Critical Design Review

# UltraViolet Imaging Telescope (UVIT)

( June 17/18, 2011, ISAC, Bengaluru)

## Overview and Overall Design/Specifications

UVIT-CDR-00-001

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List of documents for CDR on UVIT:

UVIT-CDR-00-001 :: Overview and Overall Design/Specifications by Shyam

UVIT- CDR-00-001.1: Deviations in Design/Specifications with reference to the PDR, and the impact of these on Science Goal by Shyam

UVIT-CDR-00-001.2 FM Status and Issues of Delivery by Shyam

UVIT-CDR-00-02 Main Optics- Mirror by Krishnamurthy, LEOS

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UVIT-CDR- 01-004 EMI/EMC Tests on the Detector System by Amit

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## Abbreviations

| | |
|---|---|
| ASTROSAT | Astronomy Satellite, India |
| BMU | Bus Management Unit of the satellite |
| CCD | A solid state imaging device |
| CFRP | Carbon fibre reinforced plastic |
| CMOS imager | A solid state imager |
| CSA | Canadian Space agency |
| CPU | Camera Proximity Unit; contains the Detector Module, and some electronics, and mounts on focal plane |
| DHU | Data Handling Unit of ASTROSAT; receives data on images from UVIT |
| DM | Detector Module; contains photo-cathode, microchannel plate intensifier, and phosphor coupled with fibre taper to CMOS detector |
| EM | Engineering/qualification model |
| EU | Electronic Unit for control etc. of detectors |
| FUV | Far UltraViolet : 130 nm to 180 nm wavelengths |
| FM | Flight Model, to be launched |
| FWHM | Full width at half maximum; used here as a measure of image size |
| HVU | High Voltage Units for detectors |
| ICD | Interface control document |
| IISU | ISRO Inertial Systems Unit; a laboratory of ISRO |
| INSAT 3D | An Indian satellite |
| ISAC | ISRO Satellite Centre |
| ISRO | Indian Space Research Organisation |
| LEOS | Laboratory for Electro-Optics Systems ( ISRO ) |
| MFD | Mechanical Fixing Device for mirrors/optics |
| NUV | Near UltraViolet: 200 nm to 300 nm wavelengths |
| Photek | Contractor for IIA, who supply the DMs |
| PSF | Point spread function |
| RFP | Request for Proposals to supply the required material |
| Routes | Contractor for CSA, who make detector system |

| | |
|---|---|
| P/L | Payload ( UVIT ) |
| S/C | Spacecraft |
| SAC | Satellite Applications Centre; a laboratory of ISRO |
| STR team | Structural engineering team at ISAC |
| Star 250 | A CMOS imager from Fill Factory, Belgium |
| TC | Telecommand |
| TM | Telemetry |
| UV | Ultraviolet range of electromagnetic spectrum |
| UVIT | UltraViolet Imaging Telescope |
| UVITEU | Electronic Unit for detectors in UVIT |
| VIS | Visible: 320 nm to 550 nm wavelengths |

## 1. Scope of the Document

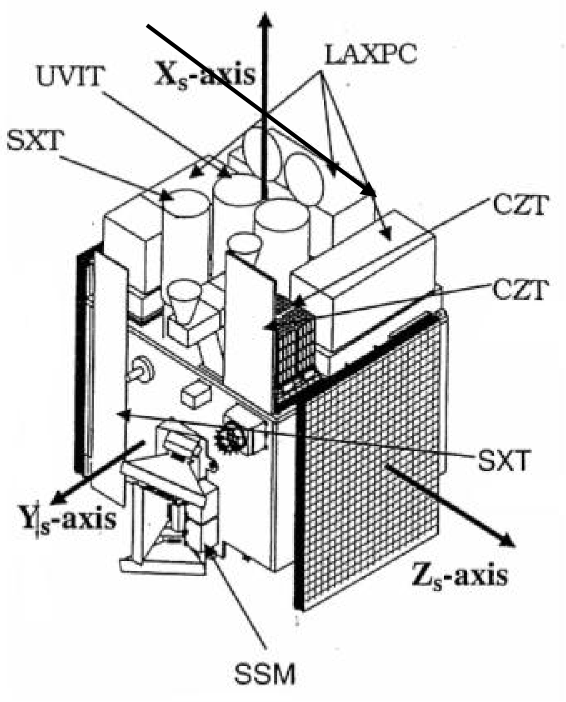
This document primarily concerns with overall design of UVIT, and an overview of the analysis/tests/calibrations carried out to check that the design specifications can be met.

The document opens with a general introduction to this project, followed by a list of specifications. Next, specifications for the different subsystem and their relation to the overall specifications are listed. Analysis and tests planned to check the performance are discussed next. In the Appendix a sheet summarises all the specifications and the tests.

