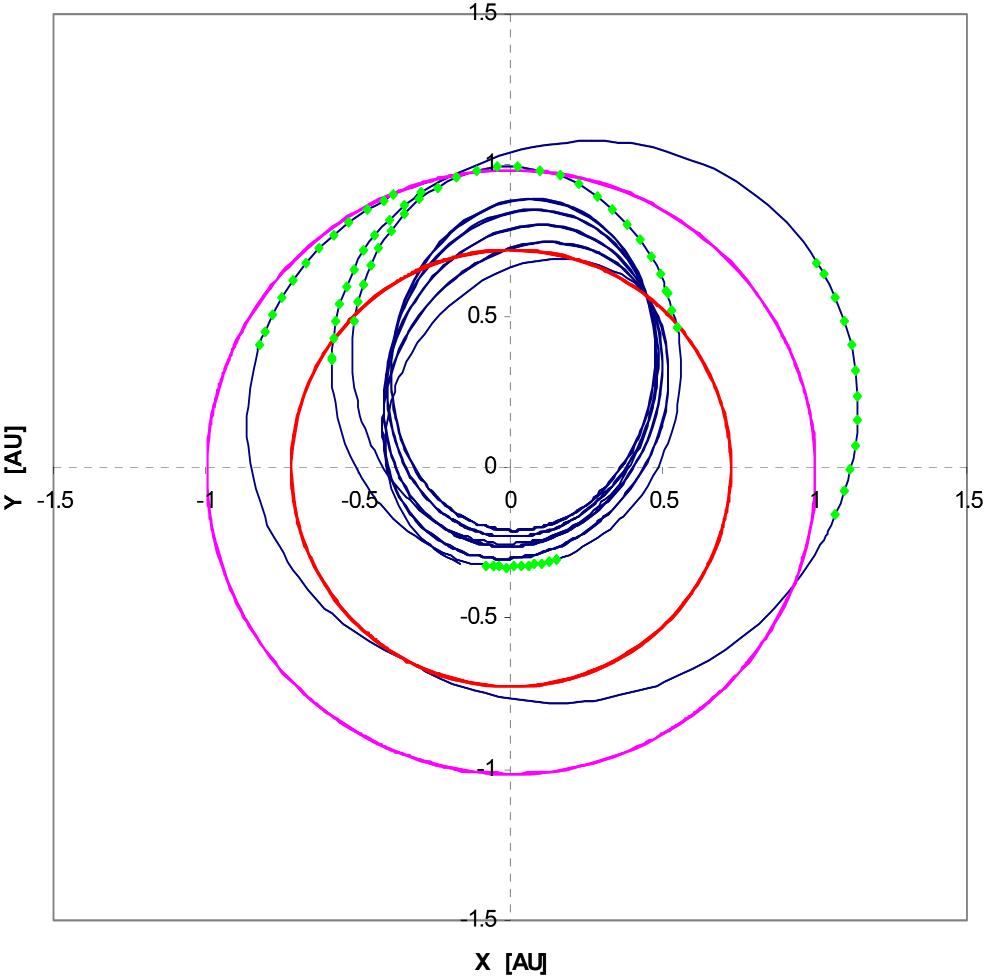
1. Sun's atmosphere and heliosphere:
   - uniquely accessible domains of space,
   - excellent laboratories for studying in detail fundamental processes common to astrophysics, solar and plasma physics

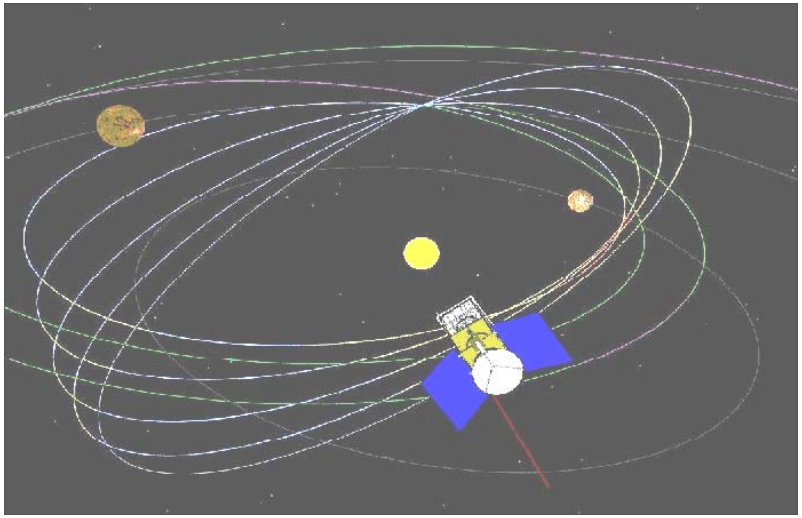
2. Remote sensing and *in-situ* measurements,
   - much closer to the Sun than ever before,
   - combined with an out-of-ecliptic perspective,

   promise to bring about major breakthroughs in solar and heliospheric physics



2. Mission Concept

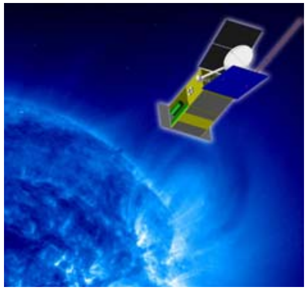




Obtain high resolution observations through proximity, a solar co-rotation vantage point and high latitude observations:

- using SEP and planetary fly-bys to achieve a 150 day orbit with 45 solar radii perihelion,
- using multiple Venus fly-bys to climb out of the ecliptic.

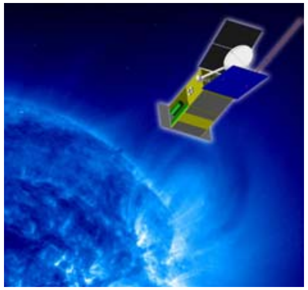
Solar Orbiter



3. Scientific Goals & Mission Firsts

Mission Firsts

- explore the uncharted innermost regions of our solar system
- study the Sun from close-up (45 solar radii or 0.21 AU)
- fly by the Sun tuned to its rotation and examine the solar surface and the space above from a co-rotating vantage point
- provide images of the Sun's polar regions from heliographic latitudes as high as 38°



3. Scientific Goals & Mission Firsts

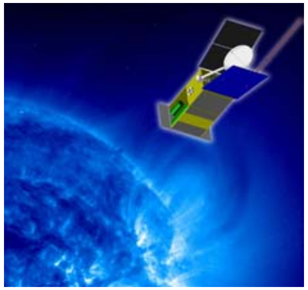
Scientific Goals - Four new aspects

• determine *in-situ* the properties and dynamics of plasma, fields and particles in the near-Sun heliosphere

• investigate the fine-scale structure and dynamics of the Sun's magnetised atmosphere, using close-up, high-resolution remote sensing

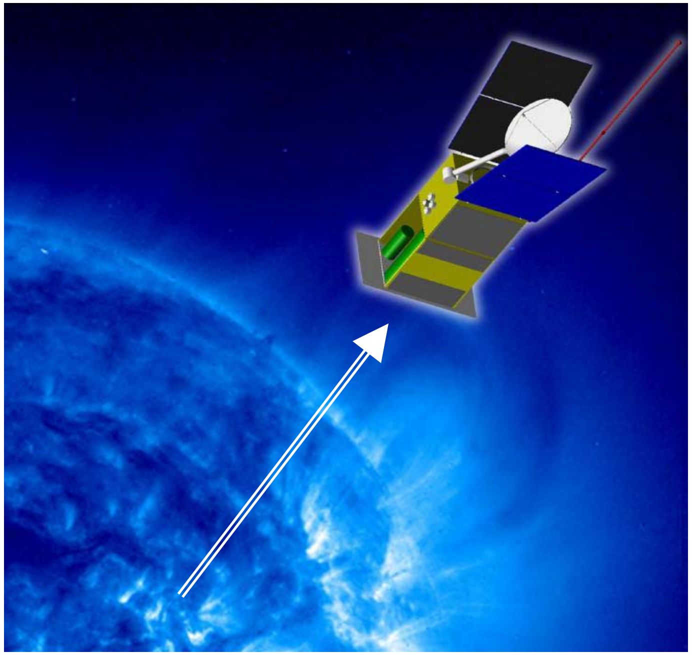
• identify the links between activity on the Sun's surface and the resulting evolution of the corona and inner heliosphere, using solar co-rotating passes

• observe and fully characterise the Sun's polar regions and equatorial corona from high latitudes

