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Calibration and Inter-calibration of SOHO's Vacuum-ultraviolet Instrumentation

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The SOlar and Heliospheric Observatory (SOHO) is equipped with a suite of instruments capable of observing the Sun from the core to the outer corona. Several of these instruments observe radiation in the vacuum-ultraviolet (VUV) wavelength range, where precise and accurate radiometric measurements are of extreme significance for solar and terrestrial investigations, but, at the same time, are very difficult to obtain due to degradation effects of most optical systems under solar ultraviolet irradiation. Radiometric-calibration and cross-calibration matters have consequently been important topics from the initial planning phase of the mission to the operational implementation. An attempt will be made here to summarize the early requirements and goals as well as the achievements of SOHO in this context. Although not all plans could be carried out, the general picture is very encouraging. SOHO allowed us to make a major step forward in solar radiometry, in particular of spatially-resolved structures.

5.1 Introduction

Solar electromagnetic radiation in the VUV (10 nm to 200 nm) is strongly absorbed in the Earth's atmosphere [cf., *Rees*, 1989]. The direct consequence is that observations at these wavelengths are only possible from rockets or spacecraft. Both for many fields of solar research (for example, elemental abundance studies and plasma diagnostics) and for an understanding of the processes in the Earth's atmosphere, it is of vital importance that the radiation be measured quantitatively. Spatially-resolved spectral radiance measurements have to be obtained for most of the solar studies, whereas spectral irradiance data are needed for terrestrial applications.

The early history of solar VUV radiometry, in particular from instruments on the Orbiting Solar Observatories (OSO) and the Skylab mission, is characterized by significant progress in obtaining radiance and irradiance data with better and better accuracy [e.g., *Dupree and Reeves*, 1971; *Huber et al.*, 1973; *Reeves et al.*, 1977; *Hinteregger*, 1977; *Heroux and Higgins*, 1977; *Schmidtke et al.*, 1992]. However, it also became evident [e.g., *Reeves and Parkinson*, 1970] that some long-term observations in this range were plagued with severe responsivity deterioration, which at least in one case [*Bruner*, 1977; *Woodgate et al.*, 1980] amounted to losses of factors of ten within days. To cope with this difficulty, two complementary strategies were developed: (1) one devises sophisticated methods of monitoring the degradation and thus maintaining an established radiometric-calibration status, and (2) one discovers and understands the processes that lead to the degradation, and then employs appropriate procedures and design concepts to eliminate them.

At the beginning of the development phase of SOHO, after the final instrument selection in 1988, the time was ripe to follow the route of the second strategy, while, at the same time, performing careful calibration tracking. The degradation problem had been clearly identified on many occasions, not only for spacecraft, but also for synchrotron applications. The processes responsible for it had been described as a combination of contamination of optical surfaces with hydrocarbons and other outgassing products from structural elements, followed by photo-activated polymerization under UV irradiation [cf., *Austin*, 1982; *Boller et al.*, 1983; *Kent et al.*, 1993, 1994; *Schühle*, 1993]. Thus a promising strategy was to eliminate sources of contamination and outgassing wherever possible and to monitor quantitatively and continuously any that may unavoidably be present. This approach was adopted for SOHO and is fully described in the contributions covering the cleanliness aspects of the spacecraft [*Thomas*, 2002] and the instruments [*Lang et al.*, 2002; *Schühle et al.*, 2002]. The cleanliness requirements were, however, not part of the SOHO Assessment Study dated September 1983, and were only briefly mentioned in the joint ESA/NASA SOHO Announcement of Opportunity (AO) of March 1987. They had to be defined in detail by the instrument and spacecraft teams. As we will see in the following sections, these endeavours were extremely successful. With a few exceptions, which will be mentioned below, the SOHO VUV instruments did not show any long-term degradation of their radiometric responsivities under nominal operational conditions.

We will discuss only the solar VUV instruments on the SOHO spacecraft, namely, CDS (Coronal Diagnostic Spectrometer), EIT (Extreme-ultraviolet Imaging Telescope), SEM (Solar Extreme-ultraviolet Monitor), SUMER (Solar Ultraviolet Measurements of Emitted Radiation), and UVCS (UltraViolet Coronagraph Spectrometer). SWAN (Solar Wind ANisotropies), although an H I Ly-α instrument, looks away from the Sun and is not included in this report. For a review of the history of the SOHO mission in general see *Huber et al.* [1996].

5.2 Scientific Requirements

5.2.1 Proposal Phase

The scientific requirements as far as VUV radiometry was concerned were discussed during this phase in a series of meetings starting in 1986 – before the SOHO AO in March 1987 – and continuing until the end of 1987, shortly before the submission deadline for the revised proposals on 8 January 1988. Some of the meetings were quite eventful as, for instance, the session in January 1987, when many potential participants were stranded somewhere in snow-hit Paris, and those actually present in Verrières could not take off their coats without freezing to death in the old Vauban castle.

It was realized early on in these discussions that the radiometric calibration was not the only calibration task at hand. Wavelength measurements, telescope and spectrometer spatial and spectral resolutions, as well as pointing performance were intimately related to the absolute calibration. This was summarized by Peter McWhirter in notes taken at the meeting held in Paris on 23 and 24 April 1987. For the radiometric work itself, it was suggested to consider a typical relative standard uncertainty of atomic data of ≈ 10 % as a guide, and aim for relative uncertainties of the observations between 25 % and 30 % at the short-wavelength range and rather better performance at longer wavelengths. All uncertainties are given here as relative standard uncertainties, unless specified otherwise.

Based on past experience, severe degradation of the responsivity was expected in flight, in particular for normal-incidence instruments. Monitoring of the calibration status was suggested to be performed against well-calibrated spacecraft instruments (e.g., SUSIM, the Solar Ultraviolet Spectral Irradiance Monitor on UARS, the Upper Atmosphere Research Satellite) and calibration rockets. In addition, internal checks and cross-calibration might be possible using atomic physics data on branching ratios and other line ratios not very sensitive to the source plasma conditions.

Synchrotron radiation was identified as the primary radiometric standard, in particular from the Super-ACO positron storage ring at the Laboratoire pour l'Utilisation du Rayonnement Electromagnétique (L.U.R.E.) in Orsay, the Synchrotron Ultraviolet Radiation Facility (SURF-II) at the National Institute of Standards and Technology (NIST), and the Berlin Electron Storage ring for SYnchrotron radiation (BESSY I), but the need for transfer standards was also recognized. It was thought that both individual components and the fully-assembled instruments had to be radiometrically calibrated. These requirements formed the basis of the VUV calibration plans in the SOHO proposals of January 1988. In addition, the desirability of a re-calibration opportunity between instrument deliveries and launch was stressed. A direct radiometric in-flight calibration using transfer standards was also considered, but it was felt that it could not reliably be implemented within the project constraints (see, however, Section 5.5 for details on the in-flight calibration).