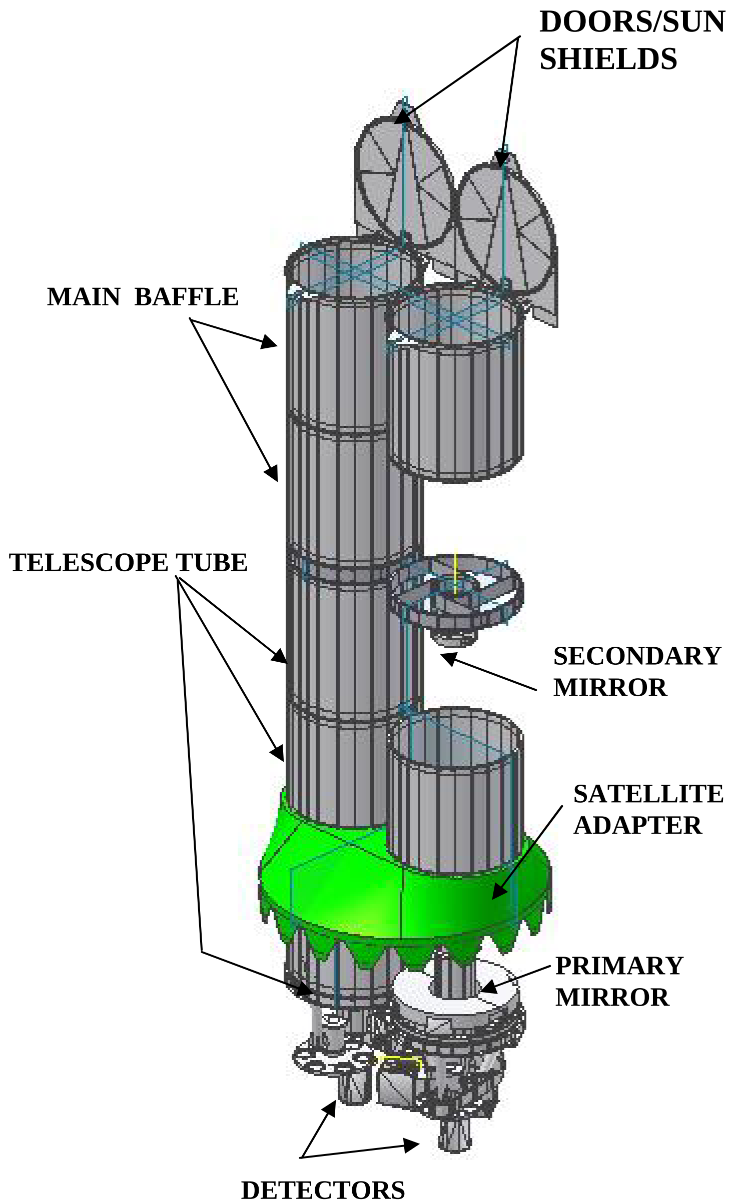
## 2. Introduction

UVIT is one of the five science payloads on ASTROSAT: there are four X-ray telescopes, which observe in soft/hard X-rays, and UVIT observes in ultraviolet and visible bands. All the X-ray telescopes and UVIT can observe simultaneously, and UVIT observes simultaneously in FUV (130-180 nm), NUV(200-300 nm), and VIS(320-550 nm). In addition to wide-field-high-angular-resolution imaging in UV, ASTROSAT aims to observe simultaneously in X-rays as well as in UV and visible. In particular, a study of phase relationships between variations in hard X-rays, in soft X-rays, and in UV is of great interest. Thus, UVIT is designed to achieve a sensitivity of mag. 20 in FUV in a 1000 s observation, and a highest time resolution ~ 10 ms. It is also desirable that UVIT images are synchronized to X-ray observations with an accuracy ~ 1 ms. The full field of UVIT is ~ 28 arcmin circle, and images can be taken for partial field for highest time resolution. Spatial resolution in FUV and NUV is better than 1.8”; and it is ~ 2.2” in VIS. See Fig. 1 for configuration of the payloads on Astrosat. )

The payload is configured as a twin telescope: one of these makes images in FUV and the other makes images in NUV and VIS; the radiation is divided between the two channels




ASTROSAT




UVIT

Fig. 1: Configuration of the payloads in Astrosat is shown on the left. The two telescopes of UVIT are shown on the right; roll of Astrosat is always adjusted to let the doors act as sun-shield.

by a dichroic filter. Each of the two telescopes is a RC configuration, with an aperture of ~ 375 mm and a focal length of ~ 4750 mm. The images from VIS channel are also used to find aspect of UVIT every second. In order that aspect obtained from VIS channel can be reliably translated to FUV and NUV channels, strong demands are placed on stability of relative aspect of these three channels. In particular, this puts severe constraints on temperature gradients and temporal variations in these.

