THE SOHO MISSION: AN OVERVIEW

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Abstract. The Solar and Heliospheric Observatory (SOHO) is a space mission that forms part of the Solar-Terrestrial Science Program (STSP), developed in a collaborative effort by the European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA). The STSP constitutes the first "cornerstone" of ESA's long-term programme known as "Space Science — Horizon 2000". The principal scientific objectives of the SOHO mission are a) to reach a better understanding of the structure and dynamics of the solar interior using techniques of helioseismology, and b) to gain better insight into the physical processes that form and heat the Sun's corona, maintain it and give rise to its acceleration into the solar wind. To achieve these goals, SOHO carries a payload consisting of 12 sets of complementary instruments. SOHO is a three-axis stabilized spacecraft with a total mass of 1850 kg; 1150 W of power will be provided by the solar panels. The payload weighs about 640 kg and will consume 450 W in orbit. SOHO will be launched by an ATLAS II-AS and will be placed in a halo orbit around the Sun-Earth L1 Lagrangian point where it will be continuously pointing to Sun centre with an accuracy of 10 arcsec. Pointing stability will be better than 1 arcsec over 15 min intervals. The SOHO payload produces a continuous science data stream of 40 kbits/s which will be increased by 160 kbits/s whenever the solar oscillations imaging instrument is operated in its high-rate mode. Telemetry will be received by NASA's Deep Space Network (DSN). Planning, coordination and operation of the spacecraft and the scientific payload will be conducted from the Experiment Operations Facility (EOF) at NASA's Goddard Space Flight Center (GSFC).

Key words: SOHO – solar interior – solar corona – solar wind

1. Introduction

The Solar and Heliospheric Observatory (SOHO) is a cooperative mission between the European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA) to study the Sun, from its deep core to the outer corona, and the solar wind. The three principal scientific objectives of the SOHO mission can be summarized:

i) Study of the solar interior, using the techniques of helioseismology
ii) Study of the heating mechanisms of the solar corona, and
iii) Investigation of the solar wind and its acceleration processes.

The helioseismology studies are based on relatively new observations in solar physics. In 1960 Leighton, Noyes & Simon (1962) reported observations of a 5-minute oscillation in the solar atmosphere. Studies of these oscillations in the chromosphere and photosphere were based on the oscillations being

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a local phenomenon and were thus aimed at understanding their relationship with energy transport. A decade later Ulrich (1970) and Leibacher and Stein (1971) independently proposed the hypothesis that these oscillations were the result of standing waves in a subphotospheric cavity which was observationally confirmed five years later by Deubner (1975). It was soon recognized that the oscillations were global (Claverie et al., 1979) and that they could be used to probe the deep interior structure of the Sun.

Since that time there have been many studies, using the oscillatory modes seen at the solar surface, aimed at observing the Sun's oscillations and using the observations to determine the Sun's interior structure (e.g. Harvey, 1995, and references therein). The most recent effort is called the GONG (Global Oscillation Network Group) program (e.g. Leibacher et al., 1995) aimed at uninterrupted observing of the oscillations from Earth. The advantage of making these observations from space is that we can avoid the effects of seeing in the Earth's atmosphere and we can get uninterrupted observations because there is no day/night effect. The high spatial resolution obtainable from space will give accurate observations of very short horizontal wavelength oscillations, thus giving us data which will more accurately describe the structure of the outermost layers of the Sun, the convection zone. The long uninterrupted viewing will give accurate measures of the longest periods, which will give us better data on the deepest interior. Thus the SOHO helioseismology observations will complement the GONG program by providing data on the outermost layers and innermost depths of the Sun.

Solar coronal studies were very much limited to brief views during solar eclipses until ultraviolet observations of the Sun were made from space by Baum et al. (1946) using rocket experiments. Shortly after that NASA launched a series of Orbiting Solar Observatory (OSO) missions aimed at observing the Sun in the ultraviolet (UV) and X-ray region of the spectrum. These observations were made with what today would be described as relatively primitive satellites and telescopes. They did show us that much could be learned about the Sun by studying it using space-based telescopes.

The most sophisticated complement of solar telescopes to be flown in space to date was carried on the Skylab Apollo Telescope Mount (ATM) in 1973 (Tousey, 1977). Skylab provided us with: high resolution X-ray and EUV images of the Sun, high resolution UV spectra of the chromosphere and corona, and high resolution white light images of the outer electron corona. Most of the data were taken with photographic film or photomultipliers, so only a limited amount of data could be recorded, providing a very restricting temporal resolution.

Skylab provided us with a wealth of information about the outer solar atmosphere. It is clearly dynamic on almost all spatial scales. It was clearly shown that future observations would need to have: high spatial resolution,

TABLE I
The SOHO Mission

Mission objectives	Investigations of the Sun, from its interior to, and including, the solar wind
Mission shares	ESA: spacecraft plus 9 experiments by member states NASA: launcher, ground segment plus 3 experiments
Launch	end of 1995
Mission lifetime	≥ 2 years (on-board consumables for up to 6 years)
Organization	
Project Managers	F. Felici (ESA), K. Sizemore (NASA)
Project Scientists	V. Domingo (ESA), A. Poland (NASA)
Principal Investigators	
GOLF	A. Gabriel (IAS, Orsay, France)
VIRGO	C. Fröhlich (PMOD, Davos, Switzerland)
MDI/SOI	P. Scherrer (Stanford University, USA)
SUMER	K. Wilhelm (MPAe, Lindau, Germany)
CDS	R. Harrison (RAL, Chilton, England)
EIT	J.-P. Delaboudinière (IAS, Orsay, France)
UVCS	J. Kohl (SAO, Cambridge, USA)
LASCO	G. Brueckner (NRL, Washington, USA)
SWAN	J.-L. Bertaux (SA, Verrières-le-Buisson, France)
CELIAS	hardware phase: D. Hovestadt (MPE Garching, Germany) data phase: P. Bochsler (Univ. Bern, Switzerland)
COSTEP	H. Kunow (Univ. Kiel, Germany)
ERNE	J. Torsti (Univ. Turku, Finland)

high time resolution, wide spectral coverage, and extended observing time scales.

After Skylab, the Solar Maximum Mission (SMM) was flown in 1980 to study solar flares (Bohlin et al., 1980). SMM was designed to study solar flares using high energy X-ray detectors, a UV spectrograph, and a white light coronagraph. This satellite greatly expanded our understanding of solar flares by providing simultaneous observations of flares in the X-ray and UV spectral regions. However, there was no EUV spectrograph on SMM so the critical temperature range between approximately 500,000 K and 1×10^6 K was not observed. Detectors available at the time SMM was developed did not have the sensitivity and spatial extent available now, so the spectral/spatial scope of the observations were somewhat limited.

The SOHO mission is not designed to observe solar flares as was SMM or the Yohkoh mission (Ogawara et al., 1991), but it does have the com-

Fig. 1. The SOHO spacecraft in launch configuration prior to acoustic tests at Intespace in Toulouse, France.

plement of instruments necessary to greatly enhance our understanding of the Sun based on the Skylab data. The spatial resolution on SOHO will be at least as good as, in some respects better than, that obtained by Skylab