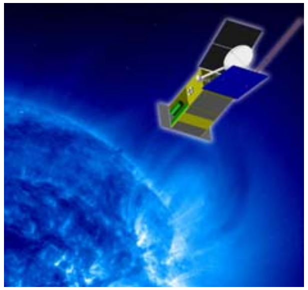


4. The Four New Scientific Aspects - (i) Co-rotation

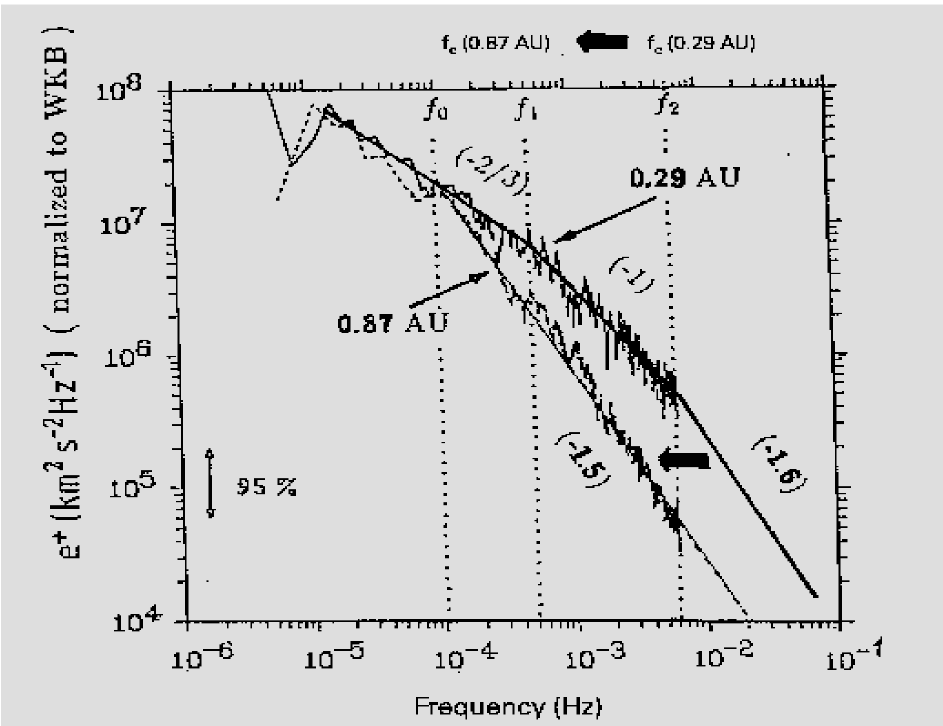
Solar Orbiter will discriminate spatial from temporal variations



- determine relationship between coronal & solar wind structures on all scales
- correlate in-situ particle characteristics with coronal sources
- identify ion compositional boundaries



4. The Four New Scientific Aspects - (ii) *In-Situ*



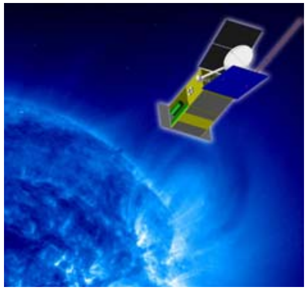
Magnetohydrodynamic waves and turbulence

Solar Orbiter will show

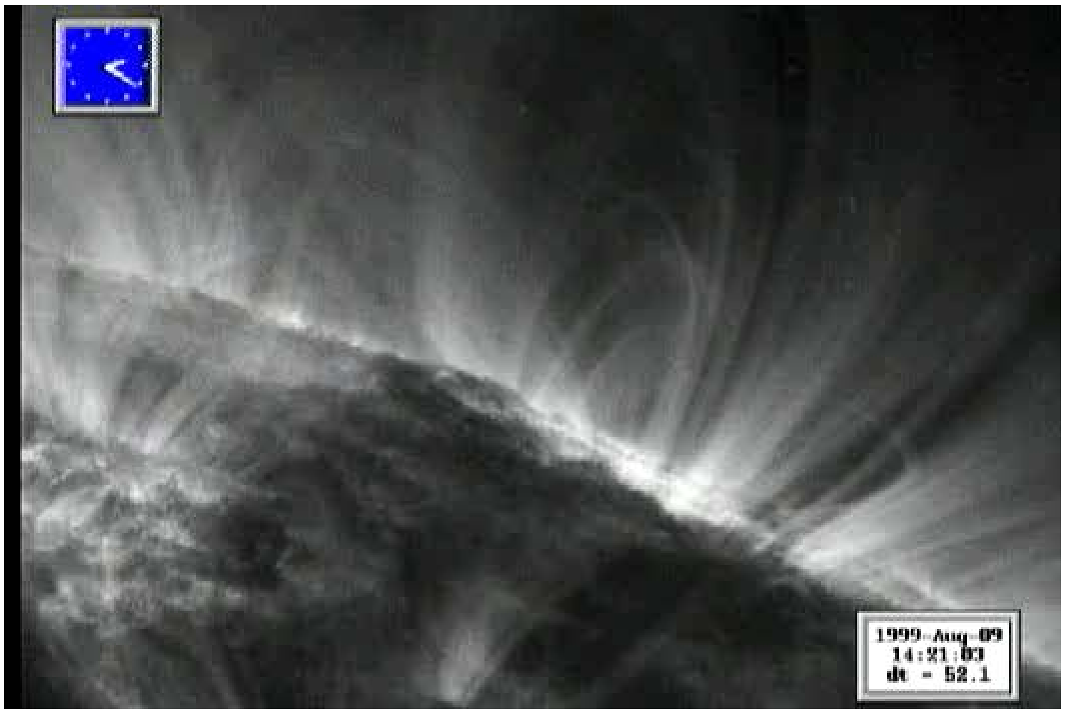
- how MHD turbulence varies and evolves spatially,
- what generates Alfvén waves in the corona,
- how the turbulence is dissipated.

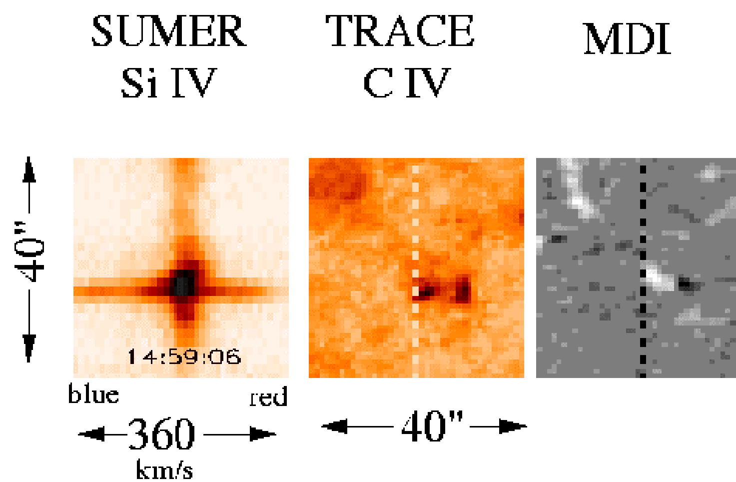
Spectrum of Alfvénic fluctuations:

Steepening and dissipation!

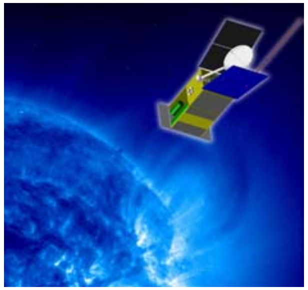


4. The Four New Scientific Aspects - (iii) Close-Up

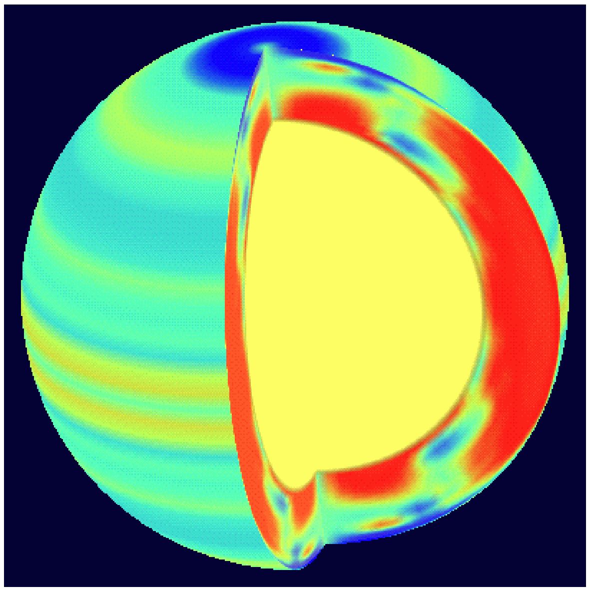


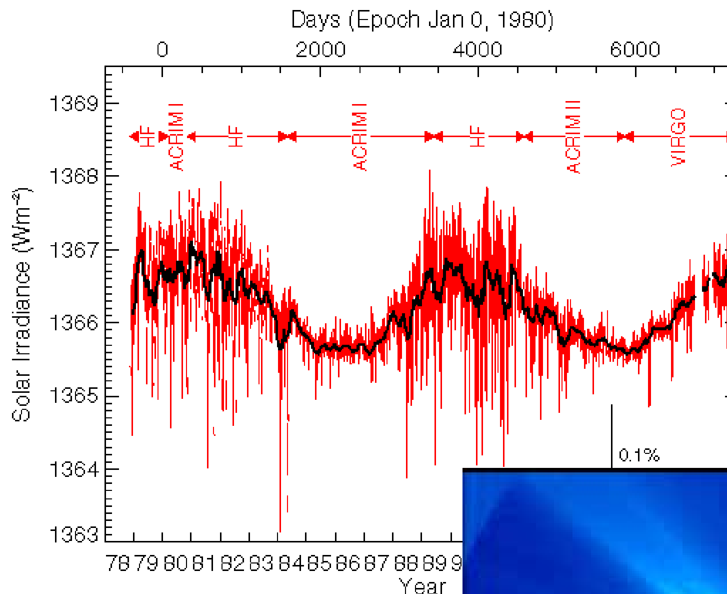


Solar Orbiter will resolve the highly structured solar atmosphere an order of magnitude better than presently possible (both images and spectra)