For selection of a band within each of the three channels a set of filters is mounted on a wheel; this wheel also carries a blind to block any radiation from reaching directly into the detector. (See Fig 2 and Fig. 3 for optical layout of the two telescopes.) The wheels for NUV and FUV channels also carry gratings to provide low resolution (~ 100) slitless spectroscopy.

Photon counting detectors are used for FUV and NUV channels, and in order to get the required spatial resolution these detectors must have a spatial resolution (FWHM of PSF image) of better than 1", i.e. better than 0.023 mm. The detectors can also be used with a low gain (called integration mode), but in this case individual photons are not detected and the spatial resolution is ~ 3" for all the channels. As the satellite is not stabilised to better than 10", it is also required that short exposures are taken and are integrated through a shift and add algorithm on ground: the shift is found by comparing successive images from VIS channel taken every second or so. The success of this algorithm depends on the absence of any jitter > 0.3" rms in attitude of the satellite (either due to some internal motions of any P/L etc. or otherwise), and a drift free relative aspect of the three channels over periods of ~ 1000 s: a duration which is large enough to collects enough photons from sources in the UV images.

Those parts of the telescopes which define locations of the optical elements are mostly made of Invar36, and the other parts are made of Aluminium alloy. The two telescopes are mounted on a cone-like structure of Titanium, which is attached to central cylinder of the S/C.

A cylindrical baffle extends over each of the telescopes for attenuating the radiation from off-axis sources. With these baffles the light reaching the detector from sources at 45 deg. from the axis is attenuated by a factor $10^9$; with such attenuation the light reaching the detector from full Moon at 45 deg from the axis is less than the average sky background. In addition to these baffles, the doors act as sun shades as long as Sun is at > 45 deg from the axis.

In order to avoid contamination of the optics due to ultraviolet assisted reactions, bright-earth-limb is kept away from the axis by >12 deg., and the sun is kept behind the sun-shield at all times even if UVIT is not observing..

The geo-coronal lines are very strong in day time, and a significant amount of solar radiation could be scattered by the other instrument son S/C into the baffles. Therefore, the nominal observation period is restricted to the night time (In special cases, observations in day time could be considered).

Development of UVIT payload involves collaboration between several Indian institutions: Indian Institute of Astrophysics, Inter University Centre for Astronomy and Astrophysics, Physical Research Laboratory, and Tata Institute of Fundamental Research. In addition, several laboratories of ISRO are participating directly in development of subsystems and testing; these laboratories are: IISU, ISAC, and LEOS. Further, Canadian astronomers are participating in this programme through collaboration between ISRO and CSA, and CSA is providing calibrated detectors.

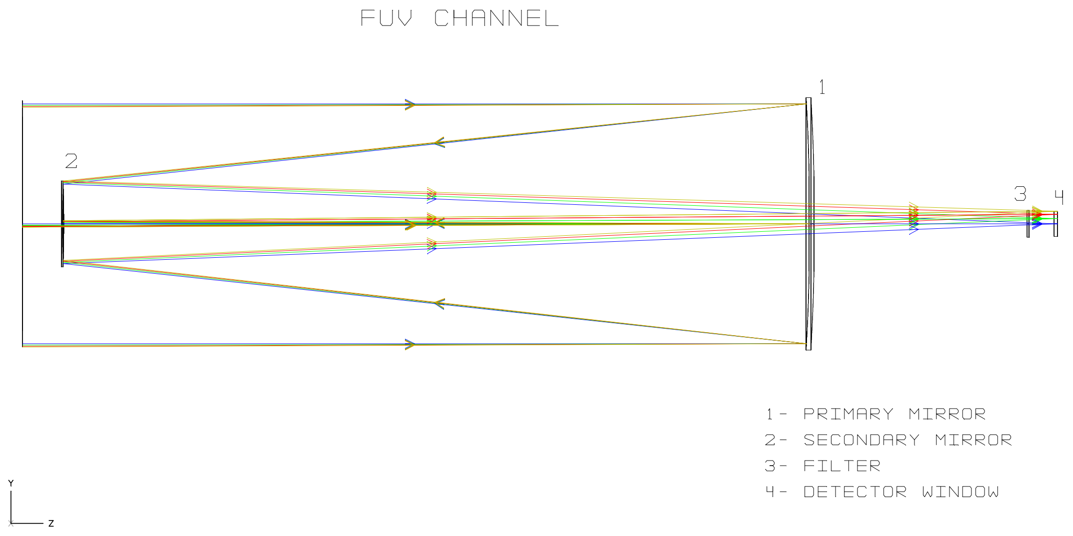



Fig. 2: The optics of FUV channel is shown. The position marked "FILTER" carries a filter wheel with selection of 5 filters, 2 gratings and a blind.