5.2.2 Definition and Design Phases

In some of the SOHO proposals, theoretical support groups were identified as Associate Scientist (AS) teams. These groups played an important rôle in the detailed definition of the scientific requirements. The SUMER AS team met in Paris in June 1988 for the first time, followed by a CDS/SUMER science workshop in Oxford in September. Since many of the participants were involved in both the CDS and the SUMER investigations, and, moreover, a close coordination of the CDS and SUMER science planning was highly desirable, the following meetings were held as Joint CDS/SUMER Science Meetings. On many occasions, radiometric-calibration topics were on the agenda and those meetings are included in Table 5.1, which lists all meetings relevant in this context held after the SOHO AO had been issued. A special calibration panel chaired by P. McWhirter (at the first JMAS meeting in February 1989) came up with a report, concluding that relative standard uncertainties should ideally be less than 20 %. A realistic aim appeared to be 35 %, and 50 % would be the lowest level worth attempting for solar radiometry. It should be noted, however, that for planetary applications uncertainties of the irradiance of less than 5 % were required. Notice also that, in narrow wavelength ranges, line ratios can be determined with smaller uncertainties without involving absolute radiometry. The required or anticipated, and later achieved, radiometric uncertainties as documented in meeting reports or the open literature are summarized in Table 5.2. The ways suggested to obtain the required accuracies were:
(1) extensive laboratory calibration with secondary standards traceable to primary standards; (2) cross-calibration (called here also "inter-calibration") on SOHO and with in-

Table 5.1: Meetings Related to SOHO Calibration and Inter-calibration Activities.

Date	Place	Meeting[a,b] and Remarks
23/24 Apr 1987	Paris	Proposal preparation; atomic data ≈ 10 % [c]
21/22 Jun 1988	Paris	1st SUMER AS Meeting; requirements
29/30 Sep 1988	Oxford	CDS/SUMER Science Meeting; requirements
7/8 Feb 1989	Lindau	JMAS-1; calibration panel report
11/12 Jul 1989	Berlin	WSVUV-1; HCL and mirror chambers
5/6 Oct 1989	Abingdon	JMAS-2; uncertainty 20 % envisaged
5/6 Nov 1989	Noordwijk	SICWG-1; irradiance for terrestrial use 5 %
14/17 May 1990	Noordwijk	SICWG-2; cleanliness important
22/23 Oct 1990	Berlin	WSVUV-2; SUSIM irradiance comparison
25/26 Oct 1990	Lindau	JMAS-3; uncertainties 20 % to 30 %
27+30 Nov 1990	Noordwijk	SICWG-3; stars; SEM recommendation
3 Jun 1991	Noordwijk	SICWG-4; HCL: uncertainty $<$ 20 %
18 Nov 1991	Noordwijk	SICWG-5; report on SUSIM degradation
15–18 Jun 1992	Killarney	SOHO/Cluster; CDS/SUMER calibration
21–23 Oct 1992	Orsay	JMAS-5; absolute wavelengths: 20 pm
25/26 Jan 1993	Noordwijk	SICWG-6; calibration rehearsals
22–24 Nov 1993	Abingdon	JMAS-6; purge directly to instruments
24/25 Jan 1994	Noordwijk	SICWG-7; uncertainties considered
13 Jun 1994	Portsmouth	SICWG-8; report on some anomalies
3–5 Oct 1994	Greenbelt	JMAS-7; calibration rockets; UARS/SOLSTICE [d]
11+13 Jan 1996	Greenbelt	SICWG-9; inter-calibration JOPs; Spartan
9 Feb 1996	Greenbelt	SICWG-10; Intercal-1, Intercal-9
17 May 1996	Greenbelt	SICWG-11; Intercal-2: No He II full disks
31 Oct/1 Nov 1996	Berlin	WSVUV-3; first results presented
5–7 Nov 1996	Orsay	JMAS-9; last meeting of this series
13/14 Nov 1997	Orsay	WSVUV-4; continue Intercal-1 and rockets
29/30 Mar 1999	Berlin	WSVUV-5; inauguration of BESSY II
12/16 Feb 2001	Bern	WSVUV-6; review SOHO calibration tasks
8/12 Oct 2001	Bern	WSVUV-7; continuation of WSVUV-6

[a] JMAS: Joint Meeting of Associate Scientists (CDS/SUMER);
WSVUV: WorkShop on VUV radiometry and inter-calibration;
SICWG: SOHO Inter-Calibration Working Group.
[b] JMAS-4 (2 to 4 October 1991, Nice) and JMAS-8 (19 to 21 September 1995, Oslo) did not cover calibration aspects.
[c] This relative standard uncertainty was originally related to branching ratios, which may even be known to 5 %. Doublets should be accurate within relative deviations of 10 % and density/temperature insensitive ratios for each ion within ≈ 20 %; ratios, in general, can be expected to have relative uncertainties of as much as 30 % [*H.E. Mason, personal communication*, 2001].
[d] SOLSTICE: SOLar-STellar Irradiance Comparison Experiment.

Table 5.2: Relative Standard Radiometric Uncertainties in Percent [%][a,b].

Phase/Document/Channel	HCL	CDS	SUMER	UVCS	EIT	SEM[c]
1987 pre-proposal	20	25...30	$<$ 25	20	-	-
1988 rev. 1 of proposals	25	25...30	30...50	20	-	-
1989 early development	**13**	$<$ 20 ... 35 ... 50		$\approx$ 10	$\approx$ 100	-
1988/90 early Coloured Books	15...20	$<$ 20	$<$ 20	20	-	-
1991/92 calibration plans	10	$<$ 20	15...30	12...15	-	$<$ 10
1994/95 final Coloured Books	**6...8**	-	$<$ 20	-	-	-
1993/95 laboratory calibration	**6...7**	$\approx$ **30**	**15**	**16**	**60...150**	**10**
unvignetted	-	-	**11**	-	-	-
1996/98 in-flight calibration	-	-	-	-	**15**(He)	**10**
CDS – NIS	-	**15...29**	-	-	-	-
– GIS	-	**45**	-	-	-	-
SUMER – Detector A	-	-	**15**	-	-	-
– Detector B	-	-	**20**	-	-	-
UVCS – H I α and O VI	-	-	-	**20**	-	-
1998/2001 in-flight calibration	-	-	-	-	$\approx$ **20**	**10**
CDS – NIS	-	**20...30**	-	-	-	-
– GIS	-	**45** (TBC)	-	-	-	-
SUMER – Detector A	-	-	**33**	-	-	-
– Detector B	-	-	**36**	-	-	-
UVCS – H I Ly α and O VI	-	-	-	**20**	-	-

