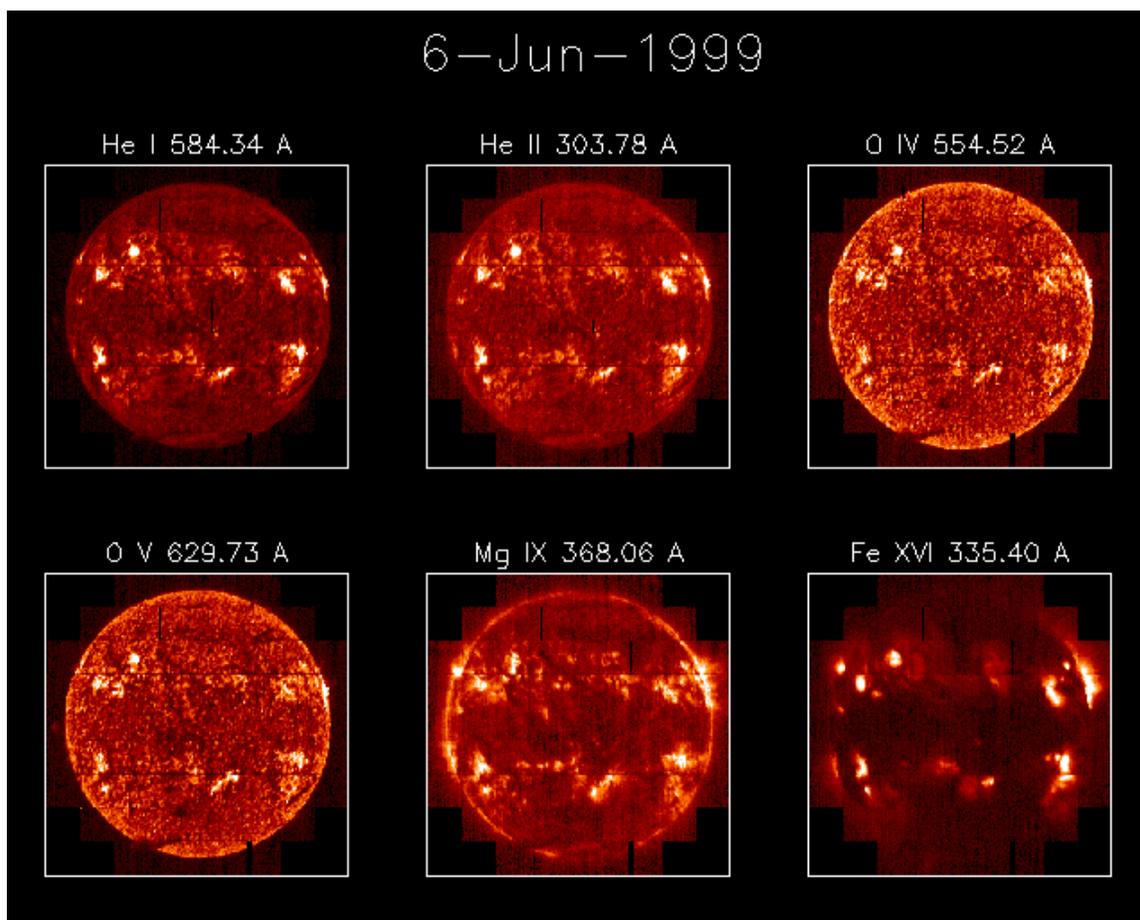


# EUV Imager and Spectrometer (EUS) for the Solar Orbiter

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Prepared by Richard Harrison  
Rutherford Appleton Laboratory



*[A set of simultaneous, full-Sun images in a selection of EUV emission lines with characteristic temperatures in the range 20,000 K (He I, top left) to 2 million K (Fe XVI, bottom right), taken with the CDS instrument aboard SOHO.]*

## **1. Introduction**

Observations of the UV/EUV spectral range are critical for the determination of plasma diagnostics in the solar atmosphere across the broad temperature range from tens of thousands to several million K. Analysis of the emission lines, mainly from trace elements in the Sun's atmosphere, can provide information on plasma density, temperature, element/ion abundances, flow speeds and the structure and evolution of atmospheric phenomena. Such information provides a foundation for understanding the physics behind a huge range of solar phenomena.