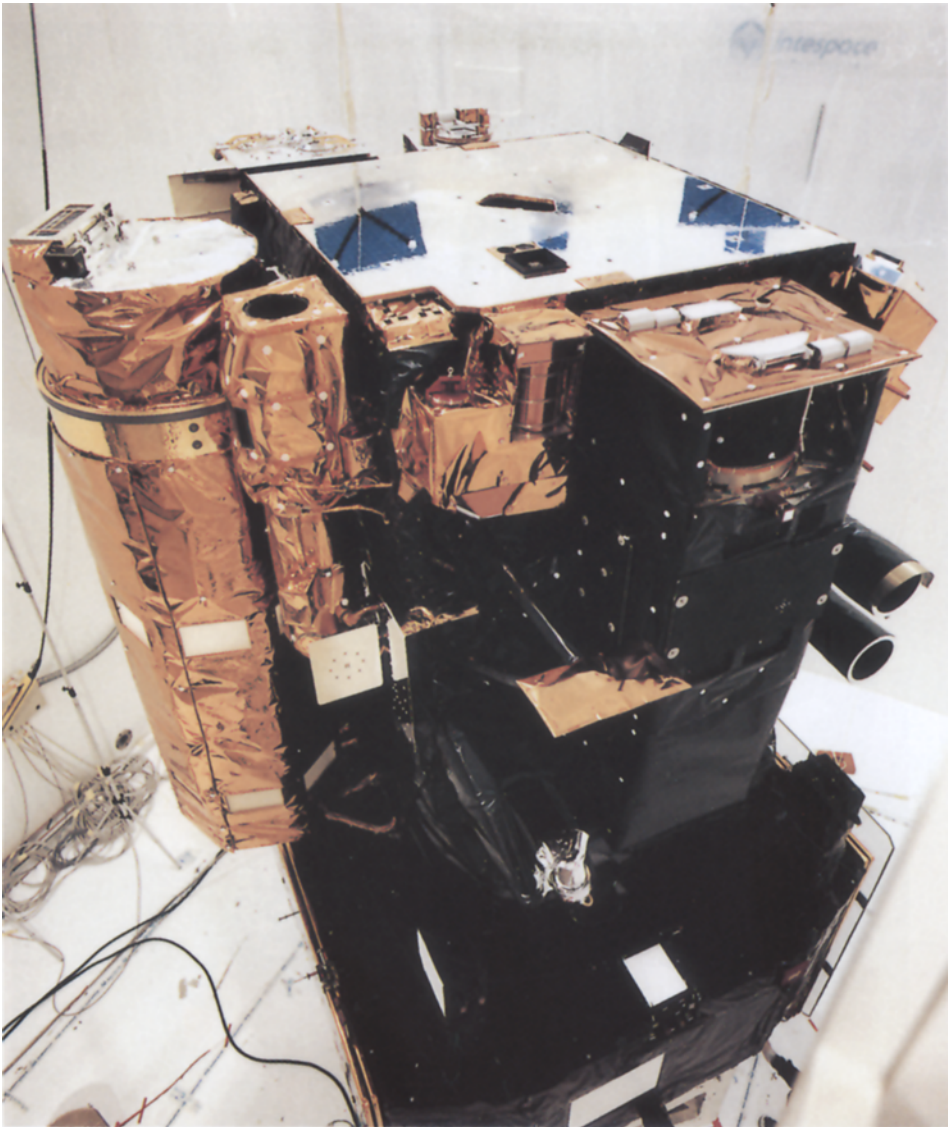

Fig. 2. Top view of the SOHO spacecraft showing the high reflectivity Optical Surface Reflector (OSR) frontplate and UVCS, EIT, the CTOF sensor of CELIAS, and CDS in the foreground (from left to right).

(≈1"). The spectral coverage will be completed in that it will include all wavelengths from the far EUV to visible regions of the spectrum. It will use two-dimensional large area detector arrays so that spatial and spectral data will be obtained simultaneously. SOHO will thus enable us to study the detailed temperature, density, and velocity evolution of solar magnetic phenomena.

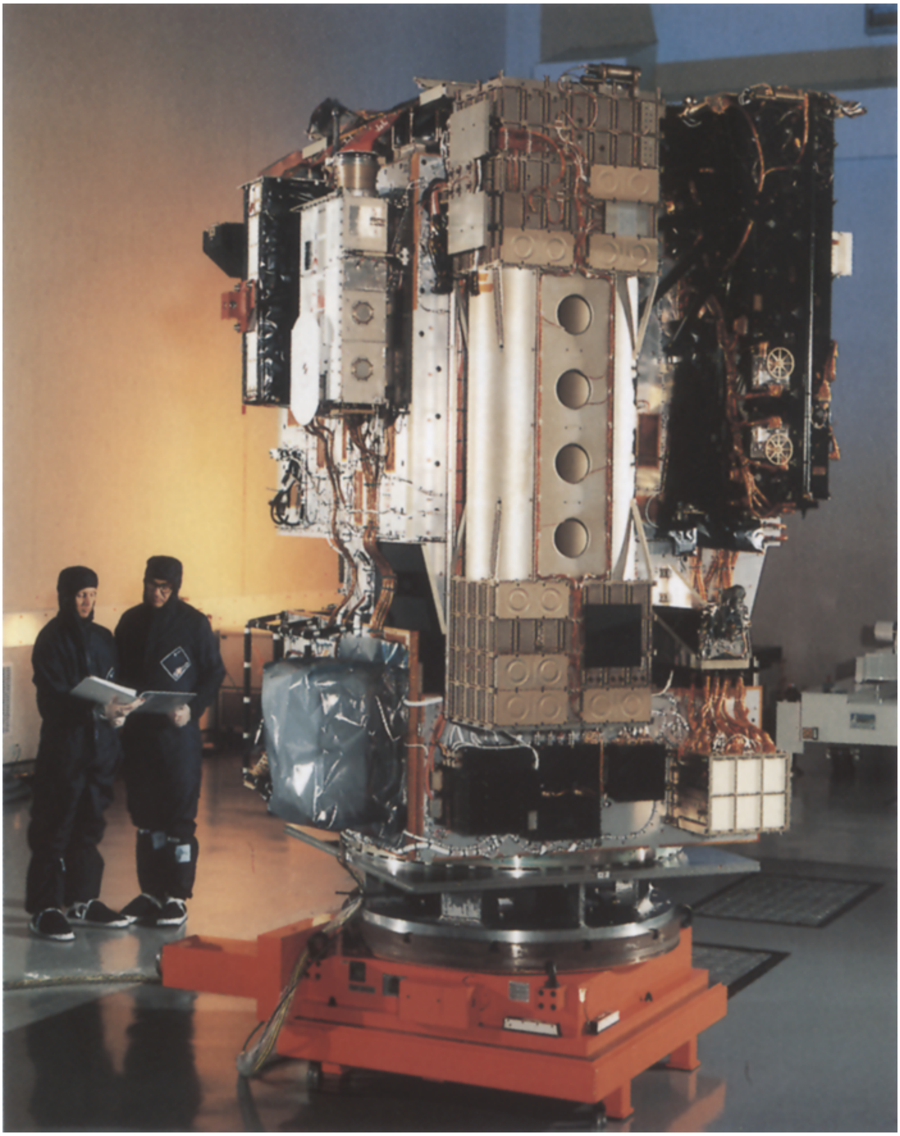

Fig. 3. The SOHO payload module, without thermal blankets, at the end of its integration and testing at Matra Marconi Space in Portsmouth, England. This view is dominated by the SUMER instrument in the foreground, with MDI and GOLF to the left and LASCO to the right.

To complete our understanding of the solar wind SOHO has a complement of particle experiments designed to study the composition of the solar wind. Together with the coronal remote observing experiments they will provide us with the composition and energy of the solar wind in the space between the

Sun and Earth. We will thus be able to observe the energy and composition of the solar wind as it leaves the Sun and travels toward the Earth with a comprehensive set of instruments.

The SOHO mission was proposed in November 1982 as a comprehensive high-resolution spectroscopic investigation of the upper solar atmosphere in response to a call for mission proposals by ESA, after the GRIST mission (e.g. Huber, 1981) had to be abandoned. Subsequently SOHO was recommended for an assessment study which was conducted between February and August 1983. Early in 1983 when it became evident that ESA's DISCO mission (Domingo and Wyn-Roberts, 1982) which would have featured the first helioseismology measurements from space was not being implemented, the scientists on the Assessment-Study team proposed to include helioseismology as one of the goals of SOHO.