[a] Radiometric uncertainties are given for the prime wavelength ranges (for further details see text and/or the corresponding instrument contributions). Bold face: values achieved as published.
[b] Solar irradiance instruments on UARS report relative uncertainties of 2 % to 5 %. For a comparison with stellar astronomy: the EUV Explorer (EUVE) calibration plan specifies a relative uncertainty of 25 % (3 σ), which corresponds to a coverage factor of $k = 3$, the Far-Ultraviolet Spectroscopic Explorer (FUSE) achieved an in-flight performance of $\approx$ 10 % relative uncertainty [*Sahnow et al.*, 2000], but experienced a change of the effective area by a factor of about 0.95 over a period of four months [*Moos et al.*, 2000]; the International Ultraviolet Explorer (IUE) relative radiometric uncertainties are $\approx$ 10 % with final adjustments of 4 % to 10 % [*Nichols and Linsky*, 1996].
[c] SEM was added to the SOHO payload in 1990/91 [*McMullin et al.*, 2002b].

struments on other spacecraft; (3) calibration rockets, and (4) comparisons with stellar sources.

It was also noted that good co-alignment, knowledge of the polarization properties, cleanliness standards, and wavelength stability were of great importance in achieving the radiometric-calibration goals. These requirements were eventually adopted in the CDS "Blue Book", the UVCS "Yellow Book", and the SUMER "Red Book" (first draft editions by *Harrison* [1988], *Kohl and Noci* [1989], and *Wilhelm* [1990]). The Blue and Red Books were subsequently revised quite often, mostly as a consequence of the deliberations at the Joint Science Meetings, but the radiometric requirements did not significantly change until the launch of SOHO on 2 December 1995. In general, the Blue, Yellow, and Red Books provided a wide exchange of information about the instruments in non-technical formats and helped during the preparation of the observations. They will be referred to as "Coloured Books" here.

Radiometric-calibration issues of SOHO instruments were specifically taken up by: (1) an inter-calibration working group chaired by John Kohl, and (2) workshops on spectroradiometry.

The SICWG was set up by the SOHO Science Working Team (SWT) of the SOHO principal investigators and the workshops were organized on an ad hoc basis (see Table 5.1). The SICWG prepared the SOHO inter-calibration activities by defining several inter-calibration JOPs (Joint Observing Programme) and monitoring the flight schedule of calibration rockets (Table 5.3), which were carried out in support of SOHO, but managed independently, and, in many cases, with additional scientific objectives. The panel repeatedly emphasized the need for stringent spacecraft and instrument cleanliness requirements. Reports that the responsivity of the operational channel of SUSIM decreased by a factor of 1.3 within days demonstrated the urgency of such measures. The workshops on spectroradiometry discussed the instrument calibration and inter-calibration aspects on a broader scope, and also covered the particulate and molecular cleanliness requirements of the mission. The first workshop took place in Berlin on 11 and 12 July 1989, where the participants outlined the calibration concepts of CDS and SUMER based on transfer standard sources [*Hollandt et al.*, 1993] consisting of Hollow-Cathode Lamps (HCL) [*Danzmann et al.*, 1988] and collimating mirror chambers.

5.3 Radiometric Calibration before Launch

In this section, no attempt will be made to cover all aspects related to the calibration effort of the VUV instruments on SOHO. Rather some events or facts directly relevant to this review will be presented. For further details the instrument-related publications should be consulted [*Clette et al.*, 2002; *Gardner et al.*, 2002; *Lang et al.*, 2002; *McMullin et al.*, 2002a; *Wilhelm et al.*, 2002]. *Hollandt et al.* [2002] discuss VUV radiometric-calibration matters in general. Some introductory remarks referring to more than one instrument are related to the cleanliness concepts.

Before the beginning of the instrument development phase, it was common wisdom that radiometric-responsivity degradation was unavoidable in the VUV range, as was mentioned above. Even after the SOHO cleanliness procedures had been defined, there was no proof that they would eliminate the problem or at least improve the situation. It was thus felt that, in order to maintain the laboratory calibration from instrument delivery to operation in space, a re-calibration just before launch was required as well as purging directly to the instruments on the spacecraft until lift-off. The purging was implemented [cf., *Thomas, 2002*]. However, when in August 1993 ESA announced that there would be no re-calibration slots for the VUV instruments before launch, it was thought that this would have an adverse effect on their calibration status in flight. Only in the case of UVCS did the final calibration occur six months before launch. Fortunately, for all the VUV instruments the pre-flight calibrations by and large nevertheless remained valid after launch.

Table 5.3: Payloads Launched[a] to Verify SOHO Calibrations.

Date	Time[b]	Payload[c,d]	Remarks[e]
26 Jun 1996	19:00	Cal-SO-2	(30.4 ± 4.0) nm: uncertainty 8 %;
			monitor spectral responsivity of SEM
15 May 1997	19:15	EGS, XPS	uncertainty 6 % to 10 %; CDS update;
		MXUVI	Fe IX/X (17.1 nm); EIT, TRACE
11 Aug 1997	18:18	Cal-SO-3	calibration update for SEM/SOHO
16 Oct 1997	19:00	EIT CalRoc	EIT degradation correction
			and flat fielding
18 Nov 1997	19:35	SERTS-97	uncertainty < 25 %; with EM (0.1 to 50) nm
			used for CDS-NIS and EIT updates
31 Jan 1998	04:30	XDT[f]	Fe XIV (21.13 nm) images; Dopplergrams
1 Nov 1998	21:49	UVCS	calibration update for UVCS;
– 3 Nov 1998	12:45	Spartan 201[g]	uncertainty 25 %
2 Nov 1998	18:20	EGS, XPS	validated SNOE SXP calibration;
		MXUVI	Fe IX/X (17.1 nm) images
24 Jun 1999	17:00	SERTS-99	uncertainty 25 %; with EM
18 Aug 1999	18:05	Cal-SO-4	calibration update for SEM/SOHO
26 Jul 2000	18:00	SERTS-00	uncertainty 25 %; with EM

[a] XDT launched from Kagoshima, all other rocket payloads launched from White Sands.
[b] In Coordinated Universal Time (UTC).
[c] Payload names:

Cal-SO	Rocket underflights for SOHO cross-calibration
EGS	EUV Grating Spectrograph
EM	EUV monitor (simplified SEM) to update SEM/SOHO channel 2
HRTS	High Resolution Telescope and Spectrograph
MXUVI	Multiple XUV Imager
SERTS	Solar EUV Research Telescope and Spectrograph
SNOE	Student Nitric Oxide Explorer
SXP	Solar X-ray Photometer
XDT	XUV Doppler Telescope
XPS	XUV Photometer System

[d] The SERTS-96 flight on 13 November 1996 at 18:30 UTC and the HRTS-10 flight on 30 September 1997 20:10 UTC are not listed, because no radiometric calibrations were available.
[e] Accuracies, a, are indicated here by their relative standard uncertainties, u_r, and not by $a = 1 - u_r$.
[f] Details on XDT have been published by *Sakao et al.* [1999] and *Hara et al.* [1999]. The instrument was calibrated at component level. An initial comparison with EIT showed a factor of two less in emission measure.
[g] Launched on the Space Shuttle.