Current spacecraft instrumentation (SOHO) provides EUV spatial and spectral resolving elements of order 2-3 arcseconds and  $0.1 \text{ \AA}$ , respectively, and UV resolutions of 1 arcsecond and  $0.02 \text{ \AA}$ . Of the future solar missions, the NASA Solar Dynamics Observatory (launch around 2007) may carry no spectroscopic instrumentation; EUV/UV spectroscopic measurements have been given a low priority. The NASA Solar Probe will not carry any spectroscopic device, though the mission is in doubt at the time of writing. The only EUV spectrometer being developed for a future mission is the EIS instrument on Solar-B with 1 arcsecond (750 km on the Sun) and  $0.01 \text{ \AA}$  resolving elements. However, this instrument is tuned to active region observations with little transition region capability.

The Solar Orbiter provides a unique platform, allowing high resolution observations due to its closeness to the Sun as well as unique observations out of the Sun-Earth line and out of the ecliptic. There has been no other remote sensing solar orbiter and no remote sensing of the Sun from out of the ecliptic. The platform will be 3-axis stabilised, making use of Solar Electric Propulsion (SEP) to enable an insertion into a 150 day solar orbit with aphelion  $\sim 0.75 \text{ AU}$  and perihelion  $\sim 0.2 \text{ AU}$ . A series of Venus fly-by manoeuvres will be used to gradually raise the orbit out of the ecliptic, culminating in an out-of-ecliptic angle of about  $38^\circ$ .

## **2. Scientific Requirements**

The Solar Orbiter goals demand high spatial, spectral and temporal resolution. We address these here to provide a prescription for the basic instrument design.

The Sun's atmosphere is a truly dynamic, fine-scale environment. Our current capabilities in image resolution (0.5 arcsec pixels with TRACE) and temporal resolution (of order seconds at best) are restricting. Spectroscopic studies show that the true fine-scale structure is much smaller than current pixels sizes, and we are aware that basic processes occur on smaller scales than currently available. Thus, our target is to provide an order of magnitude better spatial resolution than

that available for the current spectrometers, and five times better than the best imager capability. Our target is 75 km on the Sun's surface, which is 0.1 arcseconds from 1 AU. For Solar Orbiter, this translates to a 0.5 arcsecond, since we are tuning the design to the 0.2 AU perihelion.

The dynamic nature of the solar atmosphere certainly demands significantly better temporal resolution than currently available. However, we must be aware of the play off between exposure time and temporal resolution; reasonable counting statistics must be obtained. This means that the actual temporal resolution will be dependent on emission line selection and the type of solar target selected. Thus, the instrument must have flexibility, but we should aim at less than 1 second, and assume that a typical value would be of order 1 second.

*Table 1: The basic target scientific requirements for the instrument*

Spatial Resolving Element (pixel)	Target: 0.5 arcsec	75 km at perihelion
Spectral Resolving Element (pixel)	Ideal: 0.01 Å/pixel Upper Limit: 0.02Å/pixel	The lower the better
Field of View (minimum)	<u>Slit Length:-</u> Ideal: 34 arcmin or larger Lower Limit: 25 arcmin <u>Raster Length:</u> Ideal: 34 arcmin or larger Lower Limit: 25 arcmin (FOV does not have to be square)	AR size at perihelion, and solar diameter at aphelion.
Exposure time (minimum)	Ideal: <1 s Maximum acceptable: 1 s	
Count Rates	In range 1-100 counts per second per pixel	'Typical' range. May include excursions from 0 to 1000.
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	

We have considered a maximum exposure time. Normal operations would require values of order 1-50 s. Longer values can be achieved by summing consecutive images. Also, long exposures will suffer from cosmic ray hits (depending on the

detector system) and values in excess of 100 s (on SOHO for example) would tend to be swamped by particle hits. Thus, 100 s is a reasonable upper limit.

Velocity is a major parameter for this mission, which will have good viewing of the polar outflows for the first time. A value of order 5 km/s would be a reasonable target. This gives a value of 0.01 Å/pixel. This is the target value, but we recognise that centroiding could allow some relaxation of this to 0.02 Å/pixel.

The field of view is important, especially for a mission in such an eccentric solar orbit. The requirement is for the field of view to cover an active region when the spacecraft is at the 0.2 AU perihelion, and to cover the full Sun at aphelion. This can be achieved with a field of view of scale 34 arcminutes and upwards. This field of view provides a 300,000 km x 300,000 km field at 0.2 AU, which is larger than the CDS 200,000 km x 200,000 km field and easily covers an active region. The value at 1 AU is 1,500,000 km x 1,500,000 km, which covers the whole Sun.

The wavelength selections are given in the Table, but these are open to discussion. The bands given are those favoured at the 2001 Tenerife Workshop. The wavelength discussion is given later, but it is clear that we require at least 2 bands.