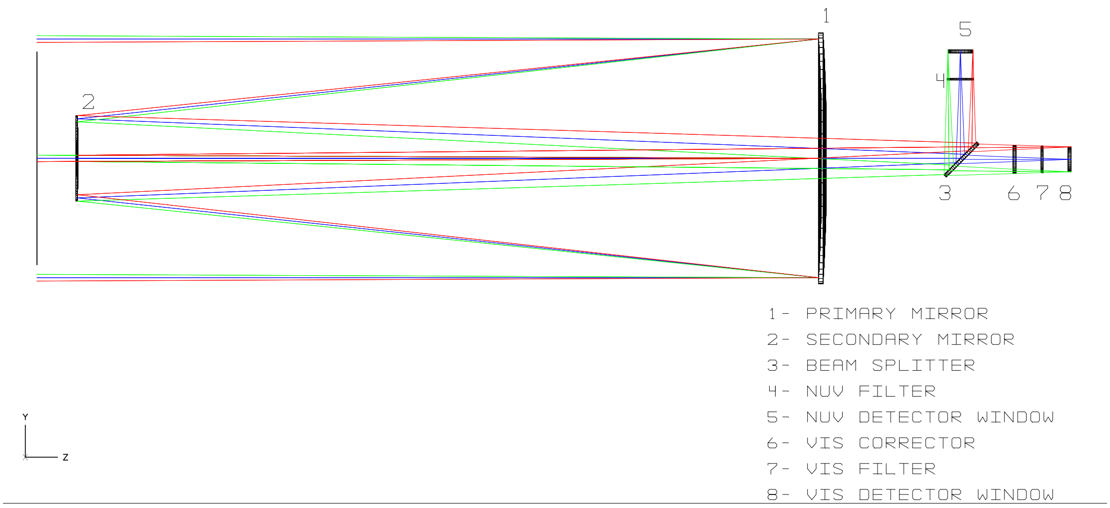



Fig. 3: Optics of NUV and VIS channels is shown. The position marked as " FILTER" carry a filter wheel; in NUV channel the wheel has a selection of 6 filters and a grating, and a blind, while in VIS channel the wheel has a selection of 5 filters and a blind.

## 3. Overall Specifications:

Overall specifications of the payload are listed in Table 1.

| | FUV | NUV | VIS |
|---|---|---|---|
| Detector<br><br>*Deviation wrt PDR* | Intensified CMOS Photon counting/ Integration<br>*None* | Intensified CMOS Photon Counting/ Integration<br>*None* | Intensified CMOS Photon Counting/ Integration<br><br>*None* |
| **Telescope Optics** | Ritchey-Chretian 2 mirror system. | Ritchey-Chretian 2 mirror system | Ritchey-Chretian 2 mirror sysem |
| Bandwidth<br><br>*Deviation wrt PDR* | 130-180 nm FUV<br><br>*120-180 in nm PDR* | 200-300 nm<br><br>*180-300 nm in PDR* | 320-550 nm<br><br>*300-600 nm in PDR* |
| Geometric Area ($cm^2$) | ~ 880 | ~ 880 | ~ 880 |
| Effective Area ($cm^2$)<br>*Deviation wrt PDR* | >~15 at peak<br><br>*None* | >~50 at peak<br><br>*None* | >~ 50 at peak<br><br>*None* |
| Field of View<br><br>*Deviation wrt PDR* | ~ 28'<br><br>*~ 29' in PDR* | ~ 28'<br><br>*~ 29' in PDR* | ~ 28'<br><br>*~ 29' in PDR* |

| | | | |
|---|---|---|---|
| **Spectral resolution**<br><br>*Deviation wrt PDR* | <1000 A (depends on choice of filters)<br><br>*None* | < 1000 A (depends on choice of filter)<br><br>*None* | < 1000 A (depends on choice of filter)<br><br>*None* |
| Spatial Resolution<br>*Deviation wrt PDR* | <1.8 arcsec<br>*None* | < 1.8 arcsec<br>*None* | < 2.2 arcsec<br>*< 1.8" in PDR* |
| Time resolution<br><br>*Deviation wrt PDR* | <10 ms<br>(For partial field)<br>*None* | <10 ms<br>(For partial field)<br>*None* | <10 ms<br>(For partial field)<br>*None* |
| Typical observation time per target. | 30 min | 0.5 - 1 day | 1 - 2 days |
| Sensitivity<br>( Obs. Time)<br><br>*Deviation wrt PDR* | 20th magnitude<br>($5\sigma$) in ~ 200s<br><br>*1000 s in PDR* | --- | --- |
| Photometric Accuracy<br>*Deviation wrt PDR* | 10%<br><br>*None* | | |
| Total Mass (kg)<br>*Deviation wrt PDR* | 229 kg<br>*Yes, increase by ~ 20 kg* | | |
| Total Power (Watts)<br>*Deviation wrt PDR* | 85 (peak 117)<br><br>*None* | | |
| Sun-avoidance angle<br>*Deviation wrt PDR* | 45 deg<br><br>*None* | | |
| Responsibility | IIA, in collaboration with IUCAA and TIFR, and CSA. With support in hardware and tests from many centres of ISRO | | |