5.3.1 CDS

The CDS team concluded that the only viable method for pre-launch radiometric calibration was a transfer standard traceable to a synchrotron radiation facility as primary source standard. At the first WSVUV in July 1989, this concept was outlined and a coordination with the SUMER calibration was agreed. The HCLs later employed for the SOHO instrument calibrations performed even better than anticipated at that time: a typical relative stability of 2.5 % was achieved over 40 h with one gas and 5 % after a change of gas. The grazing-incidence telescope of CDS required a collimating mirror different from the collimator for SUMER, but the HCLs and the general schemes were the same.

In total, twenty-nine emission lines were selected covering the spectral range of the instrument. The transfer source was calibrated against BESSY I in these spectral lines. After an end-to-end calibration of CDS, the source was returned to BESSY for a post-calibration. For the NIS-2 waveband, the comparison of the pre-launch estimates of the efficiencies of the components with measured responsivities of the instrument were close, whereas for NIS-1 and NIS-2 in second order the deficiencies were a factor of ten. They are attributed to problems with the measured detector quantum efficiencies used in the estimate. For the four GIS channels the comparison yields about a factor of twenty, noting that the estimates for the pre-launch sensitivities of the components were much poorer. The relative uncertainties in the laboratory measurements of the responsivities for both GIS and NIS were estimated at around 30 % [see *Lang et al.*, 2000, 2002].

5.3.2 EIT

The ground-based programme provided a complete calibration of the EIT system [*Defise et al.*, 1995], but time constraints during the integration schedule and difficulties in combining it with the priority scheme of a large synchrotron facility, as well as the substitution of a new detector (Tektronix, thinned back-side, back-illuminated, CCD sensor) after the end-to-end test (using silicon diodes calibrated at NIST) reduced the validity of the pre-flight characterization [*Defise et al.*, 1998; *Clette et al.*, 2002]. Consequently, *Dere et al.* [2000] suggested, for instance, formal relative combined standard uncertainties at the end of the laboratory calibration of (60, 70, and 75) % for the (19.5, 28.4, and 30.4) nm channels, respectively.

5.3.3 SEM

The main purpose of the SEM instrument [*Judge et al.*, 1998] is to measure with high precision and accuracy the solar irradiance near the prominent He II emission line in the wavelength range (30.4 $\pm$ 4.0) nm (Channel 1), but it also monitors the wavelength band between 0.1 nm and 50 nm (Channel 2). It has been calibrated with Beamlines 2 and 9 at SURF-II with typical relative uncertainties of 5 % for the 30.4 nm channel providing solar irradiances, after the convolution needed, with an uncertainty of 10 % [*McMullin et al.*, 2002a]. A typical value for the broad-band channel is also 10 % [*Judge et al.*, 1999].

5.3.4 SUMER

The re-calibration idea, which had to be abandoned in 1993, had been suggested for SUMER by ESA in a status review in October 1991 and had been the agreed scenario since November 1991. The original plan to calibrate the assembled instrument at the Super-ACO facility was also not carried out, because it was felt that cleanliness and schedule constraints would lead to severe difficulties. The controlled attenuation of the intense synchrotron radiation was another problem area. The method finally adopted at WSVUV-1, in cooperation with CDS, used a transfer standard source consisting of a lamp (HCL) attached to a chamber with a spherical concave scan mirror. A total number of thirty-two emission lines was calibrated in the wavelength range from 53.7 nm to 147.0 nm at BESSY I. The source was also successfully compared with a diode calibrated at NIST [cf., *Hollandt et al.*, 2002]. The responsivities of both detectors of the SUMER instrument were very similar, but that of detector B, when operated at nominal gain, generally was a factor of $\approx$ 1.2 higher than detector A. The actual responsivities found were between 0.65 and 1.35 of the prediction based on sub-system measurements [*Wilhelm et al.*, 1995]. The relative uncertainty of the SUMER laboratory radiometric calibration was 11 % [*Hollandt et al.*, 1996].

A specific feature of this calibration was that the calibrated beam was not vignetted inside SUMER (cf., Table 5.2). Apertures and stops therefore had to be taken into account separately in evaluating the throughput of the instrument [*Wilhelm et al.*, 2000]. To verify the imaging properties of the telescope, it was necessary to fill the whole aperture of SUMER with a collimated, even if uncalibrated, beam. This was generated with the help of the Spectral and Angular Resolution UV Tube (SARUVT). It should be mentioned that the end-to-end calibration was performed under extreme time pressure, which had been caused, at least partially, by a late change of the detector system.

The sensitivity to the state of polarization of the incident radiation could not be determined for the assembled instrument. An engineering model of the plane mirror and the holographic grating was used to determine the effects of these polarization-sensitive items at the Super-ACO facility [*Hassler et al.*, 1997].

5.3.5 UVCS

The development programme of UVCS relied on component calibrations and an end-to-end calibration as well as a rigorous contamination control programme to limit optical degradation. UVCS was delivered to ESA for spacecraft integration with its end-to-end behaviour uncharacterized (and without flight detectors). While at ESA, the flight detectors were installed, the diffraction gratings were replaced, the H I Ly-α channel telescope mirror was replaced, and the O VI-channel mirror cleaned. In June and July 1995, UVCS was returned after spacecraft-level testing to laboratories at the Smithsonian Astrophysical Observatory. There, over a period of about 32 d, the UVCS was radiometrically calibrated end-to-end and its stray-light rejection measured.