Finally, we require pointing to anywhere on the solar disc or low corona.

### **3. Other Factors which Influence the Design**

Beyond the scientific demands, there are a number of practical issues, which will influence the optical and operational design of the instrument. These are given in the table below:

*Table 2: Other factors, which influence the design of the instrument*

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	Cosmic ray background and solar events.

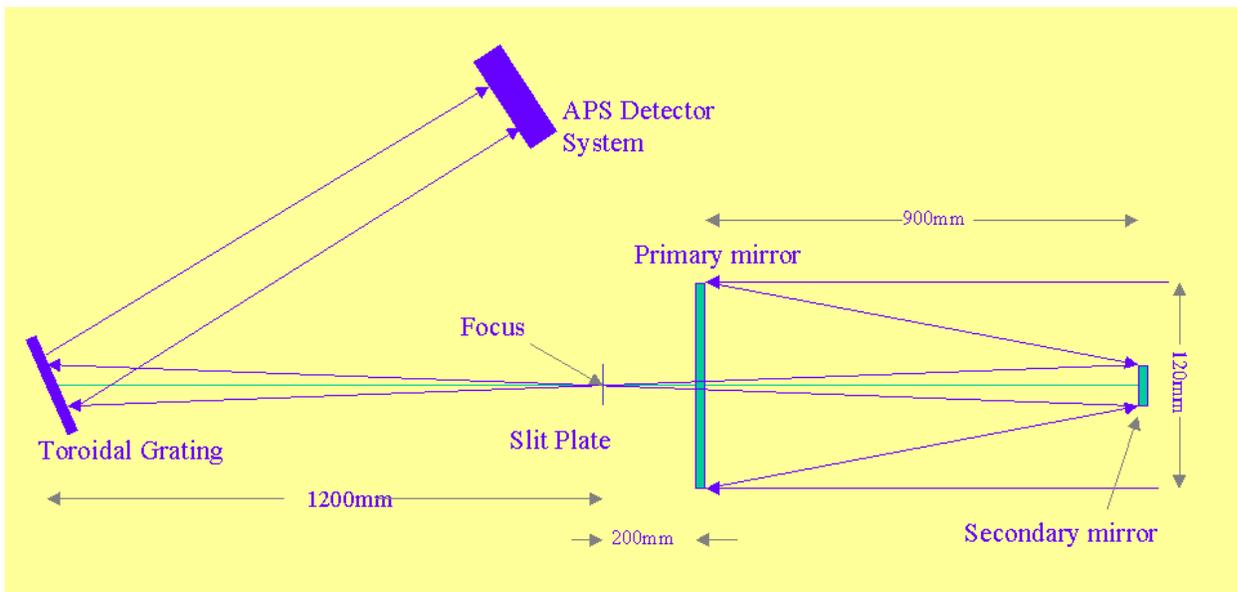
	neutrons.	
Autonomy	Pre-planned sequences in deferred command store.	No contact for solar passes
Optical Correction	May require active image stabilisation system.	Spacecraft stability to be defined.

#### **4. Instrument Concept**

To achieve the desired orbit, the Solar Orbiter mission puts a severe constraint on the payload mass and size. Thus, whilst recognising that an EUV spectrometer is an essential component of such a mission, we must be aware that it must be compact and light-weight. In addition, it must not be too telemetry 'thirsty' and must be able to cope with the thermal and particle environment of such an orbit.

The baseline design is a Ritchey-Chretien telescope, feeding a spectrometer. This design has been chosen to minimise the size of the EUS instrument whilst retaining the desired spatial resolution. It has the disadvantage of one extra reflection over, for example, a single-mirror off axis paraboloid system.

In the current design, the primary and secondary mirrors are separated by 900mm, with the focal plane 200 mm beyond the primary, making a total telescope length of 1.1 m. The telescope diameter is 120 mm, making an overall diameter of the telescope 'tube' of about 150 mm. The telescope effective focal length is 3.7 m. This basic layout is shown in Figure 1.



*Figure 1: The basic design layout of the EUS instrument.*

The slit assembly lies at the focal plane and beyond this is the spectrometer. We assume a selection of slits from one which best matches the spatial/spectral capability of the instrument (0.5 arcsec/0.01 Å per mm) to a wide slit for rapid imaging. In addition, we anticipate the possible inclusion of a detector on the slit plane to image the target area at one wavelength.