From July 1984 to October 1985, a Phase A study was carried out under the technical guidance of ESA. The Science Study Team responsible for the Phase A study was composed of European and US scientists supported by ESA and NASA. At its meeting on 6-7 February 1986 the Science Programme Committee (SPC) of ESA approved the Solar-Terrestrial Science Programme (STSP) as the first cornerstone mission of ESA's long-term programme called "Space Science Horizon 2000", to be implemented in collaboration with NASA. The STSP is based upon two missions: SOHO and Cluster, a set of four identical spacecraft to be operated as a single experiment to explore in three dimensions the plasma and small-scale structures in the Earth's plasma environment (Schmidt and Burke, 1993). SOHO, together with Cluster, Geotail (Terasawa and Kamide, 1994), and Wind and Polar (Russel, 1995) constitute the International Solar-Terrestrial Physics program (ISTP), a cooperative scientific satellite project of ESA, ISAS and NASA which aims at gaining improved understanding of the physics of solar-terrestrial relations by coordinated, simultaneous investigations of the Sun-Earth space environment over an extended period of time.

A joint ESA/NASA Announcement of Opportunity for the STSP missions was issued on 1 March 1987 calling for "Proposals for Investigations". The proposals received were evaluated on the grounds of their scientific and technical merits, and the payloads were selected following the recommendations of the joint ESA/NASA advisory bodies. ESA and NASA announced the composition of the SOHO and Cluster payloads in March 1988. The list of selected scientific investigations and Principal Investigators (PIs) are summarized in Table I. The SOHO Science Working Team (SWT), composed of the PIs and Project Scientists, met for the first time from 27 to 30 June 1988.

A consortium of European industries, led by Matra, France, as main contractor, started the industrial definition phase (Phase B) on 1 Decem-

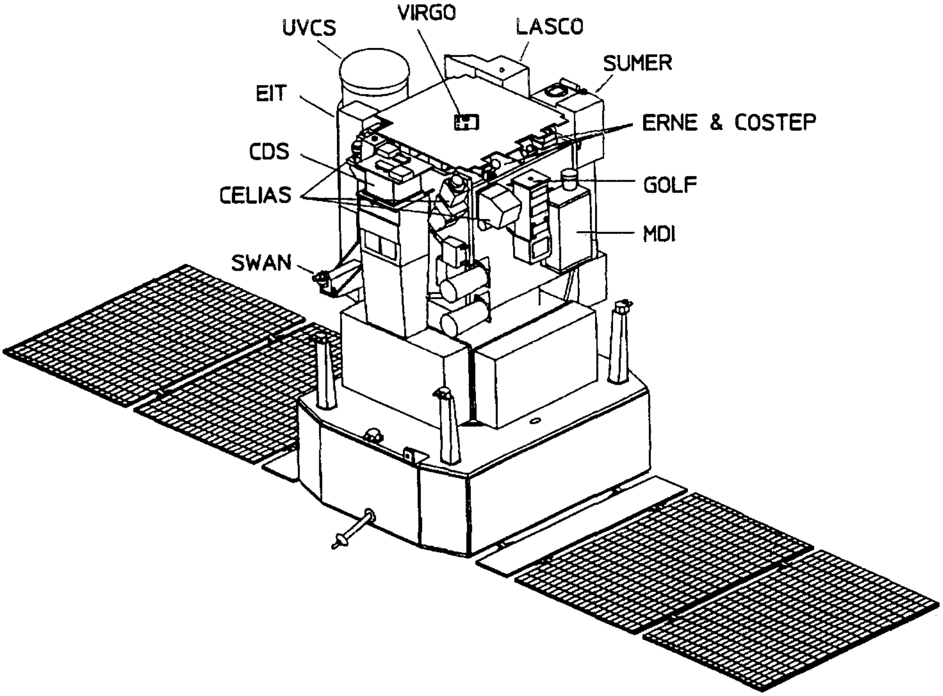

Fig. 4. SOHO spacecraft schematic view.

ber 1989. 14 months later, in early 1991, the industrial development phase (Phase C/D) started. The Structural Model (SM) programme was finished in 1993, and the Engineering Model (EM) programme was completed in early 1994. The Flight Models (FM) of the instruments were delivered in late 1993 and early 1994. The Assembly, Integration and Validation (AIV) activities of the flight model spacecraft took place throughout 1994 and the first half of 1995. The SOHO spacecraft was shipped from Toulouse, France, to Kennedy Space Center at Cape Canaveral for the launch campaign on August 1, 1995.

Fig. 1 and 2 show the SOHO satellite in flight configuration prior to acoustic tests at Intespace in Toulouse, France. Fig. 3 shows the SOHO Payload Module (PLM) after integration at Matra Marconi in Portsmouth, England. Fig. 4 provides a schematic view of the SOHO spacecraft.

In the following sections we will summarize the three groups of scientific experiments on the SOHO spacecraft: helioseismology, atmospheric remote sensing, and solar wind particle in-situ measurements. We will then describe the spacecraft and its functional capabilities. Finally, we will describe the orbit, ground operating capabilities, and the data policies for the mission.

2. Payload

The scientific payload of SOHO comprises twelve state-of-the-art instruments, developed and furnished by twelve international PI consortia involving 39 institutes from fifteen countries (Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, Norway, Russia, Spain, Switzerland, United Kingdom, and the United States). Nine consortia are led by European PIs, the remaining three by US PIs.

The experiments on board SOHO can be divided into three main groups, according to their area of research: helioseismology instruments, solar corona instruments, and solar wind "in-situ" instruments. As the technical and scientific details of these instruments are described in great detail in separate papers in this volume, only a brief summary is given below and in Table II (see also Domingo and Guyenne, 1989, and the proceedings of the four SOHO Workshops: Mattok, 1992; Fleck et al., 1994; Hunt and Domingo, 1994; Hoeksema et al., 1995).

2.1. HELIOSEISMOLOGY INSTRUMENTS

There are three helioseismology experiments on board SOHO (Fig. 5) which have been designed to provide high precision and high accuracy measurements of solar oscillations, particularly those which are difficult, or even impossible, to obtain from ground-based measurements.

Both GOLF (Global Oscillations at Low Frequencies) and VIRGO (Variability of solar IRradiance and Gravity Oscillations) aim to obtain high sensitivity observations of solar p (pressure) and — if detectable — g (gravity) mode oscillations. They lay particular emphasis on the very low frequency domain of low order p and g modes which penetrate the deep solar core. These modes are difficult to observe from the Earth because of noise effects introduced by the Earth's diurnal rotation and the transparency and seeing fluctuations of the Earth's atmosphere.

GOLF using a very stable sodium vapour resonance scattering spectrometer, aims to obtain observations of the low degree ($l \leq 3$) solar *velocity* oscillations with a sensitivity of better than 1 mm/s over the whole frequency range from 0.1 μHz to 6 mHz (periods from 3 min to 100 days). It will also measure the long-term variations of the global average of the line-of-sight magnetic field with a precision of 1 mG.

VIRGO will perform high sensitivity observations of solar *intensity* oscillations with a 3-channel sun-photometer measuring the spectral irradiance at 402, 500, and 862 nm, and with the 12 resolution elements Luminosity Oscillations Imager (LOI) ($l \leq 7$). The relative accuracy of these data will be better than 1 ppm (for 10 s integration time). VIRGO will also measure the solar constant with an absolute accuracy of better than 0.15% using two different types of absolute radiometers (PMO6-V and DIARAD).