The UVCS radiometric response was measured against secondary photodiode (cesium telluride and aluminium oxide) standards from NIST [*Gardner et al.*, 1996]. Radiation from a gas-discharge radiation source was pre-dispersed using a monochromator. A single bright spectral line was focused onto the exit slits. The radiation passing through the slits (and through insertable filters of known attenuation) was collimated by a 4.6 m focal-length mirror and directed through the UVCS instrument aperture and onto its telescope mirrors completely filling the portion not covered by the launch-locked internal occulter [*Gardner et al.*, 2002]. That portion, which is the one used for observations at 2.7 solar radii from Sun centre, was the only part of the aperture that could be calibrated during the end-to-end measurements. The radiance was found to be uniform with relative variations of less than 10 %. The UVCS entrance slits were opened sufficiently to pass all of the radiation in that image towards the gratings where it was dispersed and focused onto a detector. The counting rates registered on the detectors were compared directly to the output of the NIST photodiodes, thereby giving the system responsivity. Measurements were made for both UV channels at several wavelengths near the centres of their intended operating ranges. The relative standard uncertainty for each of the radiometric measurements was 16 %.

Laboratory measurements on gratings replicated from the same masters as the flight gratings, together with in-flight data (see Section 5.5) have allowed extension of the results from the laboratory calibration to all telescope apertures available to UVCS [*Gardner et al.*, 2000, 2002].

5.4 Inter-calibration Plans and Achievements

Whereas laboratory calibrations were to a large extent the tasks of the various instrument teams, inter-calibration could only be attempted as a cooperative effort. Most of the meetings listed in Table 5.1 therefore had inter-calibration items on their agendas. The discussions led to the definition of SOHO inter-calibration JOPs, named ICAL, which will be summarized here (all procedures can be found on the SOHO operations pages at `http://soho.nascom.nasa.gov`). Some of them have been widely used. Others were just defined for a special occasion and were either successfully executed or abandoned. Additionally, various other inter-calibration activities have been performed that are not under the formal ICAL listings and form the basis for some of the results reported in this volume. It is worth noting that data taken at regular intervals with standardized observing sequences, such as reference spectra, full-Sun rasters, etc. (not necessarily designed for radiometric purposes), turned out to be very useful in many cases.

5.4.1 ICAL 01

The roots of this JOP go back to the SOHO Assessment Study, ESA SCI (83) 3, of September 1983, where a wavelength overlap between the normal-incidence spectrometer (NIS) and the grazing-incidence spectrometer (GIS) of the model payload was recommended. Such an overlap was indeed suggested by the original CDS and SUMER proposals in July 1987, but it disappeared after the selection in 1988 according to the first published list of SOHO investigations in EOS, 69, No. 13, of 29 March 1988. Fortunately, however, the final wavelength choice of CDS in December 1988 again introduced common wavelength bands with SUMER. This made comparisons between the instruments possible in the bands: 65.6 nm to 78.5 nm CDS GIS-4 (first order) with SUMER detector A (second order) and detector B (first order); 51.3 nm to 63.3 nm CDS NIS-2 (first order) with SUMER detectors A and B (second order). (The GIS and NIS instruments of the SOHO model payload should not be confused with the GIS and NIS channels of CDS.)

In the common ranges, the bright spectral lines He I 58.4 nm, Mg X (60.9, 62.5) nm, and Ne VIII 77.0 nm are available for CDS/SUMER cross-calibrations. In 1994 the details of the wavelength selection and the procedure for ICAL 01 were discussed by the SICWG, before the agreement was reached that ICAL 01 should be an on-disk comparison of quiet-Sun regions aimed at good counting statistics. CDS, SUMER, EIT, and later the Transition Region and Coronal Explorer (TRACE) participated in most of the runs, whilst UVCS performed on-disk observations only a few times. In 1996 and 1997, UVCS/SUMER cross-calibrations at N V 123.8 nm were well within the uncertainty margins, with UVCS indicating radiances about a factor of 1.18 less than SUMER. Since August 1999, the O V 63.0 nm line has been included in the ICAL 01 sequence.

Data obtained on a regular basis with ICAL 01 were analysed to investigate in detail the CDS/SUMER cross-calibration aspects [*Pauluhn et al.*, 1999, 2001a, b]. The agreement was, in general, within the combined uncertainties. An important result was that the variations of the radiances measured by both instruments were highly correlated and, consequently, must have been of solar origin. The SUMER observations were also used to study the calibration changes during the loss of attitude control in 1998 [*Wilhelm et al.*, 2000; *Schühle et al.*, 2000a], and the long-term variability of quiet-Sun radiances [*Schühle et al.*, 2000b]. No published radiometric comparison with TRACE is known.

5.4.2 ICAL 02

The plan was to transfer SEM irradiance data of the He II 30.4 nm channel with the help of EIT images to small regions on the Sun for CDS updates. In addition, the EIT responsivity should be mapped by a full CDS raster. It was also hoped that the results could be transferred to longer wavelengths (SUMER and UVCS). ICAL 02 did not produce the expected results, because the large bandpass of SEM (cf., Section 5.3.3), with the accompanying variety of spectral lines other than He II 30.4 nm, limits a direct comparison of the SEM irradiance with the single-line radiance measurements of CDS. The CDS full-Sun rasters have not proven very useful in providing flat-field information to EIT due to the differing plate scales, the undersampling by CDS, and the timing difference ($\approx$ 12 h for a full-Sun scan as opposed to 30 s for an EIT image).

CDS/SUMER irradiance comparisons had been performed in 1996 and agreed well within the combined uncertainty estimates for He I 58.4 nm and Mg X 62.4 nm [*McMullin et al.*, 2002b]. For O V 63.0 nm, however, CDS observed irradiances were lower by about a factor of 1.35 than SUMER. Both instrument evaluations agreed on the centre-to-limb variation in this line ($\approx$ 4). These O V observations are just compatible within the combined uncertainty margins.

5.4.3 ICAL 03

This JOP was also meant to compare full-Sun data of SEM, EIT and CDS at 30.4 nm. It was not executed, because the load on the CDS detector would have been too high. *Thompson et al.* [2002] present comparisons of irradiance measurements by CDS – tied to EGS 1997 (cf., Table 5.3) – with SEM and EIT, which appear to achieve the goals of ICAL 03, albeit with a different method involving a differential emission measure analysis of the CDS and EIT data. For CDS, differential emission measures were used only to fill in the SEM bandpass below 30 nm. CDS irradiances are lower by 1.05 to 1.15 than SEM values (using a fixed spectrum) and factors of 1.05 to 1.3 lower than those of EIT. CDS and EIT give consistent results on the sum of the He II and Si XI contributions to the SEM 30.4 nm channel [*Thompson et al.*, 2002; *McMullin et al.*, 2002b].

5.4.4 ICAL 04 and ICAL 05

These JOPs were aimed at CDS/SUMER/EIT/MDI alignment and responsivity cross-calibrations. Both goals are now incorporated in the final ICAL 01 sequence. Without specific pointing adjustments, typical misalignments of the instruments were found, in line with expectations, to be less than 10″. This could be improved by an order of magnitude by correlating images with solar disk structures or the limb.