The grating ruling spacing is yet to be decided but for the initial instrument considerations we took 4800 l/mm as a guide. For the prime wavelength band selected in the Solar Orbiter proposal to ESA (580-620 Å), and assuming a spectrometer magnification of 1.5, the spectrometer would project 1.2 m beyond the focal plane with a 1.76 m distance to the detector. The detector would lie 0.55 m off-axis, adjacent to the primary mirror. Thus, without a spectrometer, the instrument cross-section would be of order 15x15 cm<sup>2</sup> but the off-axis path of the spectrometer will ensure that the back-end of the instrument is wider, making an overall boot-shaped instrument of maximum dimensions of order 230 cm x 15 cm x 55 cm. The 55 cm dimension is dependent on the choice of grating and the wavelength selection.

The design concept has developed further. The design option now being discussed uses a spherical variable line spaced grating. This has the effect of bringing the spectrometer arm more towards the central axis, reducing the envelope of the instrument and, as discussed later it reduces the off-axis aberrations.

A further development is the suggestion that we make use of smaller pixels, if the optical performance can cope. Pixels of 5 micron have been suggested. Consider a band-pass given by 0.013 (Å /pixel) x 4096 = 53.25 Å, and, for the moment, let us assume a spectrometer magnification of 1.00. The telescope effective focal length (EFL) is given by,  $EFL = 5(\text{micron})/4.85 \times 0.5(\text{arcsec/pixel}) = 2.06 \text{ m}$ .

The spectrometer magnification at 1.0 means that the grating detector-distance is equal to the slit-grating distance. This distance is determined by the spectrometer geometry.

The standard equation is  $n\lambda = d(\sin\theta + \sin\alpha)$ , where n is the order (assume 1), and the remaining parameters are wavelength, grating ruling spacing, and the angles of incidence and reflection. Assume  $\theta = 0$ . If we want a 53 Å band, centred on 605 Å, and covering the range 580-630 Å, we find:  $580 \times 10^{-10} = d \sin\alpha^1$ , and  $630 \times 10^{-10} = d \sin\alpha^2$ .

If we choose a uniform grating of 4800 l/mm, i.e.  $d = 0.2$  micron. Then,  $\alpha^1 = 16.86$  degrees and  $\alpha^2 = 18.36$  degrees. The mid-point (605 Å) is at 17.6 degrees. These figures put the grating-detector and slit-grating distances at 764 mm.

This reduces the length of the instrument. This is a bonus, but we do not want to reduce the collecting area. Further design work must establish that the count-rates can be maintained or improved and that the detector pixel sizes are well matched to the optical design and performance of the telescope. Also, for this rough calculation we have assumed a uniform grating, whereas the Variable Line Spaced Grating (VLS grating) is almost certainly the way to go.

The secondary mirror presents a portion of the Sun at the slit and can be rotated to allow rastered images (i.e. exposures interlaced with mechanism movements to build up images simultaneously in selected wavelengths). In addition, the instrument must have its own pointing mechanism to acquire particular targets anywhere on the Sun or low corona.

The instrument requires an additional electronics box which, for the purposes of this study is assumed to be 20 cm x 20 cm x 20 cm.

The heritage of this instrument comes from the SOHO/CDS, SOHO/SUMER and Solar-B/EIS projects.

## 5. Detectors and the Particle Environment

The requirements on the EUS detector system are driven by the dynamic nature and intensity of the solar atmosphere, by the wavelength selection, and the thermal/particle environment of the spacecraft. The basic needs are listed and explained in Table 3. We also include in the Table some realistic assessments of the ideal, workable and restricting scenarios with regard to the detector performance/design.