## 4. Subsystems

Here a brief description, including the key specifications, of each of the subsystems is given. Further, implication of the key specifications of the subsystem for the specification of the payload is also discussed.

### 4.1 Detectors

The detectors are intensified CMOS imagers: each photo-electron is multiplied by MCPs and high-voltages to a pulse of photons which is detected by the CMOS imager. In photon counting mode each detected photon generates a pulse of ~ 50000 photons on the CMOS imager, and each detected photon is individually recorded. In the integrated mode individual pulses are ~ 1000 photons, and only an integrated signal of many photons is recorded.

Key specifications are:

i) Spatial Resolution is specified as < 1” (23.2 microns) FWHM- it affects the overall spatial resolution. *The measured values are: ~ 0.9” for FUV and NUV, and ~ 1.3” for VIS. It is 1.1” for the EM.*

ii) Aperture was specified as 40 mm- it directly relates to the field of view. *The detectors are made with a mask of 39 mm opening.*

iii) Quantum efficiency was specified as 5% at peak in FUV, 13% at peak in NUV and VIS- it directly affects the peak effective aperture. *The specifications are met for FMs.*

iv) Variation of quantum efficiency was required to be < 10% over the aperture. – it affects photometric accuracy indirectly. *The requirement is met for FMs.*

## 4.2 Telescope Optics

Telescope optics consists of two hyperbolic mirrors. The primary mirror has an aperture of ~ 375 mm and an f-ratio of ~ 4, and the overall f-ration is ~ 12.

Key specifications are:

i) Surface figure of each mirror to be better than 12 nm rms. *The requirement is met for FM mirrors.*

ii) Reflectivity to be > 60% in 130-180 nm for FUV mirrors, and to be > 80% in 200-550 nm for NUV mirrors. This affects effective aperture of the telescopes. *In the FM mirrors the reflectivity is > 70% in 130-180 nm for FUV mirrors and it is > 80% in 200-550 nm for NUV mirrors.*

iii) The measured wavefront aberrations of the FUV/NUV mirrors give an on-axis PSF, with CaF2/Silica filters and widows of the detector, as follows:

| Nominal Focus and alignment | | Focus 0.1 mm off, and 0.1 mm and 1’ misalignment of the mirrors | | Focus 0.3 mm off, and 0.1 mm and 1’ missal. of the mirrors | |
|---|---|---|---|---|---|
| DIAMETER IN ARCSECONDS (23.2 micron/”) for FUV | | | | | |
| rms | 70% En. | rms | 70% En. | rms | 70% En. |
| 0.98 | 1.38 | 1.01 | 1.4 | 1.22 | 1.74 |

*NUV To be simulated by Sriram and noted here.)*

| DIAMETER IN ARCSECONDS (23.2 micron/”) for NUV | | | | | |
|---|---|---|---|---|---|
| rms | 70% En. | rms | 70% En. | rms | 70% En. |

## 4.3 Filters and Gratings

The filters used for FUV are low (frequency) pass crystals. For NUV and VIS channels interference filters are used. The gratings are directly ruled over CaF2 plates.

Key specifications for transmission filters are:

i) Band-pass. *The requirement is met*

ii) Peak transmission. It affects the effective aperture. *The requirements projected in PDR are not met in 200-260 nm range.*

iii) Uniformity of transmission to be 10%. It affects the photometric accuracy. *The requirement is met as per the test data from the vendor. Test done by UVIT on FM filters are not complete yet.*

iv) Thickness of each filter is adjusted to equalize the optical path of all. It affects the spatial resolution. *The requirement is met.*

Key specifications for the Beam-splitter are:

i) Reflectivity in 200-300 nm and transmission in 320-550 nm. It affects the effective aperture. *As per the tests by vendor, the reflectivity and transmission are > 75% for FMs. We are yet to make measurements of these.*

Key specifications for the gratings are:

i) Number of lines as 400 per mm, blaze angle as …, and peak transmission as 40%. These affect the resolution and the effective aperture. *The number of lines and blaze angel, for FMs, are as per the specification, but the peak transmissions are less by factors 1.5 to 2.*

## 4.4 Structure

In addition to providing a rigid support for the subsystem and interface with the S/C, the structure of UVIT also serves the function of keeping proper alignments/distances between the optical parts. In order to minimize the effect of thermal variations, many parts of the structure are made of Invar-36.