TABLE II

The SOHO Scientific Instruments

Investigation	Measurements	Technique	Bit Rate (kb/s)
HELIOSEISMOLOGY			
GOLF	Global Sun velocity oscillations (ℓ=0-3)	Na-vapour resonant scattering cell, Doppler shift and circular polarization	0.16
VIRGO	Low degree (ℓ=0-7) irradiance oscillations and solar constant	Global Sun and low resolution (12 pixels) imaging, active cavity radiometers	0.1
MDI/SOI	Velocity oscillations, harmonic degree up to 4500	Fourier tachometer, angular resolution: 1.3 and 4"	5 (+160)
SOLAR ATMOSPHERE REMOTE SENSING			
SUMER	Plasma flow characteristics (T, density, velocity) chrom. through corona	Normal incidence spectrometer, 50-160 nm, spectral res. 20000-40000, angular res. $\approx$ 1.3"	10.5 (or 21)
CDS	Temperature and density: transition region and corona	Normal and grazing incidence spectrometers, 15-80 nm, spectr. res. 1000-10000, angular res. $\approx$ 3"	12 (or 22.5)
EIT	Evolution of chromospheric and coronal structures	Full disk images (42'×42' with 1024×1024 pixels) in He II, Fe IX, Fe XII and Fe XV	1 (or 26.2)
UVCS	Electron and ion temperature, densities, velocities in corona (1.3-10 $R_\odot$)	Profiles and/or intensity of selected EUV lines (Ly α, O VI, etc.) between 1.3 and 10 $R_\odot$	5
LASCO	Evolution, mass, momentum and energy transport in corona (1.1-30 $R_\odot$)	1 internally and 2 externally occulted coronagraphs; Fabry-Perot spectrometer for 1.1-3 $R_\odot$	4.2 (or 26.2)
SWAN	Solar wind mass flux anisotropies and its temporal variations	Scanning telescopes with hydrogen absorption cell for Ly-α light	0.2
SOLAR WIND 'IN SITU'			
CELIAS	Energy distribution and composition (mass, charge, charge state) (0.1-1000 keV/e)	Electrostatic deflection, time-of-flight measurements, solid state detectors	1.5
COSTEP	Energy distribution of ions (p, He) 0.04-53 MeV/n and electrons 0.04-5 MeV	Solid state and plastic scintillator detectors	0.3
ERNE	Energy distribution and isotopic composition of ions (p - Ni) 1.4-540 MeV/n and electrons 5-60 MeV	Solid state and plastic scintillator detectors	0.7

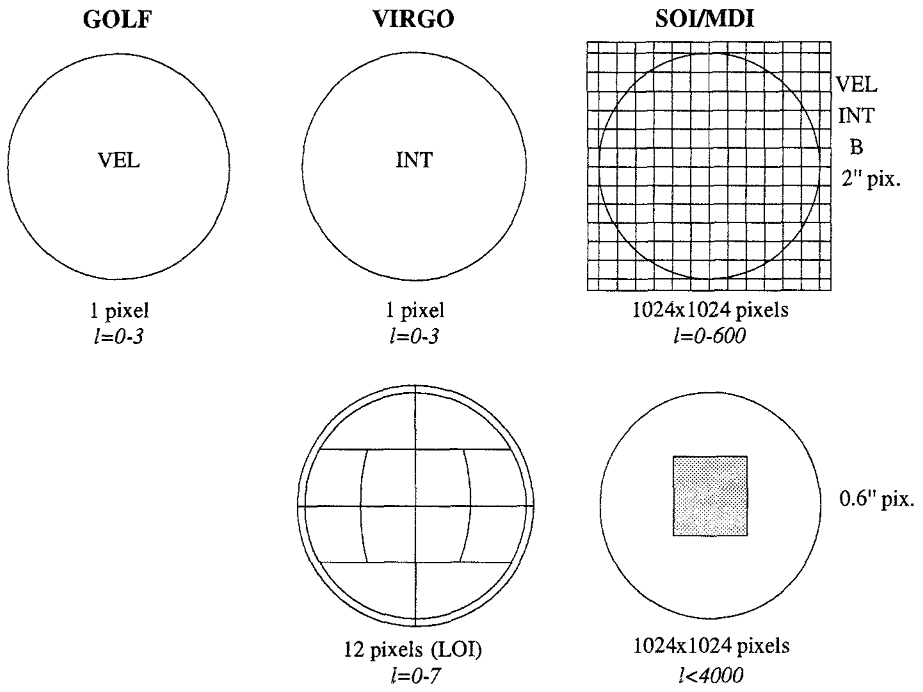

Fig. 5. Comparison of the three helioseismology experiments on board SOHO. VEL, INT, and B means measures velocity, intensity and line-of-sight magnetic field, respectively. In its high resolution mode, MDI measures only the shadowed area (figure at lower right).

The Solar Oscillations Investigation (SOI) uses the Michelson Doppler Imager (MDI) instrument to observe the intermediate to very high degree *p*-modes. By sampling the Ni I 676.8 nm line with a wide-field tunable Michelson interferometer, MDI will provide high precision solar images (1024×1024 pixels) of the line-of-sight velocity, line intensity, continuum intensity, longitudinal magnetic field components, and limb position. It can be operated in a full disk mode (2" equivalent pixel size) to resolve modes in the range of harmonic degree $3 \leq l \leq 1500$ or in a high-resolution mode (0.65" pixel size) to resolve modes as high as $l = 4500$. The high-resolution field-of-view is roughly 650" squared and is centred about 160" north of the equator on the central meridian (cf. Fig. 5). MDI will run 4 different observing programs: The "structure program" provides a continuous 5 kbits/s data stream of various spatial and temporal averages of the full disk velocity and intensity images. It runs at all times. The "dynamics program" operates during 60 consecutive days each year with continuous high rate telemetry (+ 160 kbits/s). Each minute, a full disk velocity image and either a full disk intensity image or a high resolution velocity image will be transmitted. The "campaign program" will be conducted during 8 consecutive hours each day when the high rate telemetry is available. This is a very flexible operations mode to perform a variety of more narrowly focused scientific investigations (e.g. studies of meso- and supergranulation, active region seismology, etc.). Finally, the "magnetic field program" will provide several real-time magnetograms per day for planning purposes and correlative studies.

The three helioseismology instruments complement each other in several aspects (Fig. 5). While MDI is optimized to measure the highest degree oscillations up to $l = 4500$, GOLF and VIRGO are expected to provide greater stability to the measurement of low degree oscillations. GOLF and MDI measure oscillations of the line-of-sight *velocity*, while VIRGO measures *intensity* oscillations (both radiance and irradiance). GOLF and VIRGO complement each other because given the difficulty that one may expect in identifying gravity modes it may well prove essential to have two different approaches (velocity oscillations from GOLF and intensity oscillations from VIRGO) to achieve a conclusive result.

2.2. CORONAL INSTRUMENTS

The solar atmosphere remote sensing investigations are carried out with a set of telescopes and spectrometers that will produce the data necessary to study the dynamic phenomena that take place in the solar atmosphere in and above the chromosphere. The plasma will be studied by spectroscopic measurements and high resolution images at different levels of the solar atmosphere (Fig. 6). Plasma diagnostics obtained with these instruments will provide temperature, density, and velocity measurements of the material in the outer solar atmosphere.

In the past, the coronal observations with the best spatial and spectral resolution covered only limited spectral ranges, and were obtained with only limited temporal coverage. SOHO will provide what is now vitally needed; an extended and concerted investigation of the dynamics and evolution of the physical structures in the transition region and corona. In addition, given the capability to make both (remote-sensing) coronal and (in-situ) interplanetary measurements, SOHO will help to establish the nature of the relationship between conditions in the regions of origin of the solar wind and the observed flow properties at 1 AU, in particular the elusive acceleration mechanism.