*Table 3: Detector Specification*

Array Size	Ideal: 4kx4k Restricting: 4kx2k Limit: 2kx2k Note: Spatial direction (along slit) 34 arcmin at 0.5 arcsec pixel; Spectral direction 0.01-0.02 Å/pixel over about 50 Å. If FOV reduced, we lose ability to view full Sun at aphelion or complete active region at perihelion. If wavelength band reduced to less than a ~40 Å, we would have
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	problems obtaining temperature range required.
Number of detectors	<p>Maximum: 3  Workable: 2  Limit: 1</p> <p>Note: One for each wavelength band. Only one band would be VERY restricting. 2 bands would be OK but the call from the community has been for 3. We could use different orders but 2 detectors appears to be the only workable approach.</p>
Minimum Exposure times	<p>Ideal: 0.1 s  Target: 1s  Unacceptable: &gt;1 s</p> <p>Note: Should be selectable in range between minimum and maximum (see below).</p>
Maximum Exposure times	Ideal: 100 s
Wavelength of Operation	<p>Ideal: Sensitive to range 170-1200 Å  Workable: Sensitive to range 170-650 Å  Limit of acceptability: Sensitive to either 170-220 or 580-630 Å bands.</p> <p>Note: EUV Prime Bands are: 170-220 Å, 580-630 Å, and above 912 Å.</p>
Dynamic Range	<p>Ideal: 0 to 4096 counts (14 useful bits)  Limit: 0 to 2048 counts (as long as we can cope with any saturation with some events)</p> <p>Note: This includes quiet Sun to flares. For the former, we may expect counts of tens per pixel per exposure, for the latter, counts of hundreds to even thousands per exposure.</p>
Read out time	<p>Ideal: 1 s  Workable Limit: 2 s</p> <p>Note: Images are made by rastering. For a 10 location raster of exposure 1 s and read out 1 s, we have total cadence of 20 s. The Sun is highly dynamic; the cadence must be as low as possible.</p>
Pixel Size	<p>Ideal: 5 micron  Workable/limit: 9 micron</p> <p>Note: Smaller pixel size reduces size of the instrument. The 9 micron pixel option produced a 2.3m long instrument - probably too large.</p>
Thermal Environment	Variable (150 day) solar 'constant' in range 2000 to 34000 W/m <sup>2</sup> on front of instrument with thermal control maintaining detector temperature (cold finger to radiator, local heaters etc...).
Particle Environment	<u>Solar Background Protons:</u> Factor of 25 increase in background protons (9 cm <sup>-3</sup> at average of 300

	<p>km/s and <math>4 \times 10^4 \text{K}</math> (3.5 eV) at 1 AU gives <math>225 \text{ cm}^{-3}</math> at 0.2 AU.</p> <p><u>Solar Events:</u> Increased chance of 'storms' from solar events due to vicinity, with increased dose (25 times) - anticipate storms with thousands of hits per <math>\text{cm}^{-2}</math>.</p> <p><u>Solar Neutrons:</u> Neutron half life of 15.5 min means that only flare neutrons seen at 1 AU. Neutron flux is anticipated to be of order a few <math>100 \text{ cm}^{-3}</math> at 0.2 AU.</p> <p><u>Cosmic Rays:</u> Anticipate up to 30 particle hits of about 1 GeV protons/<math>\text{cm}^2\text{s}</math> (same as at L1).</p>
Mass	<p><b>Baseline: 2.5 kg</b></p> <p><b>Workable: 3.5 kg</b></p> <p>Note: 2.5 kg was estimated for detector head plus electronics in original proposal. Mass is severely restricted for Orbiter.</p>

The standard CCD detector approach is inappropriate for a near-Sun mission such as Solar Orbiter and, thus, we baseline an APS (Active Pixel Sensor) detector system. APS detectors would provide a lower mass option, better able to cater for the particle environment of the inner solar system.

The SOHO CCD detectors receive many 'cosmic ray' particle hits, occasionally have 'bleeding' of charge for the brightest intensities (e.g. EIT flares and LASCO planets) and there must be some degradation due to protons causing damage to the silicon lattice (this creates 'traps' that can steal charge which can be transferred to other parts of the image).

The degradation/trap question is not appropriate for SOHO; the LASCO, CDS and EIT teams have found no evidence for degradation in this way. However, it is a concern for a mission such as Solar Orbiter with (potentially) significantly higher rates of particle hits. CCDs are read-out by transferring charge packets and this means that traps can steal or deposit charge as the image is extracted, degrading the final image.

In an APS device, the signal charge is sensed by an amplifier within the pixel (each pixel has its own). Therefore, it avoids the charge transfer problem. Pixels will still be hit, but the damage will not propagate because of the transfer process.

This degradation problem has been experienced by Chandra, mainly because the CCDs have a direct line of sight to space for protons and the damage was done mainly by relatively low energy protons (~100 keV) of which there are many. In SOHO, there is a lot more shielding. However, this effectively means that the

degradation will be at a slower rate, not that there will be no degradation. In addition, Solar Orbiter is close enough to the Sun to receive a significant flux of solar neutrons. Neutrons have a half-life of only 15.5 minutes, and then decay to form a proton, electron and neutrino. Thus, solar neutrons are rarely seen at 1 AU. For a long duration mission (7 years) heading into a more intense particle environment, we have to consider this seriously.