Brynildsen et al. [1998] performed an early CDS/SUMER radiance comparison in the O V 63.0 nm line and found a factor of 1.5 to 2 more with CDS. *Pauluhn et al.* [2001b] studied the O V 63.0 nm line in more detail and found agreement within relative deviations of 15 %. Variations of the solar radiance dominate over instrumental effects in this spectral line as well as in the other lines observed during ICAL 01. However, in later comparisons, CDS radiances appear to be lower by 1.31 [*Pauluhn et al.*, 2002]. These findings are thus consistent with the irradiance results in Section 5.4.2.

5.4.5 ICAL 06

Three SERTS payloads [*Neupert et al.*, 1992] were launched in the years 1997 to 2000, which also carried an SEM-type instrument for observations in the wavelength band from 0.1 nm to 50 nm (see Table 5.3). These flights span the period of the attitude loss of SOHO and can be used to study the changes of the spacecraft instrument responsivities. SERTS covers a bandpass from 29.9 nm to 35.3 nm. A radiometric calibration was performed between flights with the re-calibrated CDS transfer source standard and provided a relative uncertainty of 25 % for the instrument responsivity, confirmed by density- and temperature-insensitive line ratios. The SERTS-97 rocket underflight formed (together with EGS, see Section 5.4.10) the basis for the most recent CDS NIS-1 responsivity determination in first order and for NIS-2 in second order. Since SERTS as well as CDS can clearly resolve the strong Si XI and He II lines at 30.4 nm, this also gives information on the spectral composition of the EIT and SEM 30.4 nm channels, in addition to the results reported in Section 5.4.3. Comparisons of SERTS-97 observations with EIT are presently ongoing.

5.4.6 ICAL 07

Since 1996 SUMER and, in particular, UVCS have carried out many observations of bright, hot stars close to the ecliptic plane. The SUMER measurements of α and ρ Leo near 125 nm agreed very well with the corresponding laboratory calibration and can be taken as verification that no responsivity loss occurred during the spacecraft integration and the launch activities. At longer wavelengths the stellar calibration based on IUE (cf., Table 5.2) was adopted for SUMER, because no reliable ground calibrations were available. In this range, stellar observations also provided information on the responsivity changes in 1998 [*Lemaire*, 2002].

UVCS has observed approximately fifteen stars as well as the planet Jupiter. Included are the stars α and ρ Leo also observed by SUMER. Inter-comparison of the two instrument calibrations using those stars is progressing [*Gardner et al.*, 2002; *Lemaire*, 2002]. Several of the other stars have been observed by instruments aboard other spacecraft (e.g., IUE, Voyager, and FUSE). In general, the relative variations of irradiances measured by

UVCS and IUE are less than 10 %. A comparison of the UVCS O VI channel response to that of Voyager, observing the star τ Tau at wavelengths shorter than was possible with IUE, shows relative agreement to within 20 %. The irradiance of Feige 110, a white dwarf star measured by UVCS in February 2001 near 100 nm, has been compared to measurements made by FUSE. Relative agreement is found to within 15 %. Yearly observations of the bright star δ Sco have been carried out with nearly identical instrument configurations. They show irradiance measurements without trends and relative variations of no more than 5 % over the elapsed SOHO mission time.

5.4.7 ICAL 08

This procedure was not defined.

5.4.8 ICAL 09

The ICAL 09 procedure attempted to inter-calibrate UVCS and SUMER with a coronal streamer near the east or west limb. It was performed several times in 1996 with the participation of both instruments. This inter-calibration was not successful because of the strong radial gradient of the radiance which, for a reliable comparison, required a very good spatial coalignment of the field of view. This could not be ascertained in the featureless coronal streamer.

5.4.9 ICAL 10

The radiometric cross-calibration of SOHO instruments with the HIgh-RESolution EUV spectroheliometer (HIRES) could not be carried out, because the rocket payload has not been launched yet.

5.4.10 ICAL 11

This JOP describes a rocket payload with the instruments EGS, XPS and MXUVI and the radiometric comparisons with SOHO and TRACE. EGS [*Woods and Rottman*, 1990] was calibrated using Beamline 2 of SURF-II. The relative uncertainty in the wavelength band 25 nm to 120 nm was 6 % to 10 %. Five XUV photometers (XPS) (radiometers) in the range 1 nm to 40 nm were calibrated with 10 % to 20 % uncertainty. The EGS data were used to update the CDS calibration (see Section 5.5.1).

During the flight on 15 May 1997, SUMER observed spectra along the central meridian, but was not operating on 2 November 1998, when the rocket payload was launched again. MXUVI obtained Fe IX/X (17.1 nm) images for comparison with EIT and TRACE [*Auchère et al.*, 2001].

5.4.11 ICAL 12

This inter-calibration JOP specifies the rocket underflights in support of SEM and other EUV instrumentation aboard SOHO. The Cal-SO rockets [*Judge et al.*, 1999] are equipped with a solar EUV monitor representative of SEM. It has been calibrated using SURF-II, and transmits bands near He II 30.4 nm and from 0.1 nm to 50 nm. The first flight on

26 June 1996 obtained an irradiance in photons at 1 AU (astronomical unit) of 1.18×10^{14} m^{-2} s^{-1} with a relative uncertainty of 11 % in the band (26 to 34) nm. A comparison of this and the following flights with SEM identified a modest amount of degradation in the spacecraft instrument, probably because of a deposition of carbon (contained in hydrocarbon layers) on the optical surfaces. At SICWG-4, it was reported that there was an average relative degradation of 5.5 % between pre- and post-flight rocket calibrations of a silicon diode with aluminium filter.

SUMER observed full-Sun images in the He I 58.4 nm line on 26 June 1996 and obtained a photon line irradiance of 1.02×10^{13} m^{-2} s^{-1} with a relative uncertainty of $\approx$ 16 %.

5.4.12 ICAL 13

The first launch of the EIT CalRoc produced 512×512 pixel images in all four EIT wavebands. They have been used for deriving SOHO EIT flat-field information [*Defise et al.*, 1998]. In preparing this rocket underflight, tests showed that there was an EUV-dose dependence to the electric potential distribution in the CCD charge-collection region. The rocket flight provided input for the degradation correction, and indicated changes of the multi-layer coatings. A second launch of the EIT CalRoc is planned for 2002 with improved multi-layer sealing.