SUMER (Solar Ultraviolet Measurements of Emitted Radiation) is an UV telescope equipped with a normal incidence spectrometer to study plasma flows, temperatures, densities, and wave motions in the upper chromosphere, transition region and lower corona with high spatial (1.5") and high time resolution (typically 10 s) by measuring line profiles and intensities of UV lines in the range from 500 to 1600 Å. The spectral coverage varies between

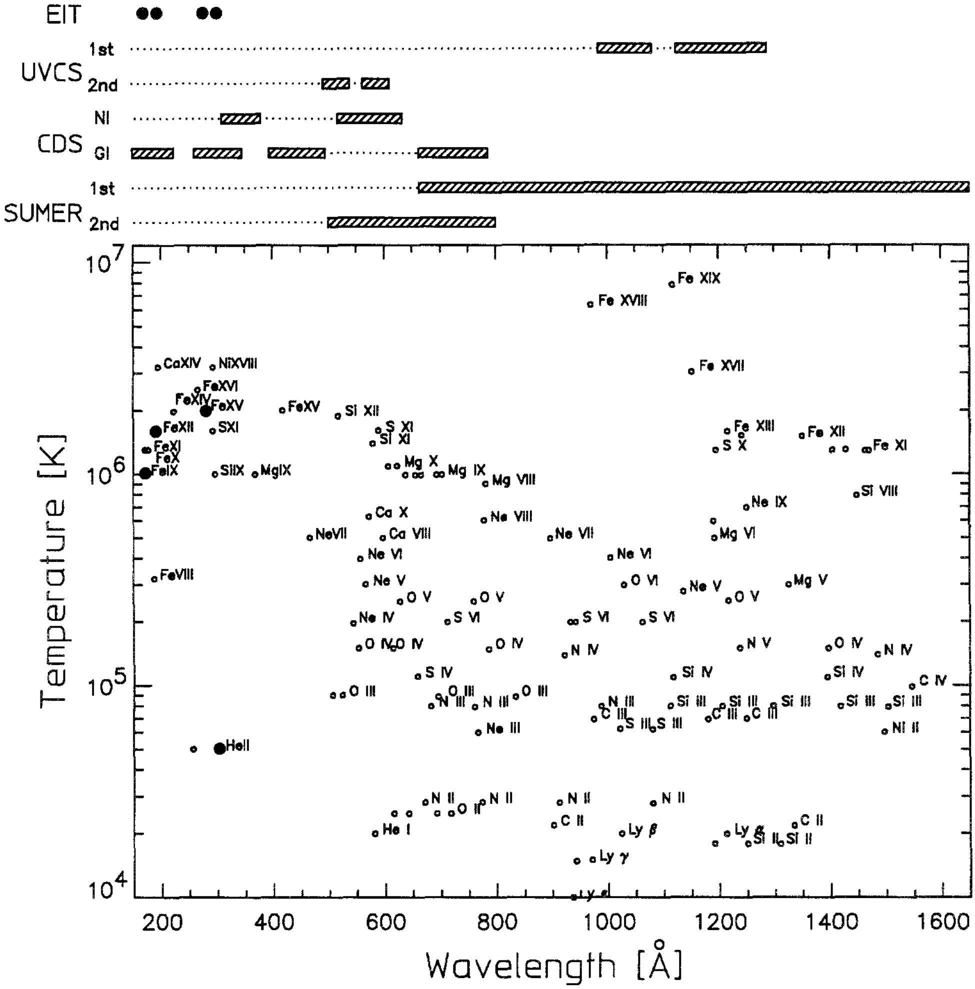

Fig. 6. Wavelength/temperature coverage of the four UV coronal instruments SUMER, CDS, UVCS, and EIT with some selected emission lines. Note the overlap in wavelength bands of all instruments, important for inter-calibration.

20 and 44 Å with a spectral resolving power of $\lambda/\Delta\lambda = 18{,}800 - 40{,}000$. With SUMER, it should be possible to measure velocity fields in the transition region and corona with a resolution of 1 km/s.

At shorter wavelengths (150 to 800 Å) CDS (Coronal Diagnostic Spectrometer), a Walter II grazing incidence telescope equipped with both a normal incidence and a grazing incidence spectrometer, will measure absolute and relative intensities of selected EUV lines to determine temperatures and densities of various coronal structures. The spatial resolution of CDS is better than 3", the spectral resolution varies between 2000 and 10000.

EIT (Extreme-ultraviolet Imaging Telescope) will obtain full Sun high resolution EUV images in 4 emission lines (Fe IX 171 Å, Fe XII 195 Å, Fe XV 284 Å, and He II 304 Å) corresponding to 4 different temperature regimes, thus providing the morphological context of the spectral observations by SUMER and CDS. The wavelength separation is achieved by multilayer reflecting coatings deposited on the four quadrants of the telescope mirrors and a rotatable mask to select the quadrant illuminated by the Sun. The detector is a 1024×1024 CCD camera with an effective pixel size of 2.6".

UVCS (UltraViolet Coronagraph Spectrometer) is an occulted telescope equipped with high resolution spectrometers to perform spectroscopic observations of the solar corona out to 10 solar radii to locate and characterize the coronal source regions of the solar wind, to identify and understand the dominant physical processes that accelerate the solar wind, and to understand how the coronal plasma is heated. One of the gratings is optimized for line profile measurements of Ly-α, another one for line intensity measurements in the range 944 to 1070 Å.

LASCO (Large Angle and Spectrometric COronagraph) is a triple coronagraph having nested, concentric annular fields of view with progressively larger included angles. The fields of view of the three coronagraphs are C1: 1.1 to 3 $R_\odot$, C2: 1.5 to 6 $R_\odot$, and C3: 3 to 30 $R_\odot$. All three coronagraphs will use 1024×1024 CCD cameras for detectors. C1 will not only be the first spaceborne "mirror coronagraph", but it will also be the first spaceborne visible light coronagraph with spectroscopic capabilities. It is equipped with a Fabry-Perot interferometer to perform spectroscopic measurements with a spectral resolution of ≈ 700 mÅ in the lines Fe XIV 5303 Å, Fe X 6374 Å, Ca XV 5964 Å, Na D_2, and Hα.

SWAN (Solar Wind ANisotropies) will measure the latitude distribution of the solar wind mass flux from the equator to pole, and its variation in time, by mapping the emissivity of the interplanetary Ly-α light which reflects the shape of the ionization cavity carved in the flow of interstellar H atoms by the solar wind. The instrument includes two identical periscope systems, each of them allowing to map a full hemisphere with a resolution of 1°. In addition to the photometric mode, a hydrogen cell can be activated to measure the shape of the interplanetary Lyman α line with a resolving power of $\approx 3\times10^5$.

All of the coronal instruments together provide the complementary ability to study the physical properties of the solar corona (Fig. 6). CDS focuses on temperature and density measurements, SUMER on velocity and turbulence, while EIT provides the imaging context at several temperatures. For the outer corona, LASCO provides the electron density, while UVCS will provide temperature and velocity. SWAN will provide the density in the outermost corona and solar wind.

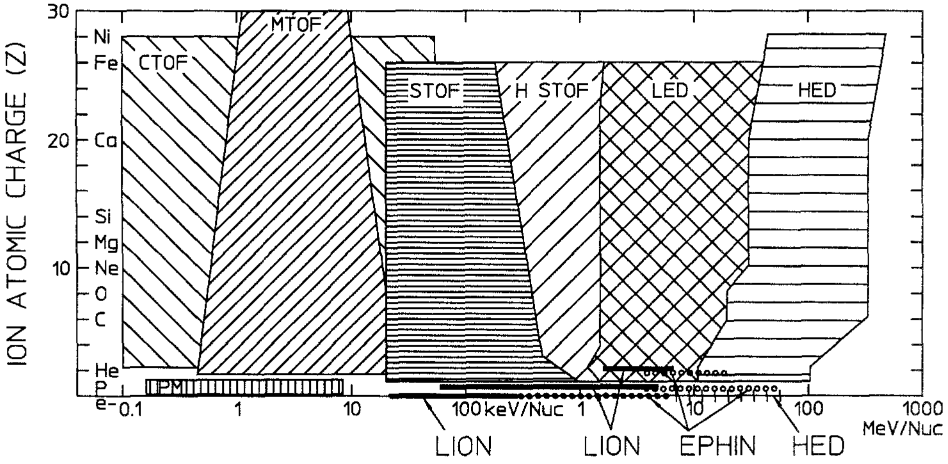

Fig. 7. Charge–energy range of the particle detectors on board SOHO. CTOF, MTOF, STOF, and HSTOF form the CELIAS experiment. HED (High Energy Detector) and LED (Low Energy Detector) are part of ERNE, and LION (Low Energy Ion and Electron Instrument) and EPHIN (Electron Proton Helium Instrument) form the COSTEP investigation.

2.3. Solar wind "in-situ" instruments

While all of the above described instruments use remote sensing to make their measurements, other instruments will measure "in situ" the composition of the solar wind and energetic particles and will determine the elemental and isotopic abundances, the ionic charge states and velocity distributions of ions originating in the solar atmosphere. The energy ranges covered will allow the study of the processes of ion acceleration and fractionation under the various conditions that cause their acceleration from the "slow" solar wind through solar flares (Fig. 7).