With regard to particle hits, CDS/SOHO sees about 30 pixels hit per second in a spectral area of 1024 x 140 pixels. Thus, at L1 for a 4kx4k array we would expect 3500 hits per second. Since most of the protons are thought to be of extra-solar-system origin, the underlying particle flux will be the same at 0.2 AU. However, during the occasional solar-generated events where protons accelerated in flares or at mass ejection fronts are directed toward SOHO, the hit rate can increase by 1-2 orders of magnitude and we should expect more events of this kind to hit Solar Orbiter due to its location. The particle environment will require careful consideration, not just for charge trapping, but also for image 'cleaning' algorithms and limits of exposure times.

The particle se hits will influence the CCD and APS detectors in the same way. However, the new (0.2 AU) environment brings with it a more demanding requirement for image cleaning software and a greater chance of trap creation.

Intense sources display bleeding on CCD devices. This is not the case for the APS detector system. This alone could be a tremendous advantage.

The APS detectors are still silicon chip devices, it is just that they incorporate individual pixel amplification and charge extraction. The EUV sensitivity will be provided in the same way as with CCDs, with back-thinned devices or intensifiers. There is no mass overhead in using such a system, relative to the CCD approach. Indeed, the APS detectors will provide a lighter-weight option. The back-thinning of APS detectors is being investigated at this time by RAL and EEV (Marconi).

## **6. Thermal Environment**

Considering the thermal environment, at 1 AU the average solar intensity is 1,371 W/m<sup>2</sup>. During the cruise phase the spacecraft will go out as far as 1.21 AU and as close as 0.25 AU, i.e. from a minimum of 936 W/m<sup>2</sup> to 21,936 W/m<sup>2</sup> (a factor of 16 increase over 1 AU). During the nominal phase, in each 149 day period, the spacecraft will encounter a range from 2142 W/m<sup>2</sup> (0.8 AU) to 34275 W/m<sup>2</sup> (0.2 AU - 25 times the value at 1 AU). This presents a severe thermal challenge which we tackle in a number of ways. These numbers are summarised in Table 4.

Table 4: The Thermal Environment

Cruise Phase solar intensity Range	936 to 21,936 W/m <sup>2</sup>
Nominal Mission Intensity Range	2,142 to 34,275 W/m <sup>2</sup> on a 149 day cycle.
Solar 'constant' at 1 AU	1,371 w/m <sup>2</sup>

The original baseline design has undergone a basic thermal study. The thermal approach includes radiators to a number of optical components, a reduced secondary mirror and gold-coating. However, this work must be regarded as preliminary.

The SiC primary mirror has a high absorption coefficient (0.8) and it 'sees' the full Sun. Whereas SiC optical components can run hotter than traditional components, the primary receives 310.6 W of which it absorbs 248.5 W and, even running at 95°C, it would need a dedicated radiator of area 0.66 m<sup>2</sup> (i.e. about 81 cm x 81 cm). Gold-coating would reduce the absorption (to 0.2). If we run the primary at 70°C, we require a dedicated radiator of 0.11 m<sup>2</sup> (33 cm x 33 cm).

Given this option, some 248.5 W are reflected from the primary. The secondary is sized such that it catches only 20% of this, i.e. it only sees 20% of the solar image and much of the image is reflected back out of the aperture. Thus, 49.7 W is received by the secondary mirror, which we also assume to be gold-coated. Thus it absorbs 9.9 W which will require dissipation via a small radiator of area about 11 cm x 11 cm if we run the secondary at 83°C.

The reflected component, now 39.8 W continues toward the spectrometer aperture in the primary. This beam can be reduced considerably by stops; only about 1/100 of this incoming beam is required for each exposure.

Finally, we assume that the APS detector system should run cold and this would require a cold finger to a further radiator.

For the current design we assume passive radiators to space.

With regard to the remaining structure, the design would include thermal blankets and the front panel could include a solar shield. Heaters will be required to maintain the correct temperature gradients throughout the orbit.

There are many areas still to be addressed. For example, this model is based on gold-coated optics. Is this consistent with the reflectivities we require? Also,

there is no consideration of the variability of the solar input. The thermal 'dynamics' of the instrument must be considered.

## **7. Telemetry**

The main mission contains two modes of operation, namely the 'nominal mission' for up to 30 days per orbit where the remote sensing package is operational, and the so-called 'time-share' period per orbit (up to 120 days) when the remote sensing package is (possibly) turned off. The nominal mission phase occurs in each orbit at the closest approach and as the spacecraft passes the highest latitude regions of the Sun.