5.5 Radiometric Calibration in Flight

Inter-calibration activities play an important rôle in most of the in-flight calibrations, and consequently the inter-calibration chapter was presented first. There are, however, some aspects, which could not be adequately treated in that context. One of them is the change in responsivity of the instruments during the attitude loss of SOHO in the year 1998.

5.5.1 CDS

Three sounding rocket payloads (EGS, SERTS, Cal-SO; see Table 5.3) on several flights provided relevant measurements for the CDS in-flight calibration. A comparison with the NIS-2 band of CDS led to a relative uncertainty of 15 % at He I 58.4 nm and 25 % at either end of the band [*Brekke et al.*, 2000]. Consideration of the wide-slit burn-in correction later led to 18 % and 29 %, respectively [*Lang et al.*, 2002]. The comparison with NIS-1 at Mg IX 36.8 nm uncovered a severe discrepancy of a factor of 2.75, which is interpreted as an effect of an undetected misalignment during ground calibration. After adoption of the Mg IX point and a further refinement with the help of a SERTS-97 flight, a relative uncertainty of 15 % (in the SERTS wavelength range) to 25 % (close to 36.8 nm) was assigned to the NIS-1 band in first order. It should be noted that the SERTS-97 instrument was calibrated using the CDS HCL and its calibration is thus traceable to BESSY I (see Section 5.4.5). The ICAL 1 observations (CDS/SUMER) are being used to check the laboratory calibration of the GIS-4 band (longest wavelength) [*Pauluhn et al.*, 2002]. The results of *Landi et al.* [1999] show that there are no gross deviations between the laboratory and in-flight relative calibrations of the GIS detectors. *Del Zanna et* *al.* [2001] and *Del Zanna* [2002] applied spectroscopic methods to achieve a relative calibration of all CDS channels. The incorporation of the results into the CDS calibration is still in progress.

The SOHO attitude loss affected the CDS channels as follows: the NIS-2 band appears to be unchanged, but a slight increase is applied to the relevant uncertainty; the NIS-1 band may have changed by a factor of 1.5. Its responsivity is still under study [*Lang et al.*, 2002]. The calibration of the CDS GIS appears unaffected by the loss of attitude control. CDS was very warm during most of the time without attitude control. This is estimated to have led to a relative reduction of $\approx$ 20 % of the burn-in pattern. This also caused the spectral lines to change position on the detector, altering the burn-in characteristics [*Thompson et al.*, 2002]. Further information, including references to in-flight measurements of line ratios which are independent of solar plasma conditions, is given in *Lang et al.* [2002].

5.5.2 EIT

In-flight calibration results are presented by *Clette et al.* [2002] including grid corrections, point-spread function and stray-light determinations. Also covered is the degradation of the responsivity caused by contamination and EUV-induced reduction of the CCD charge-collection efficiency. The latter effect is responsible for most of the degradation observed. Inter-calibration of EIT with SEM indicates a relative uncertainty close to 20 % after appropriate corrections have been carried out. The on-board, visible-light calibration lamp and SOHO off-point manœuvres were used to derive flat-field images and correction procedures, which also benefit from the EIT CalRoc data (see Table 5.3 and Section 5.4.12). During the attitude loss of SOHO, EIT was very warm and the responsivities of all channels recovered by a factor of about two.

5.5.3 SEM

The in-flight calibration of SEM is closely related to the Cal-SO rocket underflights (see Table 5.3 and Section 5.4.11). With their help, it could be determined that a carbon deposition of $\approx$ 16 nm thickness had accumulated after five years in orbit, for which correction functions have been established as far as the degradation of the EUV responsivities is concerned. After this correction, the relative SEM uncertainties in both channels are $\approx$ 10 %. During the SOHO attitude loss, SEM was warmer than nominal, but no change in responsivity was reported.

5.5.4 SUMER

As for all space instruments, the most critical task was to verify that the SUMER laboratory radiometric calibration did not degrade during spacecraft integration and launch. As a relative measure it could be confirmed that the ratios of the responsivities of the photocathodes (KBr and bare microchannel plate) for both detectors were not affected over the entire wavelength range. With invariant line ratios the relative shape of the responsivity curves has successfully been checked and, finally, stellar observations allowed a comparison with IUE data near 120 nm, for which an agreement within a few percent of the individual observations was found [*Wilhelm et al.*, 1997; *Schühle et al.*, 2000c]. A cross-calibration with SOLSTICE on UARS (calibrated at NIST before launch and with early-type stars in flight) gave consistent irradiance results with relative deviations of 10 % to 14 % in the range from 123.8 nm to 155.0 nm [*Wilhelm et al.*, 1999], and, with the latest SUMER calibration, even 4 % for C IV at 154.8 nm [*Wilhelm et al.*, 2002]. The ICAL 01 data and the H I Lyman continuum measurements acquired during flat-field exposures were used to perform calibration tracking [*Schühle et al.*, 1998]. No loss of responsivity has been found, but rather a slight increase is seen in most of the emission lines, which is considered to be of solar origin. It should be noted that the gain of the microchannel plates is a function of the counting rate and the total counts. Correction procedures for high counting rates are available. In order to maintain the radiometric calibration after the accumulation of a large number of total counts requires an increase of the operating voltage. This option is available until the maximal voltage levels of the power supplies are reached for both detectors.

After the SOHO recovery late in 1998, the SUMER responsivity had decreased by a factor of ≈ 1.31 for both detectors, and the relative uncertainty estimates had to be raised to above 30 %. A final result is not yet available [*Wilhelm et al.*, 2002]. One of the difficulties is that the ICAL 01 spectral lines are optimized for comparisons with other instruments, but not for an internal tracking of a potentially wavelength-dependent loss of responsivity. SUMER was very cold during the period when SOHO's attitude was lost.

5.5.5 UVCS

The radiometric calibration of the two UVCS ultraviolet channels has been confirmed by several methods. The successful inter-calibrations to IUE, Voyager, FUSE, and SUMER using stars have been outlined in Section 5.4.6, and the favourable on-disk inter-comparison with SUMER at N V 123.8 nm was mentioned in Section 5.4.1. Comparisons of UVCS on SOHO to UVCS/Spartan at H I Ly α were carried out in November 1998 (cf., Table 5.3). Spartan was calibrated in the laboratory before and after its flight. Agreement with UVCS/SOHO was found within 15 % of each other, well within the uncertainty of 25 % [*Frazin et al.*, 2002]. UVCS/SOHO has also made measurements of the interplanetary H I Ly-α emission, and found a radiance consistent with the accepted value.

