Foreword

This book reports on the radiometric calibration of the Solar and Heliospheric Observatory (SOHO) [*Fleck et al.*, 1995; *Fleck and Svestka*, 1997; *SOHO Webpage*]. Radiometric calibration and the strongly related issue of cleanliness are essential ingredients of SOHO's success as the most important solar-physics mission to date.

The complement of instruments carried by this spacecraft permits the study of the entire Sun – from its innermost core out into the heliosphere, beyond the Earth's orbit. SOHO's vantage point in a halo orbit around Lagrange point L_1 on the Earth-Sun line, 1.5×10^6 km away from the Earth towards the Sun (Figure 1), is fundamental to SOHO's capabilities. The location outside the magnetosphere in eternal sunshine and the small and gentle, accurately-known motion along the line of sight toward the Sun permit uninterrupted observing over the entire electromagnetic and particle spectrum of the day star and facilitate helioseismology studies, i.e., the analysis of solar oscillations. SOHO determines the latter with unequalled sensitivity and resolution, both in velocity and in radiance or irradiance space.

Six of SOHO's twelve instruments (Figure 2) observe in the vacuum-ultraviolet spectral region. These are: CDS, the Coronal Diagnostic Spectrometer; SUMER, the experiment for Solar Ultraviolet Measurements of Emitted Radiation; UVCS, the Ultraviolet Coronagraph Spectrometer; EIT, the Extreme-ultraviolet Imaging Telescope; SEM, the Solar Extreme-ultraviolet Monitor, which is mounted on the Charge, Element, Isotope Analysis System (CELIAS) and SWAN, which measures Solar Wind ANisotropies by observing Lyman-α fluorescence in the heliosphere. In addition, the VIRGO instrument, which measures Variability of solar IRradiance and Gravity Oscillations, determines also the total irradiance, i.e., the so-called solar constant. It thus includes the vacuum-ultraviolet part of the solar spectrum. These instruments started their observations in the first half of 1996, partly while SOHO was still on the transfer trajectory to L_1.

Vacuum-ultraviolet instrumentation on earlier solar space observatories has shown sometimes rather strong drops in responsivity after being exposed to solar radiation in space. Contamination – particularly, molecular contamination – deposited on the surfaces of mirrors and other optical components and irradiated by polymerising high-energy

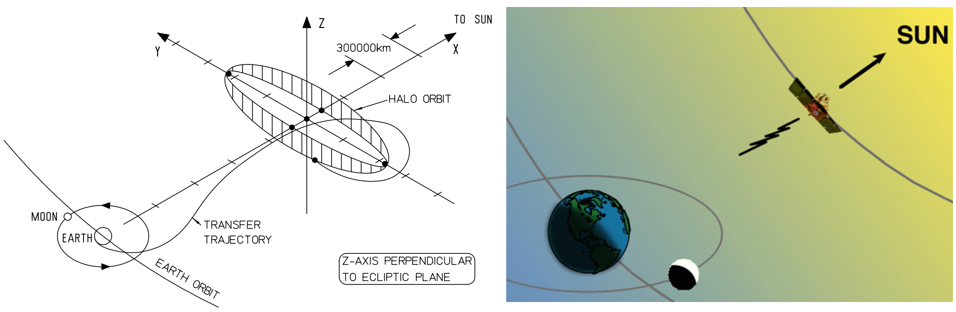

Figure 1: The halo orbit of SOHO around L_1: schematically, including the transfer trajectory (left) and in an artist's impression (right).

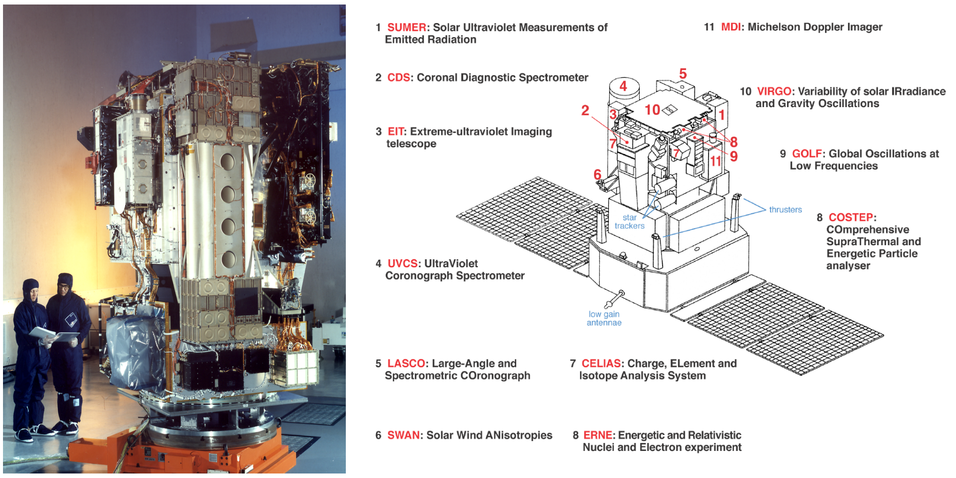

Figure 2: The SOHO spacecraft: a photograph of the payload module in the clean room (left) and a drawing of the satellite, including the service module, with the location of the instruments (right).

photons is at the root of such changes in responsivity. This means that the radiometric calibration of vacuum-ultraviolet instruments, which has been established in the laboratory, can rapidly become invalid once orbit is reached and the optics are exposed. Molecular sources of contamination – paints, potting materials, lubricants and plastics of all kinds – are widespread, and molecular sinks are not only mirrors, gratings, filters etc., but also detectors, since the latter are often cooled to achieve low noise levels.