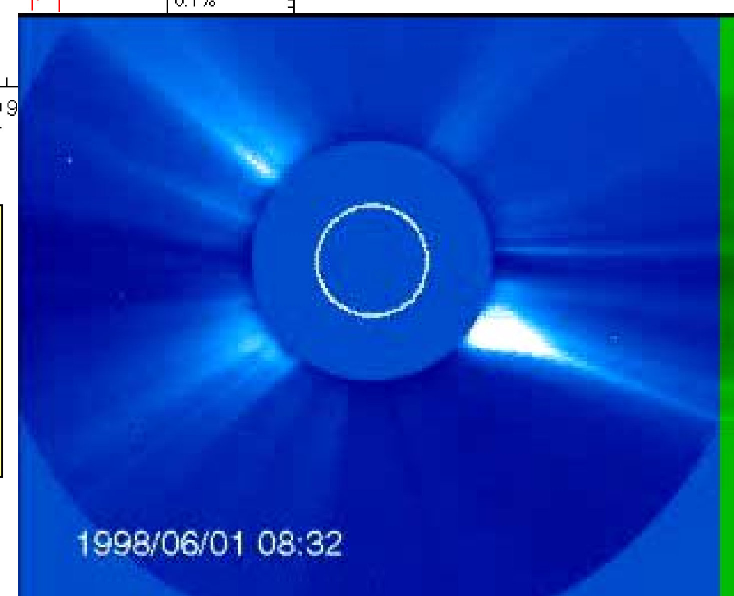


4. The Four New Scientific Aspects - (iv) Out of Ecliptic

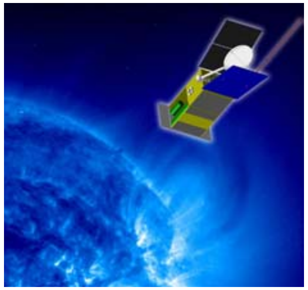




Solar Orbiter will reveal the magnetic and rotation characteristics of the polar regions, mass ejection global distributions and spreads, and 3-D luminosity



Solar Orbiter



5. Mission Overview

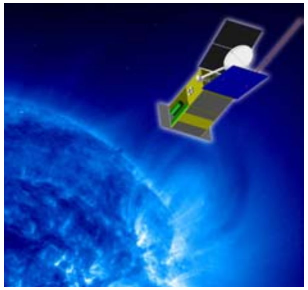
Orbit : solar orbits achieving high heliographic latitudes (goal over 30°) with perihelion inside 0.3 AU, and co-rotation phases

Launch: as early as 2007 (in principle every ~ 19 months); Soyuz-Fregat from Baikonur, assumed for study (2009, 2011…)

Mission duration: cruise phase ~1.9 years (3 orbits); nominal mission ~2.9 years (7 orbits); extended mission ~2.3 years (6 orbits)

Spacecraft: 3-axis stabilised, Sun-pointed (absolute ± 3arcmin, stability ± 0.7 arcsec/15min. SEP technology benefits from BepiColombo; 1296 kg lift-off mass

Payload resources: 130 kg, 127 W, 74.5 kbit/s.



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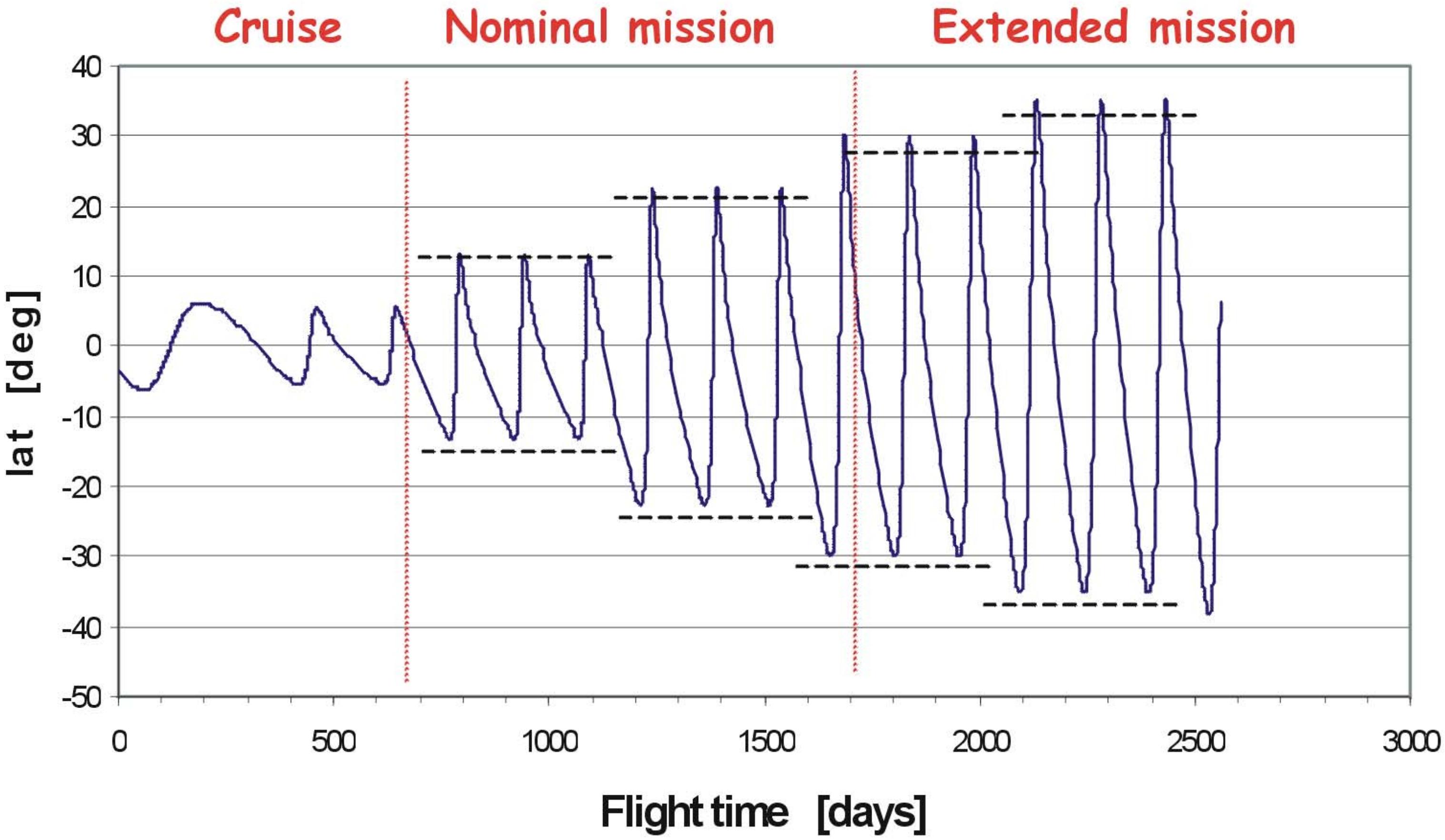