CELIAS (Charge, ELement and Isotope Analysis System) consists of three mass- and charge-discriminating sensors based on the time-of-flight technique (CTOF, MTOF, STOF), making use of electrostatic deflection, post-acceleration and residual energy measurements. It will measure the mass, ionic charge and energy of the low and high speed solar wind, of suprathermal ions, and of low energy flare particles. It also carries SEM (Solar Extreme-ultraviolet Monitor), a very stable photodiode spectrometer which will continuously measure the full disk solar flux in the He II 304 Å line as well as the absolute integral flux between 170 and 700 Å.

COSTEP (COmprehensive SupraThermal and Energetic Particle analyser) and ERNE (Energetic and Relativistic Nuclei and Electron experiment) together form CEPAC, the COSTEP-ERNE Particle Analyser Collaboration. To study the energy release and particle acceleration processes in the solar atmosphere as well as particle propagation in the interplanetary medium, COSTEP will measure energy spectra of electrons (up to 5 MeV), protons and He nuclei (up to 53 MeV/nuc). It is composed of two sensor units: LION (Low Energy Ion and Electron Instrument), consisting of three ion-implanted silicon detectors, and EPHIN (Electron Proton Helium Instrument), a multi-element array of solid state detectors (cf. Fig. 7).

ERNE (Energetic and Relativistic Nuclei and Electron experiment), will measure energy spectra of elements in the range Z=1–30 (up to 540 MeV/nuc), abundance ratios of isotopes as well as the anisotropy of the particle flux. It is composed of two sensors: In the Low Energy Detector (LED), semiconductor detectors are used. The High Energy Detector (HED) employs scintillators in addition to semiconductor detectors.

Fig. 7 shows the charge–energy range of the three particle experiments on board SOHO.

In summary, the coronal remote sensing and the "in situ" experiments on board SOHO will provide a comprehensive data set to study the solar wind from its source at the Sun through the heliosphere. The solar imagers and spectrographs will allow the study of the morphology, magnetic structure, and heating and particle acceleration processes occurring at the Sun. At the same time it will be possible to make direct measurements of the particle composition and energy spectrum in the solar wind with the particle experiments.

3. Spacecraft

3.1. GENERAL

The design of the SOHO satellite is based on a modular concept with two main elements, the Service Module (SVM) and the Payload Module (PLM). The SVM can itself be split into two sub-assemblies: the service equipment module and the propulsion module (Fig. 8). This configuration provides easy mounting and accessibility to the payload instruments, while satisfying all instrument functional requirements, particularly viewing direction, field-of-view clearance, straylight avoidance, and pointing stability. The attitude sensors are installed on the PLM to allow achievement of the highest possible alignment stability. Sun sensors, star trackers, gyros, and reaction wheels are included for attitude control, and a hydrazine propulsion system is used for momentum unloading and orbit adjustments as well as attitude control in the early transfer trajectory.

The SVM consists of the following subsystems:

- Antenna Subsystem (ANTS)
- Data Handling Subsystem (DHSS)
- Central On Board Software (COBS)
- Attitude and Orbit Control Subsystem (AOCS)

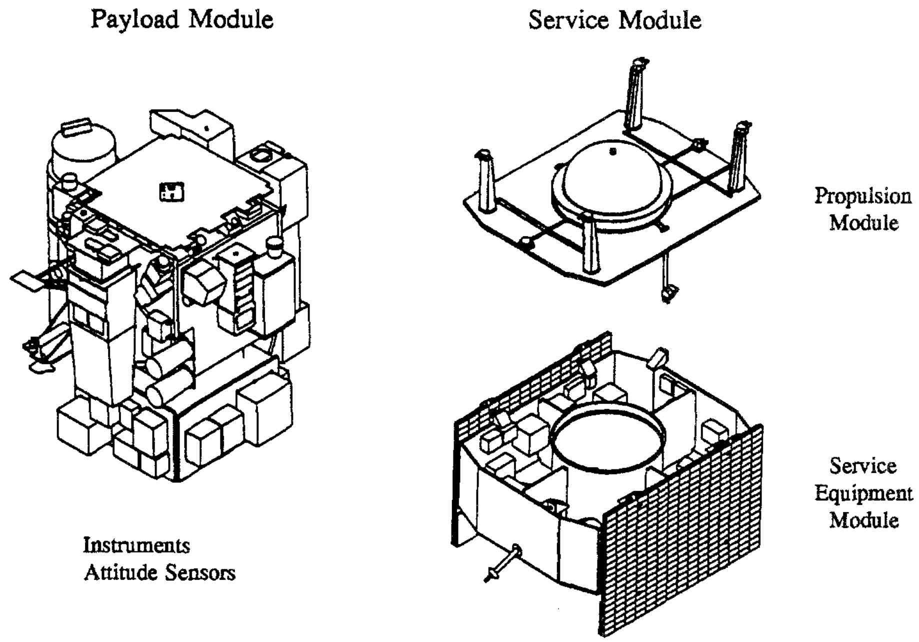

Fig. 8. The SOHO spacecraft consists of two independent subassemblies, the payload module (PLM) and the service module (SVM). The PLM carries all scientific instruments while housekeeping equipments are mounted onto the SVM. Only the attitude measurement sensors are installed on the PLM for achieving highest alignment stability.

- Propulsion Subsystem (PROS)
- Electrical Power Subsystem (EPSS)
- Solar Generator Subsystem (SGSS)
- Payload module Thermal Control Subsystem (PTCS)
- Service module Thermal Control Subsystem (STCS)
- Structure and Harness Subsystem (SHSS)

The major parameters of the SOHO spacecraft are summarized in Table III.

3.2. COORDINATE SYSTEMS

The SOHO satellite uses five fundamental reference frames (for a detailed definition see SOHO Experiment Interface Document Part A (EID-A)):

1. Spacecraft mechanical build axes X_b, Y_b, Z_b
2. Spacecraft optical axes X_O, Y_O, Z_O
3. Payload interface reference frame X_{pi}, Y_{pi}, Z_{pi}
4. Inter-instrument flag reference coordinates X_{ii}, Y_{ii}, Z_{ii}
5. Absolute attitude frame X_a, Y_a, Z_a

The *spacecraft optical axes* are defined with respect to the optical alignment cube of the Fine Pointing Sun Sensor (FPSS), with the optical X axis (X_O) nominally perpendicular to the spacecraft launcher separation plane

TABLE III
Major parameters of the SOHO satellite

Size	$4.3 \times 2.7 \times 3.7\,\mathrm{m}^3$
Mass	total: 1861 kg
	payload: 655 kg
	propellants: 250 kg
Power	1400 W (maximum supply from solar cells)
	payload (mean/max): 440/625 W
Data rate	scientific (continuous): 40 kbits/s
	MDI high rate (part time): 160 kbits/s
	housekeeping: 1.3 kbits/s
Data storage	2 Gbits (Solid State Memory) + 1 Gbits (Tape Recorder)
Telemetry rate	245.8, 54.6 and 1.4 kbits/s (high/medium/low rate)
Orbit	halo orbit around L1
semi diameters	(x) (within eclipitic, earth-sun) $\approx$ 200,000 km
	(y) (within eclipitic) $\approx$ 650,000 km
	(z) (out of eclipitic) $\approx$ 200,000 km
period	6 months
Attitude control	3-axis stabilization
Absolute pointing error	X_{pi} axis: < 5 arcmin
	roll: < 15 arcmin
Medium term stability	X_{pi} axis better than 10" (over 6 months)
Short term stability	X_{pi} axis better than 1" (over 15 min.)
	roll < 1.5 arcmin
Autonomy	> 48 hours
Telemetry and tracking	26 m (primary) and 34 m DSN stations in Canberra, Madrid, and Goldstone

and pointing from the separation ring through the spacecraft. The X_O axis is the reference axis (boresight) of the FPSS measurements. The spacecraft optical Y axis (Y_O) is along the direction of the solar panel extension with positive Y_O pointing from the interior of the spacecraft towards the UVCS instrument. The Z_O axis concludes a right handed orthogonal frame.