A number of other radiometrically-important instrument functions has been determined in flight. For example, field uniformities have been measured. A major effort has been to track the degradation of field uniformity resulting from changes in detector gain, and make periodic increases in the high voltage to keep the local detector responses within 5 % of the nominal values. These measurements use a combination of star observations and grating scans of bright coronal emission lines. Details of these measurements can be found in *Gardner et al.* [2002] and references therein. The response of the H I Ly-α redundant path in the O VI channel is dependent on the irradiation of the redundant path mirror, which is a function of the grating angle as well as the unvignetted telescope mirror area. These functions have also been evaluated in flight. Such observations were also used to ensure radiometric consistency for observations common to both ultraviolet channels.

The yearly observations of several stars by UVCS indicate that there were no changes in its responsivities as a consequence of the SOHO attitude loss, during which UVCS experienced moderate temperature excursions. Indeed these same observations indicate that there have been no significant changes to date at all. This is likely to be due to the strict cleanliness programme and to the fact that UVCS has a telescope with occulter. Its mirrors thus are not routinely exposed to direct solar irradiation.

5.6 Conclusions

A reliable and consistent radiometric calibration of the SOHO VUV instrumentation on the ground and in flight is a major undertaking, which is still in progress as the mission continues. It has been closely related to the corresponding cleanliness programmes of the spacecraft and the instruments. Together with the coordinated calibration rocket flights, the calibration and inter-calibration activities (not restricted to SOHO instruments) have been very successful and have led to a large database of solar VUV radiation measurements with high accuracy from the sunspot minimum in 1996 to the sunspot maximum in 2000 and beyond. The accuracy achieved must be considered as the minimum standard for future solar missions, which will have the advantage of building on these experiences and results.

Acknowledgements

This history of the SOHO calibration and inter-calibration work was compiled after reading the relevant documents starting in 1983. In the first years of the instrument and spacecraft definition period, a group of people actively pursued the VUV calibration and cleanliness aspects that eventually led to the success of SOHO in this area. I want to list those involved here in alphabetical order: J. Austin, C. Becker, J.-P. Delaboudinière, R.A. Harrison, J. Hollandt, M.C.E. Huber, B.J. Kent, J.L. Kohl, M. Kühne, J. Lang, P. Lemaire, R.W.P. McWhirter, B.E. Patchett, U. Schühle, R. Thomas, J.G. Timothy, and O. von der Lühe. I wish to thank F. Clette, K.P. Dere, B. Fleck, L.D. Gardner, H. Hara, R.A. Harrison, D.M. Hassler, J.L. Kohl, J. Lang, D.R. McMullin, J.D. Moses, J.S. Newmark, W.H. Parkinson, A. Pauluhn, C.D. Pike, J.C. Raymond, U. Schühle, R.J. Thomas, W.T. Thompson, and T.N. Woods for many suggestions and for providing information on details of some of the instrument performance characteristics or the data obtained.

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This vacuum calibration bath company list contains a wide range of vacuum calibration bath factories serving all industries. This trusted vertical directory contains premier China suppliers/vendors, trading companies, custom manufacturers (OEM/ODM) and plants. They are experienced China exporting manufacturers offering tens of thousands of high-quality, competitive pricing products to distributors, wholesalers, resellers, and buyers. You can buy best budget vacuum calibration bath in bulk or cooperate with some ideal ones of these credible suppliers for your import/export business on our b2b p Sep 15, 2017 - Explore srpcontrolON's board "Calibration Instrumentation Canada" on Pinterest. See more ideas about Control system, Srp, Repair.Â Transmille 3000 Series Multi-Product Calibrator - SRP Control Systems Ltd. Calibration Instrumentation Service & Repair. Process Control Control System Ac Dc Current Ac Dc Voltage Arcade Games Canada. Transmille 1000 Series Multi-Product Calibrator - SRP Control Systems Ltd.

Calibration. Metrological instrumentation. Radiometric calibration. Solar radiation.Â In view of the flight history of many previous solar UV instruments, the stability of calibration of the extreme-ultraviolet instruments on SOHO has been a major concern. Results obtained during the first year of operation show that excellent radiometric stability has been achieved with SUMER. These results were accomplished by stringent cleanliness and contamination-control procedures during all phases of the project. We describe the strategy and results of the in-flight calibration tracking program performed with SUMER. Â© 1998 Optical Society of America. Full Article | PDF Article. OSA Recom Everything about principle and calibration of uv spectrophotometer, Control of wavelengths, Control of absorbance, Limit of stray light and Resolution power.Â A spectrophotometer, suitable for measuring in the ultraviolet and visible ranges of the spectrum consists of an optical system capable of producing monochromatic light in the range of 200 nm to 800 nm and a device suitable for measuring the absorbance. The two empty cells used for the solutions under examination and the reference liquid must have the same spectral characteristics. Radiometric-calibration and cross-calibration matters have consequently been important topics from the initial planning phase of the mission to the operational implementation. An attempt will be made here to summarize the early requirements and goals as well as the achieve-ments of SOHO in this context. Although not all plans could be carried out, the general picture is very encouraging. SOHO allowed us to make a major step forward in solar radiometry, in particular of spatially-resolved structures. The assembly, calibration, and end to end testing of the Colorado Ultraviolet Transit Experiment (CUTE) Paper 11444-3 Author(s): Arika Egan, Kevin C. France, Brian T. Fleming, Nicholas DeCicco, Nicholas J. Nell, Lab. for Atmospheric and Space Physics, Univ. of Colorado Boulder (United States); Dmitry Vorobiev, Stefan Ulrich, Ambily Suresh, Richard Kohnert, Lab. for Atmospheric and Space Physics.Â The ground calibration of the ATHENA mirror assembly raises significant difficulties due to its unprecedented size, mass and focal length.Â Optical alignment, characterization and calibration vacuum UV facility: ICON FUV and SMILE UVI case studies. Paper 11444-148 Author(s): Pascal Blain, Christian Kintziger, Lionel Clermont, Yvan Stockman, JÃ©rÃ´me Loicq, Ctr. with calibrated instrumentation, i.e. the observations must be compared to laboratory-based standards, thereby providing a baseline for short-term and long-term investiga-tions of any solar variability (cf. Quinn and FrÃ¨ohlich, 1999; Lean, 2000; Willson and Mordvinov, 2003; Wilhelm, 2009, 2010). The physical quantities have to be given in units of the International System of Units (SI: Le syst`eme international dâ€™unitÃ´es) (BIPM, 2006; see also NIST, 2008).Â Wilhelm, K.: 2002b, Calibration and intercalibration of SOHOâ€™s vacuum-ultraviolet instrumen-taion. In: Pauluhn, A., Huber, M.C.E., von Steiger, R. (eds.), The Radiometric Calibration of SOHO, ESA SR-002, 69â€“90. Wilhelm, K.: 2009, Solar energy spectrum.