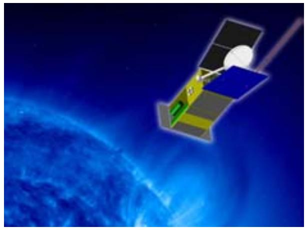

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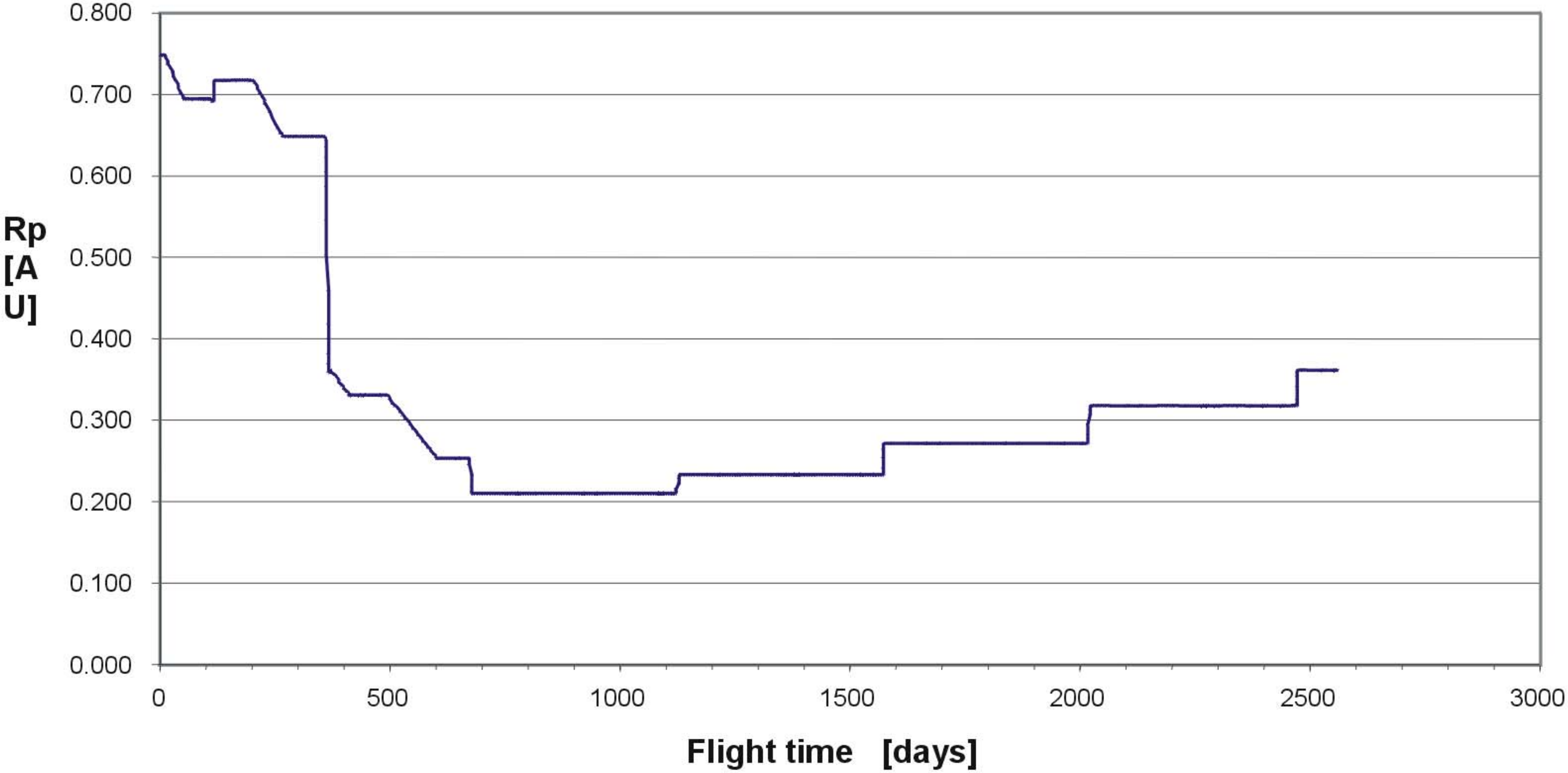

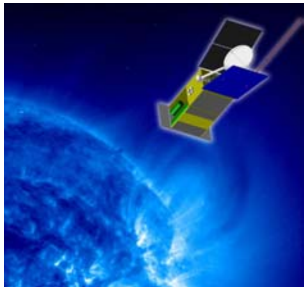

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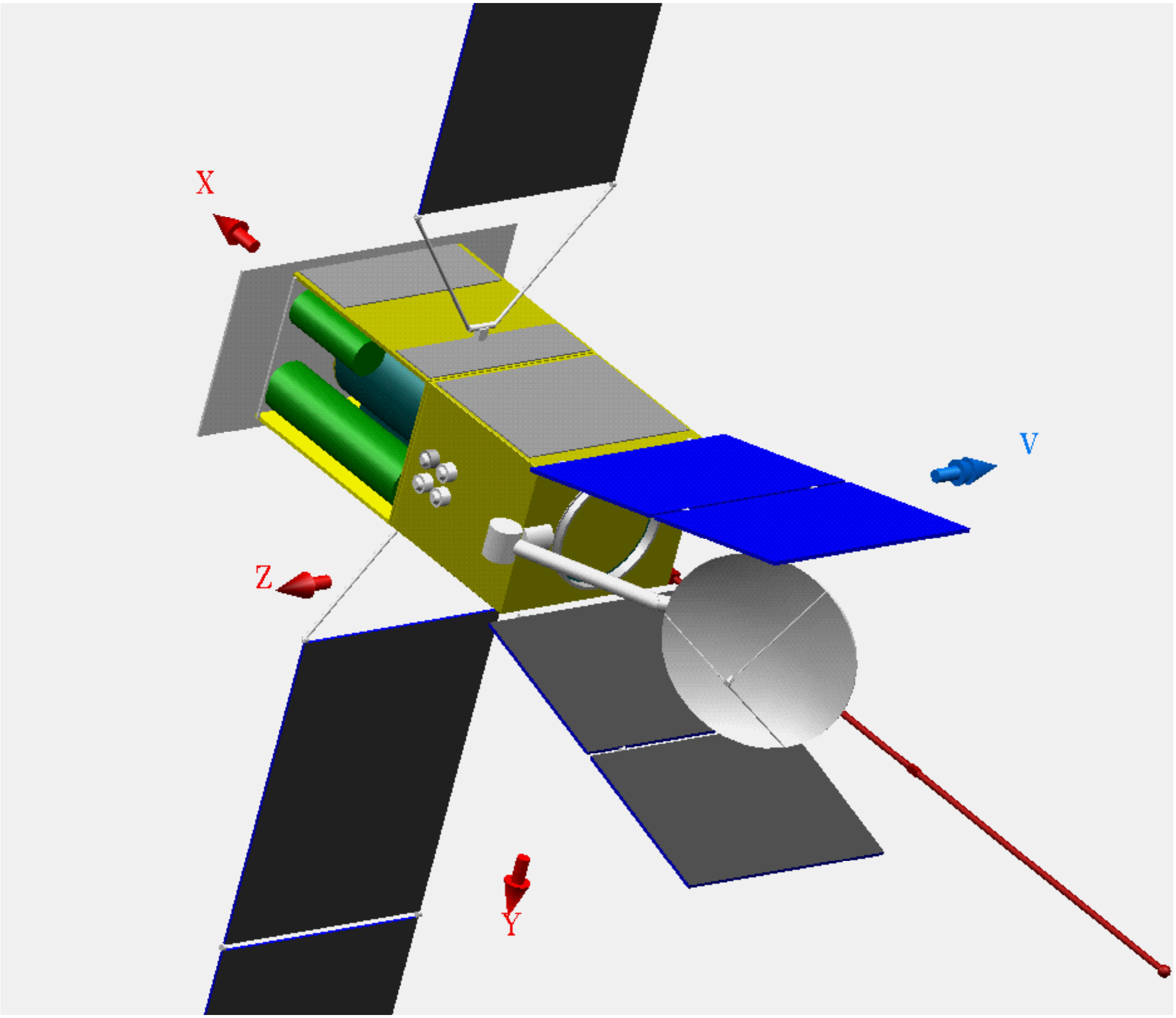
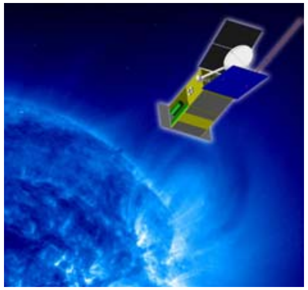


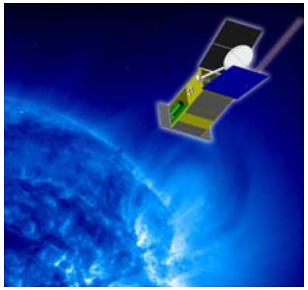


5. Mission Overview

- The science goals require a sophisticated suite of remote sensing and *in-situ* instruments

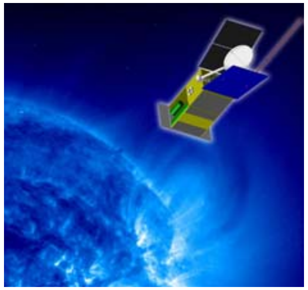
- The mission profile demands that the instruments be low-mass, autonomous and thermally robust

- The thermal aspects have demanded quite mature instrument concepts at this early stage



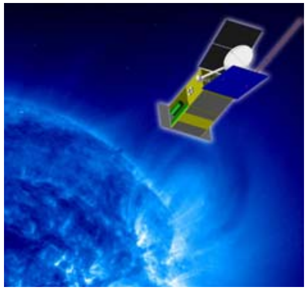
5. Mission Overview

Instrument	Mass kg	Power W	kb/s
Solar Wind Plasma Analyser (SWA)	6	5	5
Radio & Plasma Waves Analyser (RPW)	10	7.5	5
Coronal Radio Sounding (CRS)	0.2	3	0
Magnetometer (MAG)	1	1	0.2
Energetic Particle Detector (EPD)	4	3	1.8
Dust Detector (DUD)	1	1	0.05
Neutral Particle Detector (NPD)	1	2	0.3
Neutron Detector (NED)	2	1	0.15