The nominal position of the optical reference frame is such that its axes X_O, Y_O, Z_O are parallel to the *spacecraft mechanical build axes* X_b, Y_b, Z_b.

For each experiment, a *payload interface reference frame* (X_{pi}, Y_{pi}, Z_{pi}) has been defined and all the requirements concerning alignment and alignment stability are specified between the spacecraft optical reference frame (X_O, Y_O, Z_O) and this frame. The X_{pi}-axis is defined as being nominally parallel to the Sun pointing direction of the experiment sensor and to be in ground alignment with X_0.

The *absolute reference frame* (X_a, Y_a, Z_a) is a time varying frame. Its axes are defined as follows:

- Its origin coincides with the spacecraft centre of mass.
- Its X-axis (X_a) is along the spacecraft–sun line and oriented towards the photometric centre of the Sun.
- Its Z-axis (Z_a) is such that the (X_a, Z_a) plane contains the normal to the ecliptic plane as defined in the J 2000 inertial reference frame, Z_a being oriented towards the north ecliptic hemisphere.
- Its Y-axis (Y_a) completes the right handed orthogonal reference frame, i.e. it will be parallel to the solar equatorial plane pointing towards the east (opposite to the solar rotation direction).

The nominal (i.e. aimed) attitude of the SOHO spacecraft will be defined with respect to this reference frame.

A standard coordinate system is required for on board communication between instruments (cf. Sect. 4.5). This system, designated (X_{ii},Y_{ii}), is defined as follows: The *inter-instrument flag system* (X_{ii},Y_{ii}) has its origin at the Sun centre, its Y_{ii} axis is in the plane containing the solar rotation axis pointing north, and its X_{ii} axis positive towards the west limb. This means that on the ground, the Y_{ii} axis is parallel to the spacecraft Z_0 axis and the X_{ii} axis is anti-parallel to the spacecraft Y_0 axis. The instruments participating in the flag exchange report the coordinates of their observations in (X_{ii},Y_{ii}) coordinates in units of 2 arcsec.

3.3. MECHANICAL ARCHITECTURE

The SOHO spacecraft overall configuration has been dictated by a series of major requirements which can be summarized as follows:

- Provide easy mounting and accessibility to the payload instruments, while satisfying all instrument functional requirements, particularly with respect to their viewing direction, field-of-view clearance, straylight avoidance, pointing stability, and other specific requirements.
- Ensure a modular concept with two main elements, namely the Service Module (SVM) and the Payload Module (PLM). The SVM can itself be split into two sub-assemblies: the service equipment module and the propulsion module (Fig. 8).

The integrated spacecraft body is approximately $4.3 \times 2.7 \times 3.7\,\mathrm{m}^3$ in dimensions. After solar array deployment the total span is about 9.5 m. The solar arrays are folded during launch and are maintained with hold down points mounted on lower and upper floors of the SVM.

The SVM is a relatively flat rectangular box with slightly cut corners. Structurally, the SVM consists of a central cylindrical tube, shear panels, lateral walls and upper and lower floor panels. All service dissipative equipment is mounted on the lateral walls which provide important mounting surfaces and radiative area. The high gain antenna is integrated in the spacecraft central tube. The two low gain antennae mounted on fixed booms at the bottom section of the service module protrude from the main body to provide full geometrical coverage.

The PLM, approximately 2.7 m long, consists of four upper panels, each approximately 1.4 m high, to support experiment sensors at their outside and three lower panels of 0.7 m to support experiment electronics. A central tube of approximately 1.7 m in length provides load transfer to the SVM central tube via the propulsion support ring. Lateral panels are connected to the PLM central tube via floors whose location is such to optimize the experiment interface loads distribution into the payload module structure.

The propulsion module which forms part of the SVM is considered as a separate assembly since it can be integrated as a whole on the SVM (cf. Fig. 8). A specific interface cylinder supports the propulsion tank and is connected on one side with the PLM internal cylinder and on the other with the SVM thrust tube. The propulsion equipment is mounted onto the SVM upper platform with the exception of two thruster blocks located onto the lower floor.

The interfaces between the SVM and PLM are mainly dictated by (a) geometrical constraints, (b) considerations of the thruster plume impingement on experiments, (c) the experiments control stability requirements and sensor field-of-view, and (d) the modularity. A simple bolted circular interface links the SVM central tube to the PLM one (48 bolts M 10). Most of the attitude control sensors are accommodated onto the PLM in order to benefit from its high stability with regard to experiments (Fine Pointing Sun Sensor (FPSS), star trackers), or have a direct view to the Sun direction (Solar Acquisition Sensor (SAS)).

3.4. THERMAL ARCHITECTURE

The PLM Thermal Control Subsystem (TCS) guarantees the following major requirements:

- Maintain all equipment mounted on the PLM structure within acceptable temperature range limits.
- Provide stable thermal environment in order to meet all the pointing requirements of the AOCS and experiment sensors.
- Provide acceptable radiative environment for the experiment sensors.

To meet the above requirements, a mix of multi-layer insulation (MLI), coatings and heater circuits has been defined:

- The PLM external surfaces are covered with MLI consisting of 13 layers. The outer layer is made of carbon filled Kapton and the inner layers are made of Mylar or Kapton.

- The PLM internal surfaces are also black painted in order to allow good predictable radiative coupling and to minimize temperature gradients.
- The PLM is thermally decoupled from the SVM propulsion ring through insulation washers. The PLM/SVM interface is controlled at 20° C ± 5° C in order to limit PLM deformations induced by the SVM.

All experiment sensor units (except VIRGO) perform their own thermal control; the PLM thermal control thus only guarantees the temperature range of their temperature reference points and their radiative environment through the definition of appropriate heat sink temperatures. For the other units, i.e. VIRGO and all electronic units (except MDI and LASCO electronics), the PLM is in charge of the full thermal control. The PLM thermal control also provides the lines for the substitution heaters which are activated when their associated experiment units are not powered. The basic concept of the PLM thermal control is to use a heater fixed power mode with adjustable power levels for each heater circuit which is commandable from the ground.

3.5. ELECTRICAL ARCHITECTURE

The electrical system is organized around two main buses (Fig. 9): the On Board Data Handling (OBDH) data link and the 28 volts power distribution. The interface between these buses and different subsystems/experiments are performed through standard and identical units: conventional Remote Terminal Units (RTU) for data link and Power Distribution Units (PDU) for power buses. Each subsystem is located on a dedicated panel and near its respective interface units (PDU, RTU). Fig. 9 shows schematically the electrical architecture of the SOHO satellite and the interfaces between the subsystems (for the acronyms see Appendix A).