Key specifications for the structure are:

i) Adequate rigidity to stand vibrations of the launch. *This was verified by analysis and vibration tests on an engineering model. Small modifications in the structure were indicated during reviews of the tests by the committee. These modifications are included for the FM.*

ii) To give a < 5 micron shift in separation of the two mirrors for 2C variations in temperature of the tubes supporting the mirrors. This affects the spatial resolution through shift of the focal plane. *This requirement is met as per the theoretical thermal expansion of Invar. However, the tubes are coated for blackening and this coating could increase the variation. Tests on FM are yet to be done to determine shift, with temperature, in the focus.*

iii) To keep alignment between the two mirrors to < 0.05 mm and < 30”. This affects spatial resolution and relative aspect of axes of the two telescopes. *The vibration tests on the EM do not indicate any variations in the alignment.*

iv) To keep the relative alignment between the two telescopes to < 0.3” over 15 minutes in the orbit. This affects spatial resolution, as any such variation in the relative alignment is equivalent to an uncorrected drift of the S/C. *The structure is designed* *with a high level of symmetry. However, no modeling or tests are done to see effects of thermal variations on this parameter.*

v) To minimize the stray light from out of field sources. This is achieved by black coating of all the surfaces in the optical cavity. The requirement is that the main baffle-tubes (on top of the optics) and the telescope tubes (supporting the two mirrors) have reflectivity of < 5% in the VIS – with this < 1 part in million from a source at > 45 deg. From the axis reaches the detector. *The reflectivity of the parts is assessed as < 5% -- based on tests on samples for the process. The attenuation was estimated by an analytic model and verified by a half size model.*

vi) Doors are closed during the launch and these are opened ~ 6 weeks after the launch. The doors can only be deployed once. The doors isolate UVIT from the S/C during the initial phase of degassing in the orbit. The doors also act as sun-shield after these are opened.

## 4.5 Assembly

Given the complexity of the payload and the requirements of optical precision, detailed procedures for opto-mechanical tests at various levels of integration have been evolved. The procedures also required design and development of many accessories specific to the payload.

## 4.6 Thermal Control

Thermal control is required to keep the parts within acceptable temperatures. The thermal control has been modeled in detail.

The key specifications are:

i) Temperature of the telescope tubes be maintained within 20 C +- 2 C. This affects spatial resolution through shift in the focus. *The temperature obtained is 20 C +- 3C, and defocus would make a larger contribution to the spatial resolution.*

ii) Temperature of the CPU (head of the detector) to be in range 10 C to 20 C. This affects dark current in the CMOS imager. *The requirement is met.*

## 4.7 Contamination control

As the FUV radiation can be absorbed by monomolecular layers, it is very critical that all possible controls and checks be observed through all phases of the project. Therefore, great care is taken in selecting materials which go in the optical cavity. (Before approval for use, any non-metals are tested for their effect on FUV-transmission of a Mgf2 window exposed in close proximity of a sample. The sample is typically heated to 100-120 C in high vacuum and the window is kept at ~ 30 C. Duration of the exposure is 24-48 hrs.) As an example, for the structure inorganic black coatings were developed by ISAC.

Overall contamination is controlled and monitored by regular monitoring of any loss in FUV-transmission of MgF2 windows kept in the laboratory, in the instruments, and any test areas (e.g. TV chamber).

The key specification is:

i) The overall FUV-transmission loss on a window during all the operations from assembly o launch to be < 5%. This affects the effective area of the telescopes, and a loss of 5% in the transmission implies an overall loss of 15-20% in the effective area. *Tests on the windows used during the assembly and vibration testing of the engineering model have given satisfactory results; transmission of the window after the TV test is yet to be measured.*
*( SRIRAM TO MEASURE TRANSMISSION OF THE WINDOW SOON, AND give the number .)*

4.8 Transport Box

In order to transport the payload to ISAC, a specialized box was made. The box is in two parts: an inner box which encloses the paylod and is purged with high purity Nitrogen to minimize any contamination, and an outer box for protecting the inner box from weather and shock. In addition to shock-watches, real time monitoring of accelerations is available on the outer box. The box has been used successfully during the tests on the EM payload.

## 5. Analysis and Tests

**Here all those tests are listed which have been done or will be done on ground or in the orbit.**

5.1 Detectors

Design of the intensifiers was to checked that the required spatial resolution is obtained in photon counting mode. The analysis indicated that the separation between the photo-cathode and the MCP be < 0.15 mm. Such a small raised the possibility of collision between these two members during the launch. Therefore, extensive analysis and tests were done to ensure that this did not happen. The completed EM/FM detectors have gone through the vibration/TV tests to prove the design.