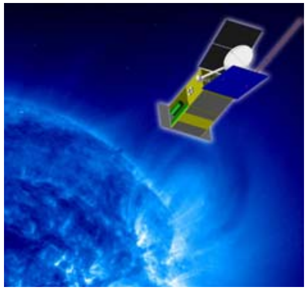
5. Mission Overview

Instrument	Mass kg	Power W	kb/s
Visible Light Imager & Magnetograph (VIM)	26	25	20
Extreme UV Spectrometer (EUS)	22	25	17
Extreme UV Imager (EUI)	36	20	20
UV & Visible Light Coronagraph (UVC)	17	25	5
Radiometer (RAD)	4	6.5	0.5



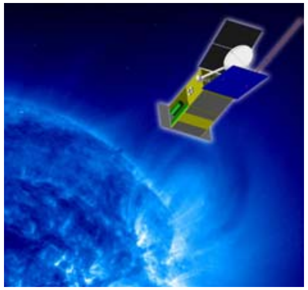
6. Mission Status

- Selected F-mission for launch ‘after 2009’
- Letters of Intent to Propose - 2002
- AO - 2003/4?
- November Ministerial??
- Payload Working Group study - being formed now for study period 2002-3 (R. Marsden & B.Fleck)



7. Conclusions

- Solar Orbiter is an exciting and challenging mission which will allow major advances in solar and heliospheric physics
- It is a logical 'next step' from the on-going solar (Yohkoh, SOHO, TRACE) and heliospheric (Ulysses, Cluster) missions

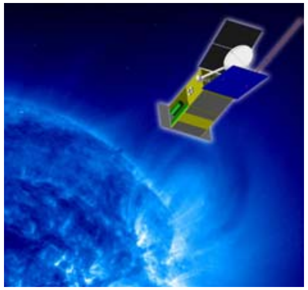


The EUS Instrument

Richard A. Harrison,

Rutherford Appleton Laboratory

1. Scientific requirements
2. Concept & initial design strategy
3. The hardware consortium
4. Web site/documentation
5. Aims of this meeting



The EUS Instrument

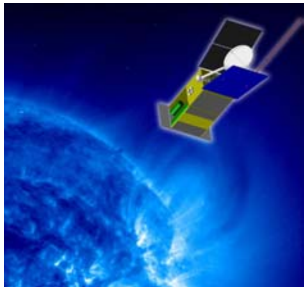
1. Scientific Requirements

The Need for a UV/EUV Spectrometer

1. UV/EUV spectral range critical for solar plasma diagnostic analysis; provides foundation for exploring the physics of a huge range of phenomena.

2. Current and near-future UV/EUV capability:

Yohkoh None
SOHO EUV 2-3″ and 0.1 Å & UV 1″ and 0.02 Å.
TRACE None
STEREO (2005) No spectroscopy.
Solar-B (2005) EUV 1″ & 0.01 Å; on 2″ platform; coronal λ selection with little TR capability.
SDO (2007) Possibly none; EUV/UV spectroscopy given low priority.
Solar Probe (2007??) None



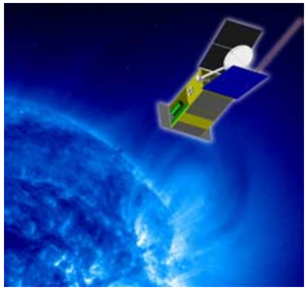
The EUS Instrument

1. Scientific Requirements

Proposed Requirements

Spatial Resolving Element (pixel)	0.5 arcsec	75 km at perihelion
Spectral Resolving Element (pixel)	0.01-0.02 Å/pixel	lower the better
Field of View (minimum)	34 x 34 $arcmin^2$	AR size at perihelion
Exposure time (minimum)	<1 s	
Maximum Exposure Time	Few 100 s	cosmic ray limit
Wavelength Bands	170-220 Å 580-630 Å > 912 Å	Prime bands from Tenerife meeting
Pointing	To anywhere on Sun and low corona	

The Sun's atmosphere is a truly dynamic, fine-scale environment. Current imaging resolutions (0.5" & few S) are restricting; A consideration of filling factors and basic processes shows that we need to do better. Target: OM improvement in spatial resolution, and 5x better than the best imager capability (75 km on the Sun's surface, i.e. 0.1" from 1 AU, is 0.5" at 0.2 AU)



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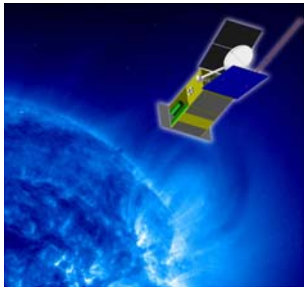
We need to separate emission lines, but the spectral resolution is driven by velocity, which is a major parameter for this mission; we will have good viewing of the polar outflows for the first time. A value of order 5 km/s would be a reasonable target, i.e. about 0.01 Å/pixel. Use of centroiding could allow some relaxation of this to 0.02 Å/pixel.



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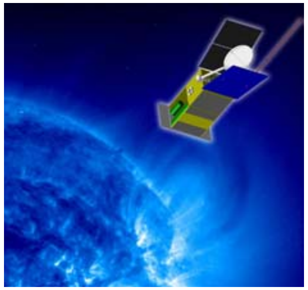
The FOV is important, especially for a mission in such an eccentric solar orbit. The requirement is for the FOV to cover an active region at the 0.2 AU perihelion, and to cover the full Sun at aphelion. This can be achieved with a FOV of 34′ and upwards (300,000 km square field at 0.2 AU, which is larger than the CDS 200,000 km field; at 1 AU this is 1,500,000 km square.



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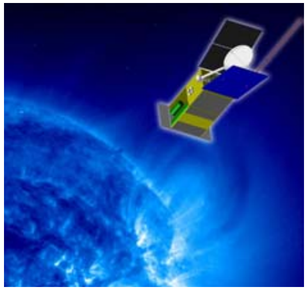
The dynamic nature of the solar atmosphere demands significantly better temporal resolution than currently available. There is a play-off between exposure time and temporal resolution; reasonable counting statistics must be obtained. The actual resolution will depend on the line used and the solar target. The instrument must have flexibility, down to under 1 s.



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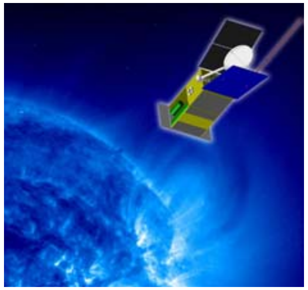
We have to consider a maximum exposure time. Normal operations would require exposures of order 1-50 s. Long exposures will suffer from excessive cosmic ray hits and values in excess of 100 s (e.g. on SOHO) would tend to be swamped by particle hits. Long accumulations can be achieved by summing consecutive images. 100 s is a reasonable upper limit.



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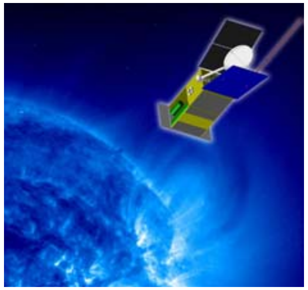
We require a wavelength range to cover a good temperature range from chromosphere to flare plasmas, with sufficient diagnostic tools. This most likely requires several bands. The bands listed are those favoured at the 2001 Tenerife workshop.



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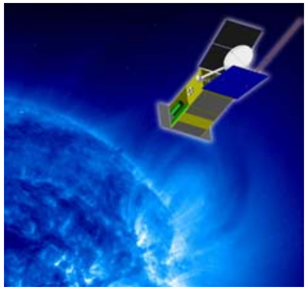
We require that the instrument can be pointed to anywhere on the solar disc or low corona.