Having said that, for our studies, we are assuming a full 150 day per orbit operation, with the prime observations close to the Sun (30 days) and secondary observations in the rest of the orbit.

The current plan provides some 63 kbps to the remote sensing package during the nominal phases. During these phases, the HGA will be folded down into the shadow of the spacecraft; thus, data will be telemetered to Earth in the 'time-share' phases.

The baseline EUV instrument detector has 4096x4096 pixels. It is clear that data from individual exposures will have to be selected carefully, as given by pre-defined observing sequences - i.e. only selected fractions of the full range would be returned in any exposure. In addition, a number of compression schemes should be available with a common ('lossless') compression of order 3-5 but other schemes up to a factor of 10 would be available.

Consider a 'typical' pre-defined sequence. We assume 12 bits per pixel and take an exposure time of 20 s. Let us assume a factor of 5 compression has been selected and a selection of, say, 10 emission lines has been requested with 20 pixels across each in the direction of wavelength dispersion (200 pixels) and a slit length of 10 arcminutes has been chosen (1205 pixels). For this, we would require a telemetry rate of  $(1205 \times 200 \times 12)/(20 \times 5) = 29$  kbps.

This basic calculation exposes a severe concern, which will be evident for all imagers and spectrometers on the Solar Orbiter platform. A combination of novel compression schemes, large dedicated instrument memory and careful emission line selection will have to be considered. In the light of the successful operation of the CDS instrument on SOHO - where a similar, severe selection and compression consideration was applied - and the new opportunities given by the Orbiter's location, it is anticipated that this instrument can make significant advances with a

telemetry rate of order 20 kbit/s. Anything greater than this would be a great advantage and should be sought.

However, with the lack of contact at the perihelion pass, it is clear that the instrument must have a large on-board memory. This will be essential for many scientific observation runs. The size of such a memory will be estimated based on the design of a number of prototype observational studies.

## **8. Stability and Pointing**

ESA anticipates a platform stability of better than 1 arcsec/15 min. This is 15 years after SOHO, which achieves 0.99 arcsec/15 min, so one might hope that we can do better. However, given our plan to achieve 0.5 arcsec resolution elements, we must choose one of the following options:

- (i) do not include an image stabilisation system, assuming that the variations of the spacecraft stability occur on time-scales much less than the exposure time of the spectrometer and thus any corrections could be done on the ground, or
- (ii) include an image stabilisation system possibly making use of a small guide telescope driving adjustments to the secondary mirror (see e.g. the TRACE system, which accounted for an additional 1.34 kg).

Spacecraft pointing to better than 2 arcminutes would be acceptable. The EUV instrument would require an independent pointing system to enable independent observation of any solar location.

## **9. Lifetime**

The instruments should be sized for a mission totaling 8 years.

This is made up of three parts. First, we have a 1.86 year cruise phase with limited scientific operation. Indeed, the EUV spectrometer would probably not be operational for much of this time, but it would provide an extended period for instrument commissioning, outgassing, and first-light tests. This is followed by a nominal mission from 1.86 to 4.74 years from launch (2.8 years duration). This is made up of the basic 149 day solar orbits. An extended mission for a further 2-3 years was suggested in the Solar Orbiter report to ESA (1999), in particular because of the high latitudes being achieved in this phase (up to 38 degrees).

## **10. Structure and Materials**

The instrument structure would be made of a light-weight composite material. The UK teams have some experience of this with the Solar-B EIS instrument. We are also considering silicon carbide (SiC) optical components. Multilayers will be considered if the final wavelength selection requires it.

## **11. Spacecraft Shield**

The basic design of Solar Orbiter requires a shield on the solar-oriented face (+X plate), through which the instruments view the Sun. The design of the instruments must be consistent with this.

The EUS can view a 34 x 34 arcmin area of the Sun, which is about 170 arcmin across at 0.2 AU. Thus, as mentioned above, an independent pointing mechanism is required which needs to cover the range about +/- 3 degrees. The instrument has an aperture of 120 mm.

This must match a viewing port in the spacecraft +X-plate shield. To minimise the viewing port size, the instrument will be mounted on six legs (like the SOHO/CDS instrument) with the actuators at the back and the pivot near the front of the instrument. Thus, we envisage a port size of approximately 130 mm. The front shield of the EUS instrument will act as a secondary to the spacecraft shield when the aperture edge and viewing port edge are not aligned.

## **12. Mass Breakdown**

A rough breakdown of the estimated mass is given here. We take the view that this is a new generation instrument made of light-weight materials which really ought to be significantly lighter than, for example, the equivalent (100 kg) instruments on SOHO. The figures were part of the strawman instrument of the ESA study and should be used as a guideline for the instrument.