Cleanliness, therefore, was recognised during the development of SOHO as a prime concern, and was insisted on in designing, fabricating, integrating and testing the instruments and spacecraft. A cleanliness control plan, produced in late 1989 as part of the interface documentation, spelled out the risks and gave advice on ways to minimize the effects of contamination on critical hardware. This resulted in careful design and strict material selection for instruments and spacecraft as well as a stringent observation of cleanliness procedures. The permanent monitoring of the cleanliness has been an issue right from beginning as well.

Given these extensive efforts towards cleanliness, one could hope for a stable radiometric performance of the vacuum-ultraviolet (and other) instrumentation once the spacecraft had reached orbit. And it made sense to strive toward a proper radiometric calibration – on the ground as well as in orbit.

In contrast to Earth observations, where in-orbit calibration is much advanced, but also facilitated by the possibility of using ‘ground-truth’, the inaccessibility and dynamic behaviour of the Sun makes in-orbit monitoring of instrument responsivity by use of solar radiation problematic, especially in the vacuum ultraviolet and X-ray regions.

Carrying standards into orbit for a proper end-to-end recalibration in space is still impractical. In order to compare the responsivity of different experiments and assess the stability of their radiometric calibration, one must, therefore, take recourse to co-temporal observation of the same areas on the Sun, or to the use of an ensemble of hopefully stable stars located within the field of regard of the instruments.

The present Scientific Report on the Radiometric Calibration of SOHO is the result of two Team Workshops that have been held at the International Space Science Institute (ISSI) in Bern in February and October 2001. The participants in the workshops reviewed the entire calibration effort, that in the laboratory as well as that in orbit, and examined, and immediately used, the experience and knowledge gained by the SOHO experiments during every step of the mission. SOHO, fortunately, has carefully crafted in-orbit calibration programmes, which are designed to monitor the responsivity of its instruments. The extensive data material obtained during these in-orbit calibration programmes turned out to be particularly useful when the effects of the extreme conditions experienced during SOHO's accidental loss of attitude had to be evaluated.

This ISSI Scientific Report summarises and documents the radiometric calibration of SOHO's instruments for the first six years in orbit. Following a statement on SOHO's calibration heritage – a general message agreed to by all the workshop participants – the Report starts with an introductory part. This contains basic information, such as a description of solar variability, a general discussion of issues in spectroradiometry for solar physics from space and a digest of radiation from spatially-resolved structures. The introduction also includes a report on the development of the secondary source standards that are traceable to the primary synchrotron-radiation standard and have been developed for, and used in, the calibration of some of SOHO's telescope-spectrometer combinations. Further, the introduction also presents a précis of the actual steps taken to assure the radiometric calibration of SOHO's ultraviolet instruments as well as a summary on the subject of cleanliness.

The following two parts describe the radiometric calibration of individual instrument and their cross-calibration in orbit by use of solar or stellar radiation as 'transfer standard'. (A comparison of polarisation measurements made in the visible by the two coronagraphs on SOHO is included here, too.) A part on the use of atomic physics in radiometric calibration then follows.

The next part contains the reports and recommendations of three Working Groups that met during the workshops. The topics of the Working Groups were: (i) cleanliness, (ii) the cross-calibration between CDS and SUMER and (iii) the comparison of solar irradiance measured by SOHO and other missions.

The final part presents an outlook on space experiments and missions that address solar physics, which are either under preparation or are firmly planned. The outlook, it is hoped, will help to ensure that the experience gained with SOHO is being passed on to the benefit of future missions.

In the Workshops, the cultures of the different experiment teams coalesced into a productive, amiable atmosphere of uninhibited exchange and collaboration. Subsequently, participants showed great commitment, and invested much time and effort to write the interesting articles now being published in this ISSI Scientific Report.

The editors greatly appreciate the work of several external referees. We also want to acknowledge J.L. Kohl, C.D. Pike and K. Wilhelm, who participated in an editorial meeting that helped to improve the scientific coherence of this volume and set the rules for a consistent notation. Subsequently, K. Wilhelm, C.D. Pike and J. Lang splendidly supported the editors: they checked the final manuscripts, and without them a lot of ambiguities and typos and many instances of improper use of the English language would have passed unnoticed. M. Böge is thanked for Unix scripts that helped in processing the manuscripts. Finally, we want to thank the SOHO Project Scientist, B. Fleck, and his team for their great support and for providing material.

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Anuschka Pauluhn, Martin C.E. Huber and Rudolf von Steiger

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