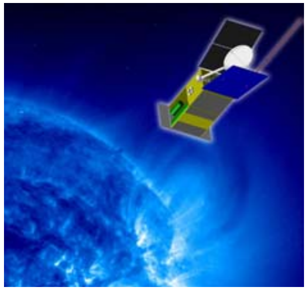


The EUS Instrument

2. Concept & Initial Design Strategy

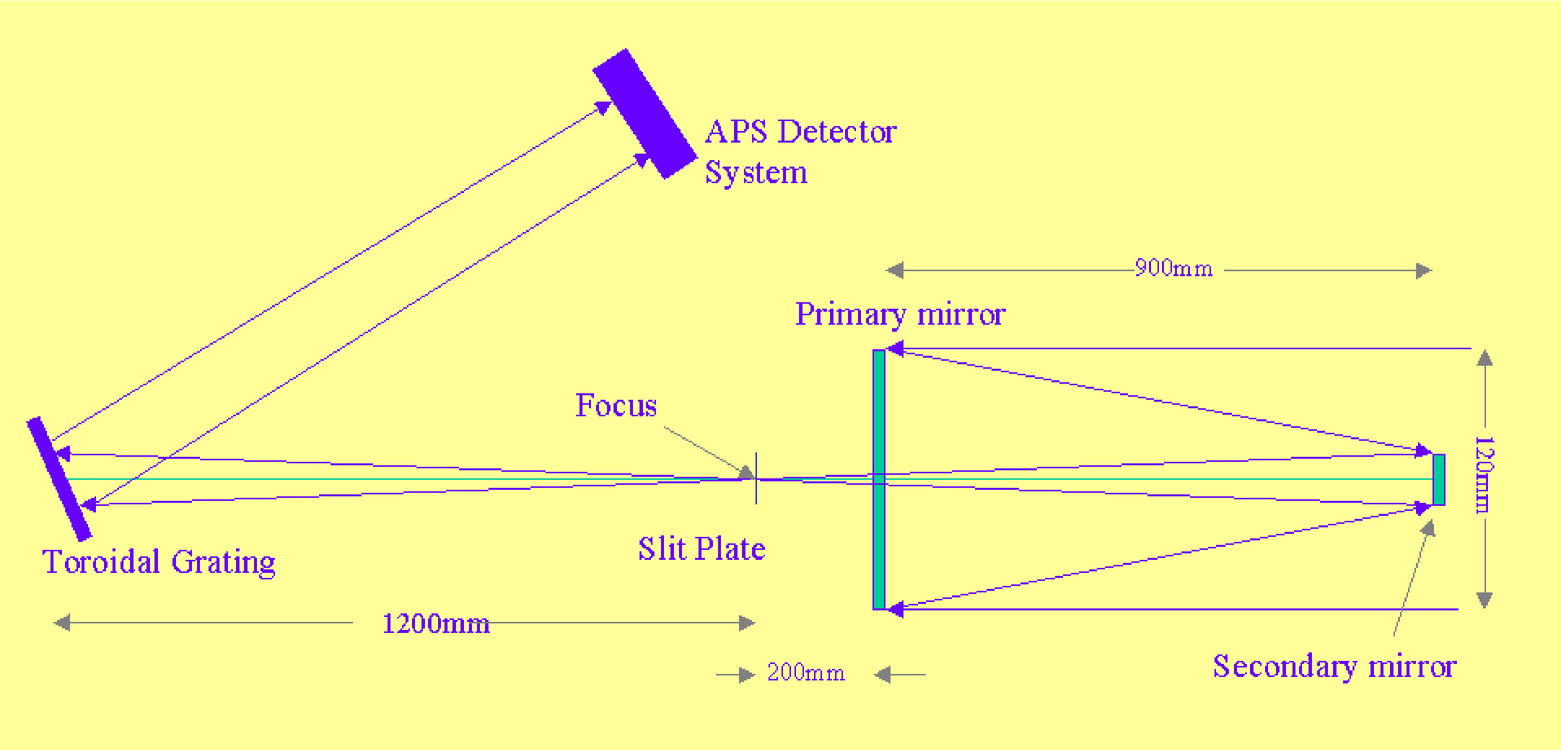
Other Factors Which Influence the Design

Instrument Size	Max. Length 2.5 m	Due to spacecraft size
Mass	25 kg target	Under 30 kg
Telemetry	20 kbit/s target	Demands large on board memory
Power	30 W target	
Thermal Environment	Varying and high levels of heat input requiring careful control .	Due to solar proximity and eccentric orbit.
Particle Environment	Varying levels of particle events with some extreme 'storms'. Includes solar neutrons.	Cosmic ray background and solar events.
Autonomy	Pre-planned sequences in deferred command store.	No contact for solar passes
Optical Correction	May require active image stabilisation system.	Spacecraft stability to be defined.

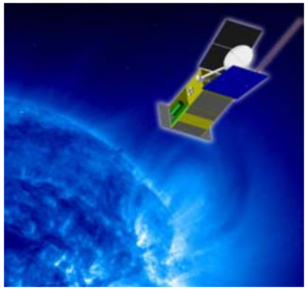


The EUS Instrument

2. Concept & Initial Design Strategy

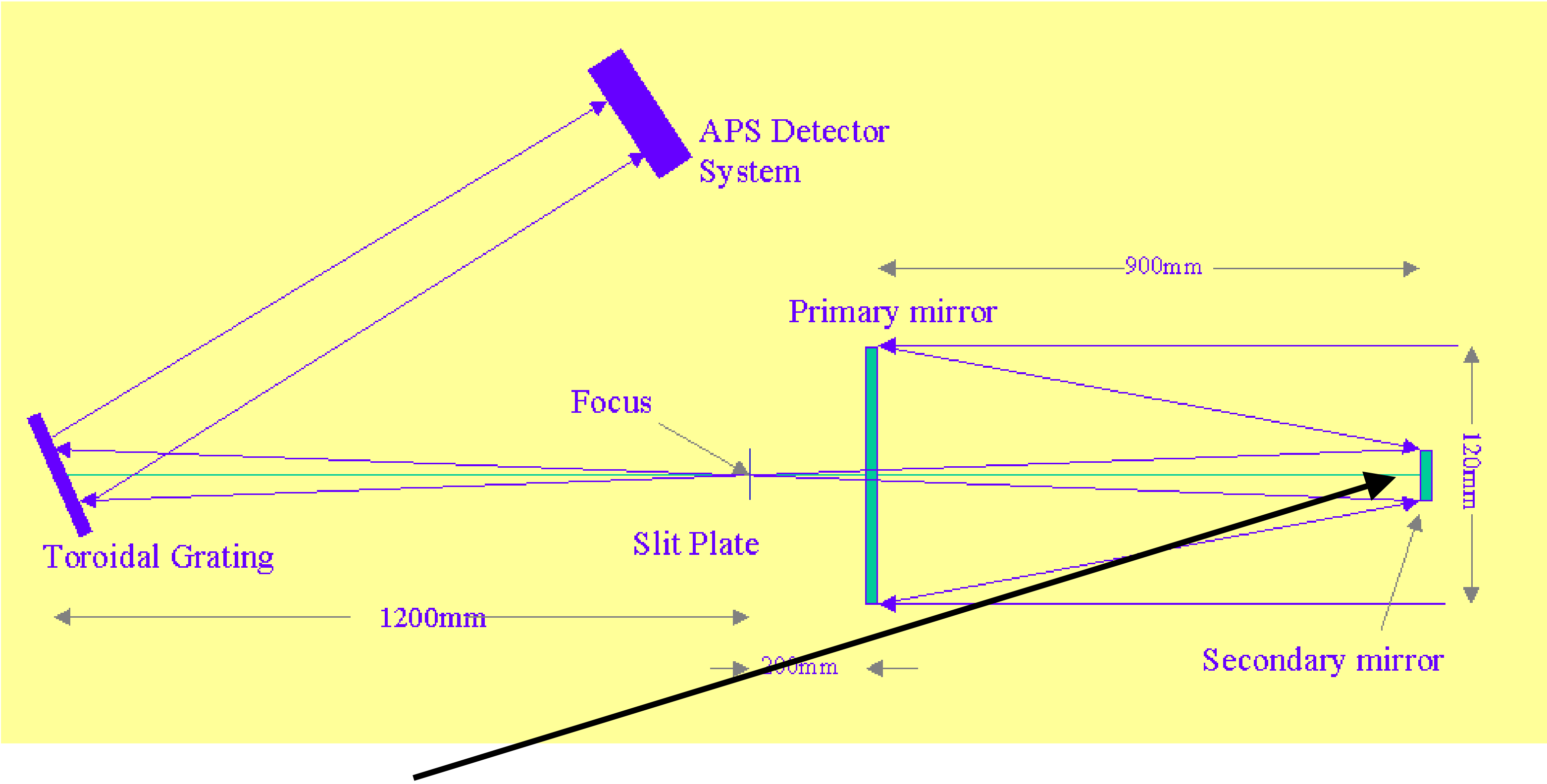


Ritchey-Chretien design feeding spectrometer - 2 reflections to restrict length - retains desired resolution. EFL = 3.7 m. Size: 15cm x 230cm x 55cm.

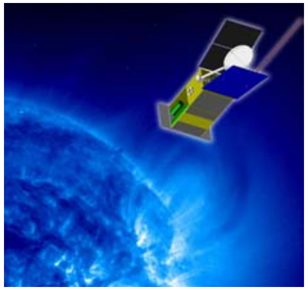


The EUS Instrument

2. Concept & Initial Design Strategy



Secondary mirror can be rotated to 'raster' image across slit. Other options include rotation of primary, scan mirror or pointing instrument.