<b>Component</b>	<b>Mass (kg)</b>
Primary mirror	0.5
Mirror support	0.3
Secondary mirror	0.1
Mirror scan mechanism	0.6
Slit assembly	0.3
Grating assembly	0.6
OPS	1.5
Detector	1
Detector electronics.	1.5
Baffles	0.5

Structure	5.4
Thermal subsystem	3.5
Harness	1.2
Margin	2
<b>TOTAL instrument</b>	<b>17</b>
Main electronics incl PSU	6
<b><u>GRAND TOTAL</u></b>	<b><u>25</u></b>

### **13. Operations**

Solar Orbiter will not have the luxury of frequent, long-duration passes, combined with high telemetry and almost real-time commanding, such as we have on SOHO. The down-link and up-link limitations and the low telemetry rate dictate a rather more pre-programmed approach.

We envisage a semi-synoptic operation - i.e. a basic set of operation modes, which are run in a pre-defined sequence or over long periods. Day to day planning will be minimised.

Observing sequences should be defined/designed well ahead of time, defining raster sizes, wavelength selection and compression details etc.... These would be uplinked and stored on board in a deferred command store. The operations for a defined period would be stored in this way and sequences would be run autonomously.

Planning will be centred on a meeting once every orbit (150 days) and refined on a monthly and weekly basis; the mission will not be able to cope with the daily uplink demands of a SOHO-like mission.

### **14. Further Options**

There are many other options being considered.

One design option under consideration is the inclusion of two instruments within the same structure, one is the device described and the other a grazing incidence spectroscopic instrument geared to better (wider) spectral coverage but at reduced spatial capability. The instruments could share electronics systems, camera etc... thus making the combined mass quite reasonable.

Another option being considered is the inclusion of a 2-D detector on the EUV Spectrometer slit plane to provide images in a selected band. The combination of spectroscopy and a dedicated imaging capability is extremely attractive.

## **15. Instrument Specification - Summary**

The basic design of the current instrument is given in the Table 5.

*Table 5: Current baseline instrument design*

Telescope	Ritchey-Chretien type: <ul style="list-style-type: none"> <li>- 120 mm diameter</li> <li>- 900 mm primary to secondary</li> <li>- 1100 mm secondary to focus</li> <li>- effective focal length 3.7 m</li> <li>- SiC mirrors</li> </ul>
Spectrometer	Normal Incidence: <ul style="list-style-type: none"> <li>- Spherical variable spaced grating (original baseline 4800 l/mm uniform grating with slit/grating distance 1200 mm and grating/detector distance 1760mm).</li> </ul>
Spatial resolving element	0.5 arcsec (75 km on Sun at 0.2 AU)
Spectral resolving element	0.01 Å/pixel (5 km/s)
Raster Mechanism	Through motion of the secondary
Detector	Active Pixel Sensor (APS): <ul style="list-style-type: none"> <li>- 4096x4096 array</li> <li>- back thinned</li> </ul>
Preliminary Wavelength Selection	<ul style="list-style-type: none"> <li>- First Order: 580-620 Å</li> <li>- Second Order: 290-310 Å</li> </ul> (e.g. Fe XII 291, Si X 293, He I 584, Si IX 296, O III 599, He II 304, Mg X 610, Fe XIX 592).
Slit Length/Width	34 arcmin length/several widths available
Field of View/Pointing	Raster over 34 arcmin; pointing to anywhere on Sun with independent pointing mechanism.
Telemetry	20 kbit/s
Mass	25 kg
Power	30 W

Size	Instrument = 230 cm x 15 cm x 55 cm Electronics box = 20cm x 20cm x 20cm
Thermal	Mirror operating temperatures 70 and 83°C, both with radiators. APS detector cooled with cold finger and radiator. Possible shield at front. Standard thermal blankets with heaters for thermal control.
Operation	On board deferred command store in which can be loaded time-tagged observation sequences designed on the ground.
Stability	Active image stabilisation system at secondary may be considered if jitter is significant over common exposure times.

## **16. Contact Information**

Professor Richard A. Harrison, Space Science and Technology Department, Rutherford Appleton Laboratory, Chilton, Didcot, Oxfordshire OX11 0QX, UK. (+44) 1235 44 6884, r.harrison@rl.ac.uk, [www.orbiter.rl.ac.uk](http://www.orbiter.rl.ac.uk).

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