The FM detectors are calibrated for: i) Quantum efficiency as a function of wavelength, ii) Spatial variation of the quantum efficiency, iii) Spatial resolution, and iv) Distortion; these calibrations are either completed or are planned.

In the orbit different modes of operations, and the performance parameters would be tested. Most of these tests can be done in dark and before opening the doors, and the rest are done after the doors are opened.

5.2 Telescope Optics

The overall spatial resolution of the instrument was estimated for PDR with an assumption that any aberrations of the mirrors have negligible effect on the resolution. The wavefronts for individual mirrors and the telescopes for FM have been measured by LEOS. These wavefronts will be used in simulations to estimate the resolution.

Reflectivity of the mirrors is not measured directly, but witness samples are measured. Interferometric tests are done to check alignment of the two mirrors.

5.3 Filters and Gratings

Transmission of the FM filters is measured as a function of position. For the beam splitter reflectivity is measured but NOT transmission – for the transmission measurements made by the vendor are taken.

Dispersion and transmission of the FM gratings are measured.

The filter wheel drives are tested for correct positioning of different filter-slots.

5.4 Structure

Since the PDR, design of the structure has gone through several iterations of analysis and modifications. The engineering model of the structure has gone through vibration/TV tests. Some modifications have been made based on analysis of the tests by a committee.

5.5 Thermal Control

Design of thermal control has been analysed and reviewed. As some of the demands of this control are very stringent, several iterations of analysis and redesign were required.

## 5.6 Environmental Tests

5.6.1 Vibration Tests

Vibration tests have been done on the engineering model. In this model the telescope for FUV was fully replaced by a model, made of stainless-steel and aluminium, to simulate rigidity and mass distribution. Further, FUV detector system was simulated by masses. In all other details this model was a faithful representation of the actual payload.

The test shall be done for the FM as per the protocol of ISRO.

5.6.2 Thermo-vacuum Tests

These tests were completed successfully on the engineering model

The tests shall be done on FM as per the protocol of ISRO.

5.6.3 Test on Susceptibility to Electromagnetic Interference

These tests are done on the detectors and the filter-drives by the respective vendors. In the case of the detector, a need was felt to repeat the test with a close simulation of the ground plane – as per the configuration expected in the S/C. These tests were done for EM detector. The results indicate that for certain frequencies an increase, in noise of the signals from CMOS imager is seen:

*Nominal noise is 6 units rms*

*Noise for 33-35 MHz interfering field is ~ 31 units rms—this does not have significant effect on the performance, and*

*Noise for 59-63 MHz interfering field is ~ 88 units rms—this adds ~ 0.13 square arcsec (~*

*20%)*
*to the variance of spatial resolution.*
*Though the effect is within acceptable limits, it is very important that during the integration with S/C noise due to the interference is checked and minimised. (For a comparision, the signal in photon counting mode is ~ 2000 units per photon, and it is 100-200 units per photon in the integration mode.)*

**5.7 Tests on the Integrated FM-Telescopes**

5.7.1 Effective Area

The signal in detectors of the assembled telescope is measured for all the filters, for a known flux from a point source shining on the collimator. The effective area can be calculated by assuming reflectivity of the mirrors of the collimator. Expected accuracy is 30%.

In the orbit, standard sources are used to get the effective area for each of the filters.

5.7.2 Field of View

The field of view is estimated by focal length of the telescopes and parameters of the detectors. It is also checked directly for FUV and VIS channels by sighting aperture of the detectors by a theodolite placed behind the secondary mirror. (The NUV detector cannot be seen as the beam splitter only reflects in NUV). In orbit, observations of astrometric fields give an exact estimate of the field and the plate scale.

In addition, it is checked that centres of the NUV and VIS fields are aligned to < 1'.

5.7.3 Spatial Resolution

Positions of the detectors are adjusted to get the best focus. In this process, rms size of the images is also measured for all the filters.

Effect of temperature on the focus is checked interferometrically by changing temperature of the room.

Correction for effects of the S/C drift are checked by simulations, and it is found that the any residual effect of the drift on spatial resolution is very small.

Distortions of the detector are calibrated to better than 0.5".

5.7.4 Photometric Accuracy

Final calibration for the effective area is done in the orbit with standard sources.

In orbit, data are taken for 5 positions in the field. These data can be used to correct for any low-spatial-frequency variations in the effective area. Any high-spatial-frequency variations are derived from calibrations done on ground for the filters and the detectors; in case these variations change after the ground calibrations errors would result.

5.7.5 Spectroscopic Calibration

Dispersion for spectroscopy and transmission is checked.