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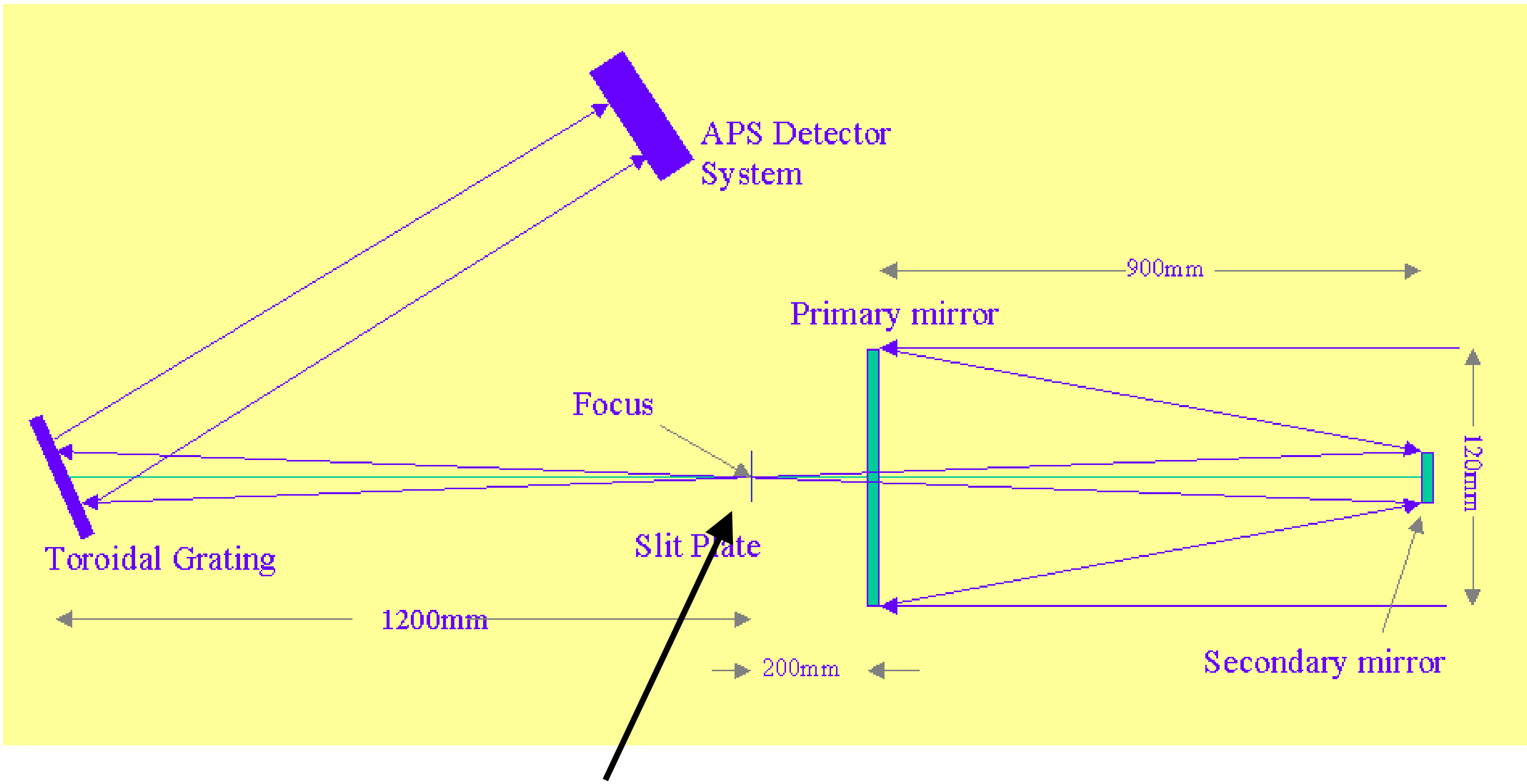
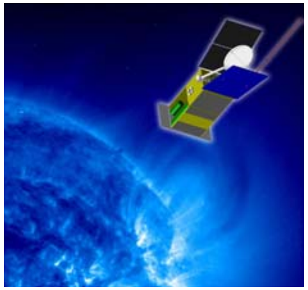
2. Concept & Initial Design Strategy

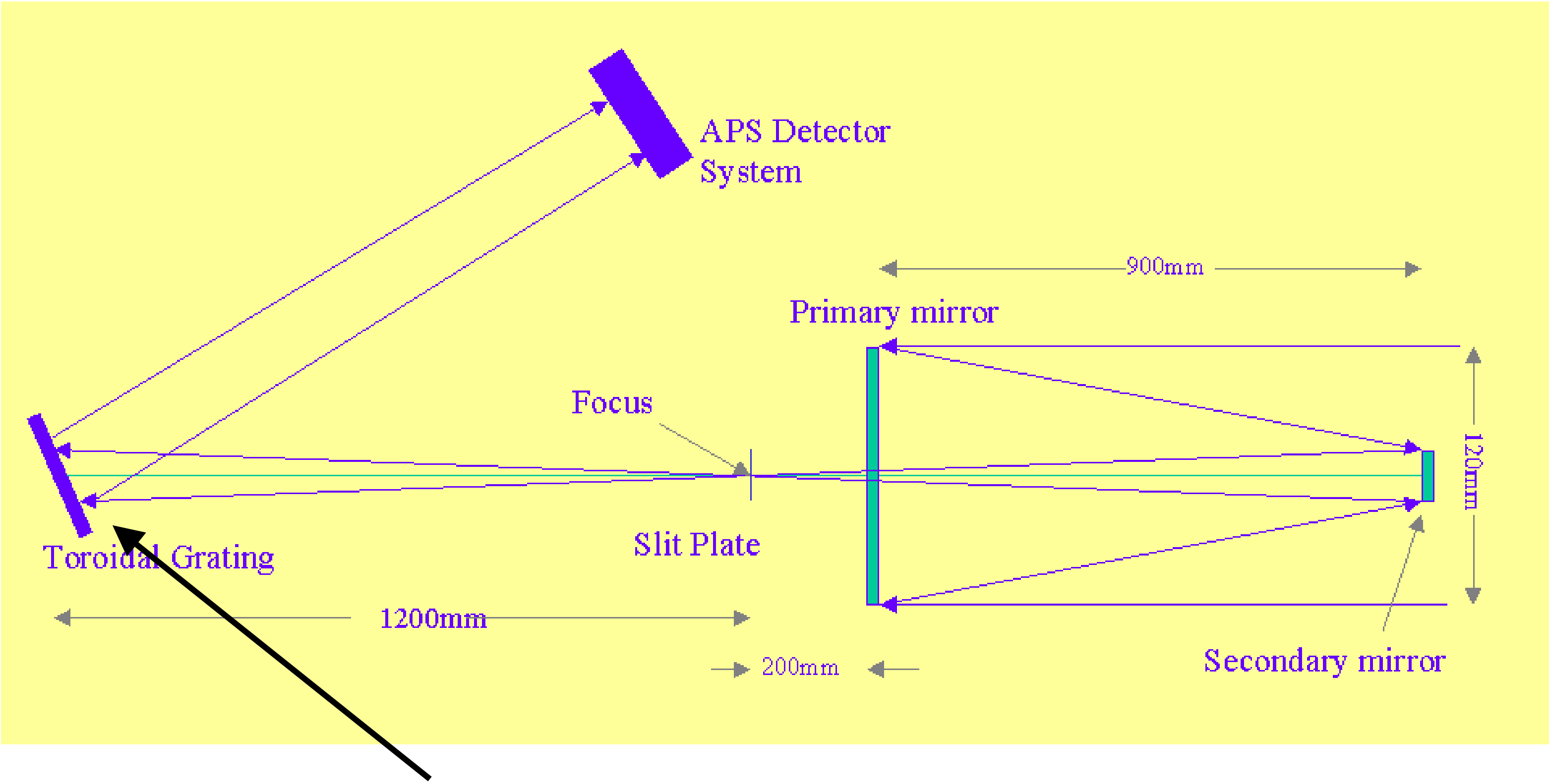


Selection of slits? Slit plane 'imager'.

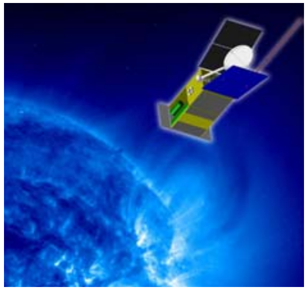


The EUS Instrument

2. Concept & Initial Design Strategy

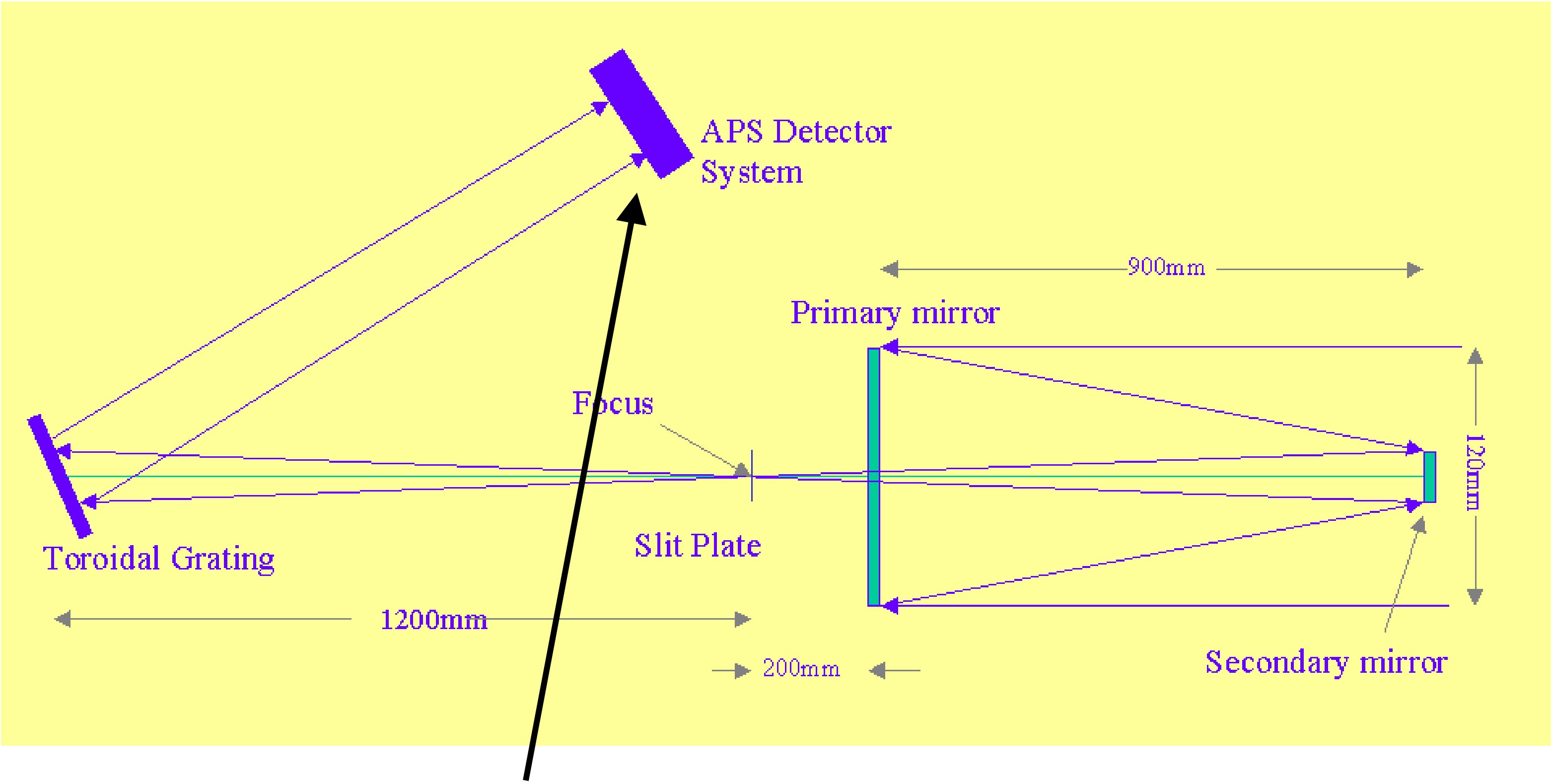


Grating baseline was 4800 l/mm but spherical VLS grating option is most likely choice (reduces off-axis aberrations; reduces instrument envelope)

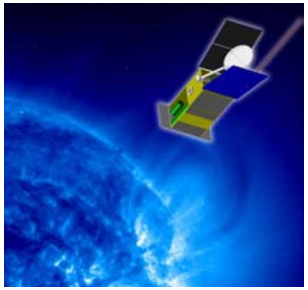


The EUS Instrument

2. Concept & Initial Design Strategy



Active Pixel Sensor detector baselined. Better suited to particle environment. Initial design: 9 micron 4kx4k array. Considering: 5 micron.



The EUS Instrument

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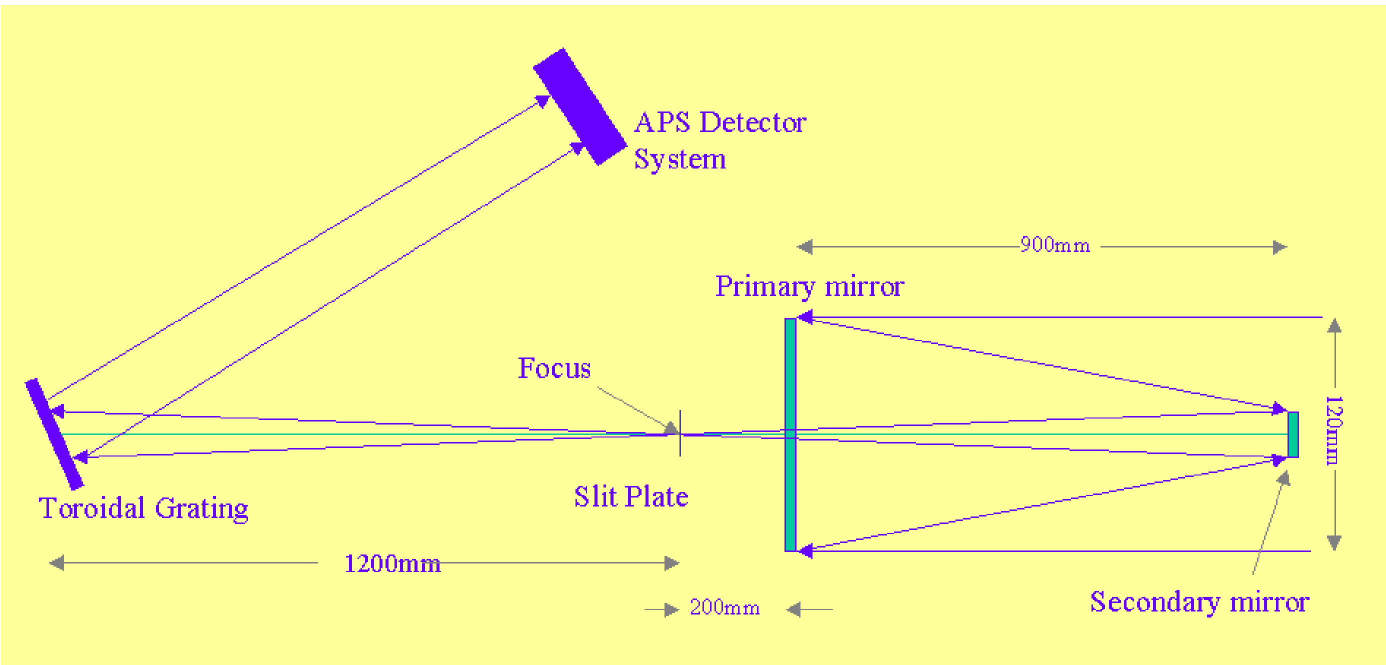
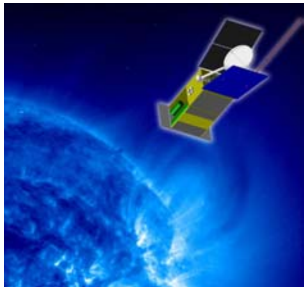


Solar 'constant' 34,275 W/m² to 2,142 W/m² on 149 day cycle (1 AU = 1,371 W/m²)

Initial Thermal concept: Dedicated radiators to primary, secondary and detector, reduced secondary mirror, gold-coating.



The EUS Instrument

3. The consortium

Rutherford Appleton Laboratory, UK

Mullard Space Science Laboratory, UK

Birmingham University, UK

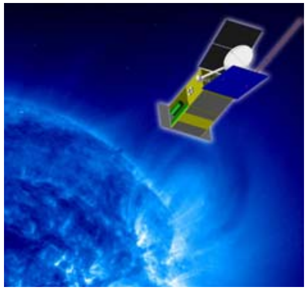
Max Planck, Lindau, Germany

Padua University, Italy

Goddard Space Flight Center, USA

Oslo University, Norway

IAS, Orsay, France



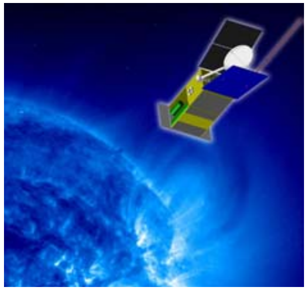
The EUS Instrument

4. Web site/documentation

1. Concept document ('Blue Book')

2. Technical notes (TN1 - Wavelength selection; TN2 - Orbiter goals; TN3 - Optical design requirements; TN4 - Detector requirements

3. Contact info., message board, links and Solar Orbiter information



The EUS Instrument

5. Aims of this meeting

- To kick-off a year-long pre-AO study of the feasibility of developing a spectrometer for Solar Orbiter.

- To begin to form a 'solid' consortium with an instrument that caters for our scientific needs and utilises our hardware strengths.

- Specific task: To address the technical needs in open discussion and ensure that the required studies are embarked upon. So, expect some actions! Also, to enable us to set up a schedule and further meetings