### 5.7.6 Time Synchronisation with the Other Payloads

Through synchronization pulses from the BMU a high long term accuracy of time is possible in the images after processing on ground.

In order to find any constant shifts in time relative to the absolute time or the time of the other payloads, it is planned to observe some pulsars which are bright in UV as well as in X-ray.

## 5.8 Tests on Integrated FM-Payload

### 5.8.1 Field of View

The effective field of view of the payload is given by the overlap between the fields of the 3 channels. Thus, in order to maximize this overlap, axes of the two telescopes are checked to be aligned to <30”.

This is obtained through checks at various levels of assembly. A final check is made by sighting apertures of the FUV and NUV detectors by a theodolite from behind the secondary mirrors – this check is repeated after the vibration and TV tests.

### 5.8.2 Field Illumination

This test is done to check sensitivity of the detectors, and integrity of the filters in NUV and VIS. The illumination is given, by a pin-hole mounted on output of a monochromator, at a selected wavelength. The pinhole is kept on the silica window in the door. This test is first done at CREST, IIA. The detector is expected to give a near flat image over its area, unless there is some defect in the filter or some other optical element. The images obtained at CREST are compared with the images obtained after the tests/assembly at ISAC.

### 5.8.3 Environmental Tests

These tests are done as per the protocol followed at ISAC.

## 5.9 Tests done in Orbit

### 5.9.1 Tests on the Detectors

Performance of the detectors is checked by going through the different modes of operations. Most of these tests are done before the doors are opened, and the rest are done later.

### 5.9.2 Tests on Filter Wheel Drives

Filter wheel drives are tested, before opening the doors, for correct functioning of the various commands, and being in proper health.

### 5.9.3 Thermal Control

The thermal control is checked to ensure that the thermal variations are within the specified limits—some of these can be tested before opening the doors.

5.9.4 Spatial resolution

Spatial resolution is checked, with standard stars for all the filters, for short exposures and long exposures (which are affected by drift of S/C and distortions)

5.9.5 Photometric Calibration

This is done for all the filters with standard stars. Typically, observations are made at 5 points in the field. The calibrations done on ground for spatial variations of detector-sensitivity and filter-transmission are combined with the observations in orbit. Finally, mean effective area and variation of the effective area over the field of view are obtained.

5.9.6 Spectroscopic Calibrations

These are done with standard stars to find dispersion and transmission in the spectroscopic mode.

5.9.7 Astrometric Calibrations

These are done using astrometric pairs of stars and astrometric clusters. With these the average plate scales of the three channels can be found, and the distortions can be mapped. These data on distortion are combined with the data obtained on ground to get the best estimates of distortion.

5.9.8 Time Calibrations

In order to have common time-base for all the instruments on ASTROSAT, suitable pulsars are observed simultaneously with all the instruments.

# Appendix 1.

**This sheet summarises all the key performance parameters of UVIT payload, and for each of the parameter lists all the tests done to confirm that the target is met.**
**The tests done on components and individual telescope are written in "Normal font", the tests done on total payload are written in "Italics", and the tests done in orbit are written in "Bold"**

| **Parameter** | **Target value** FUV | NUV | VIS | **Tests Done** | | | | |
|---|---|---|---|---|---|---|---|---|
| Peak Eff. Area Sq. cm | > 15 | > 50 | > 50 | Quantum Efficiency of detector | Reflectivity of coating | Transm. Of Filters | Signal in tel. with known flux Only done in FM and is expected to give accuracy ~ 30% | **Observe standard stars** |
| Field of View | ~ 28 arcmin | | | Gain of Fibre-taper in det. | Measured by theodolite in telescope Done for EM and FM | Clearance in baffles seen visually Done in EM and FM | *Alignment of telescopes checked* *Only for FM* | **Observe astrometric fields** |
| Spatial Resolution -- I | < 1.8" FWHM | | <2.2" | FWHM of detector | Distortion of detector | Simulate optics with measured wavefront of telescope | Size of image in telescope Only for FM | Simulate correction of drift of S/C |
| Spatial Resolution -- II | < 1.8" FWHM | | < 2.2" | Thermal effect on Focus of tel. Only for FM | **Observe stars and astrometric fields** | | | |
| Photometric Accuracy | 10% over the field | | | Spatial uniformity of detector | Spatial uniformity of filter | **Observe stars at 5 locations** | | |
| Time Synchronisation | | | | **Observe pulsars which are bright in UV and in X-ray.** | | | | |
| Illumination | Only Functional Test Only done for FM | | | *A point source is kept on the door, and resulting image is seen in the detector. Done for all the filters in NUV and VIS* *Only done for FM* | | | | |
| Contamination control | *Witness MgF2 widows kept to check that total FUV-attenuation during the assembly & tests is < 5% per element* | | | | | | | |