3.5.1. Data Management and Data Handling

The heart of the system is the Central Data Management Unit (CDMU) which is composed of a redundant intelligent processing unit including a 16 bit MAS281 microprocessor. The main functions of this subsystem are:

- data acquisition and formatting from experiments and SVM
- data storage during periods of no ground data collection
- acquisition, decoding, validation and distribution of commands from ground to experiments and SVM
- thermal control of SVM and PLM
- maintenance and distribution of time base references for synchronization and time tag purposes
- inter-instrument data exchange (see Sect. 4.5)
- on board surveillance and monitoring to ensure the safety of the spacecraft

The exchanges between on board computers and users are realized by the digital OBDH bus which is controlled by the central processor and uses sep-

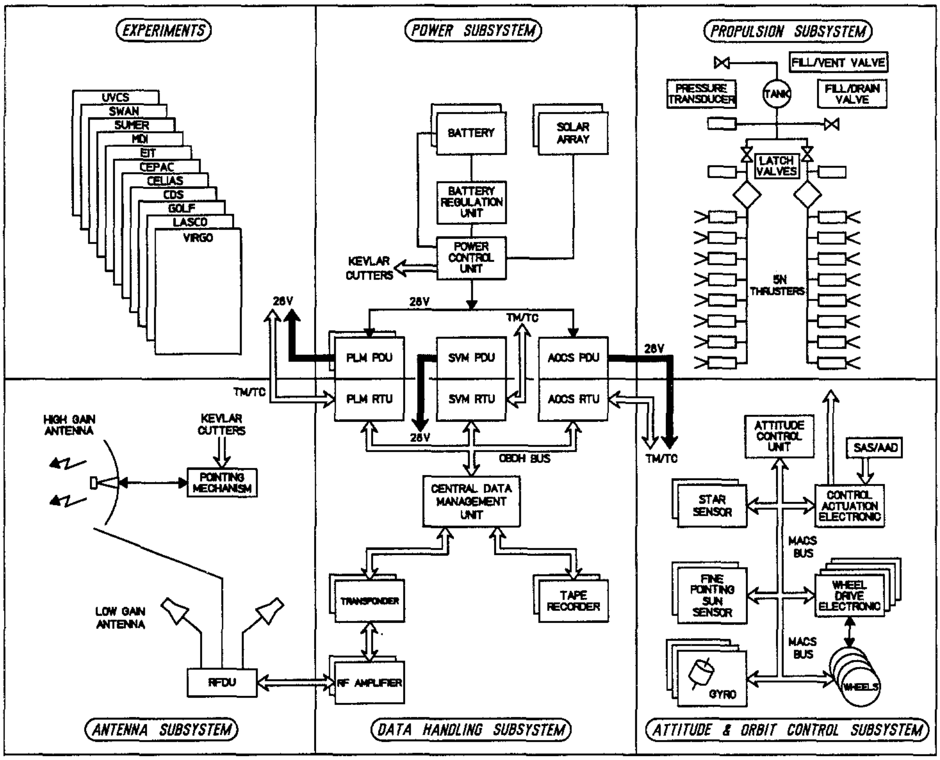

Fig. 9. SOHO electrical block diagram

arate lines for interrogation (computer commands or requests) and response (data or acknowledge to computer). The bit rate is 524 kHz and uses the litton code.

In order to simplify as far as possible the data interfaces, the telemetry and command functions (monitoring, actuating, switching) are combined in three Remote Terminal Units (RTU) which operate under the control of the main computer via the OBDH bus. The RTUs are dedicated respectively to the PLM, the SVM equipments (data handling/telecommunications and power subsystems), and the Attitude Control Unit (ACU). The ACU is based on the same microprocessor as used in the CDMU of the data handling subsystem. The system is fully redundant. Moreover, an independent mode (hardwired) provides a safe mode in failure cases.

Two data recorders (one tape recorder of 1 Gigabit plus one fully self-redundant solid state recorder of 2 Gigabits capacity) provide the on board data storage function. The data are transferred to and from a data recorder on a dedicated link connected to the transfer frame generator.

Fig. 10 illustrates the various layers of the Central On-Board Software (COBS).

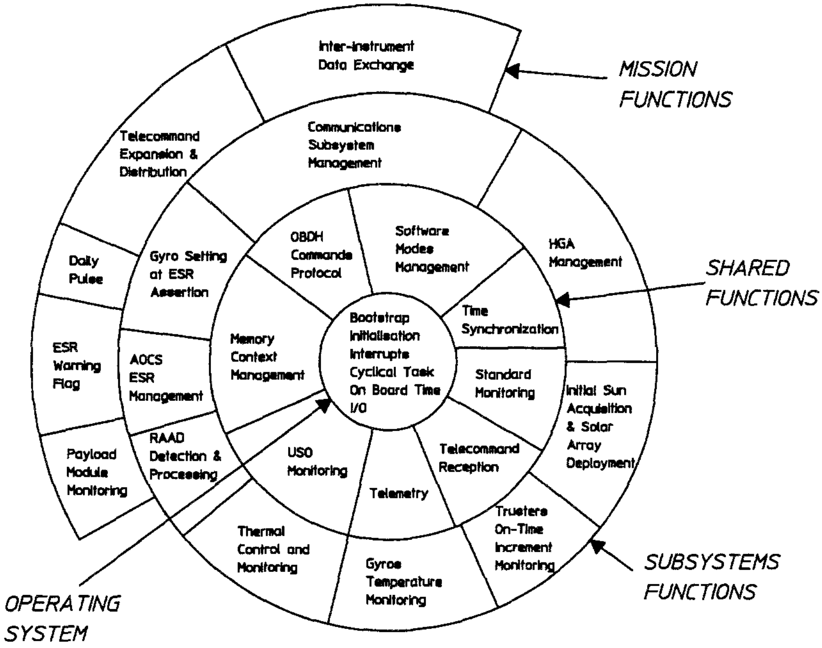

Fig. 10. Central On-Board Software Layers

3.5.2. On Board Time (OBT)

A spacecraft On Board Time (OBT) clock is maintained within ±20 ms to International Atomic Time (TAI) ground reference time during the whole mission. It is driven by a redundant, oven controlled Ultra Stable Oscillator (USO) having a stability better than $3.6\,10^{-8}$ per day. It is used for precise time-tagging of on board events and telemetry data. Ground adjustments of the OBT are anticipated every 2.5 days to maintain the above accuracy.

The time tags for the spacecraft and instrument housekeeping packets are generated by the OBDH system. The time tags for the instrument science data packets are inserted by the instruments generating the science data. The time tags are provided in 6 bytes; the first 4 bytes are TAI seconds (2^0 to 2^{31} seconds) and the last 2 bytes are fractions of a second with the resolution of the On Board Time Pulse (2^{-11} seconds).

The helioseismology experiments center one minute observations on the TAI minute, that is where TAI modulo 60 is zero.

Coordinated Universal Time (UTC) is used as the operational time reference in the EOF. The "SOHO operations day" is defined to begin at 00:00 UTC and the computer systems in the SMOCC and EOF are synchronized to run on UTC.

3.5.3. Power Management

1400 W power are generated by solar cells and regulated to 28 V ± 1 % by a classical sequential switching shunt regulator (S^3R). There are two solar array wings, of two panels each, which are based on standard/production line ARA panels. The cell type is a Back Surface Reflection (BSR) silicon cell with a resistivity of 2 Ωcm.

Power storage is realized by two 20 Ah NiCd batteries which are sized to deliver power during initial acquisition phase and for peak power (950 Wh). The battery cells are protected against open circuit failure through discharge diodes.

3.6. COMMUNICATIONS

Telemetry data transmission to ground, telecommand reception and tracking/ranging functions are conducted via NASA's Deep Space Network (DSN). The ground to satellite links are provided by an S-band Radio Frequency (RF) system (2245 and 2067 MHz for down- and uplink, respectively). Receivers, transmitters and antennas on board the spacecraft are either duplicated or internally redundant. A High Power Amplifier (HPA) provides 10 (3.2) W output levels in its high (low) power mode. For high rate scientific data, RF coverage is provided by a pointable high gain antenna (HGA). Two low gain antennas (LGA) ensure omni coverage, usable only with low rate telemetry.

The two LGAs are quadrifilar short resonant helix mounted on a short skirt. They are installed on the + and − Z side of the spacecraft. Each LGA operates in S-band right handed circular polarization at both uplink and downlink. The antenna pattern is quasi-rotationally symmetric and quasi isotropic in the region of elevation between 0 and 108.5° (LGA reference axis).

The HGA is a 804 mm S-band shallow reflector antenna. It comprises a carbon fiber reflector, an aluminum feed cone with a crossed dipole feed and a reflective disk on top. The HGA operates in S-band, right or left handed circular polarization for both uplink and downlink.

The SOHO spacecraft utilizes the ESA standard packet telemetry structure. Each transfer frame contains 1279 bytes, including the Reed-Solomon (R-S) code. The downlink data are both R-S coded (interleaved to a depth of five) and convolutional encoded.

In halo orbit, during normal operations, a continuous tracking of the Earth is not necessary to transmit the HGA RF signal with the requested RF gain. A certain depointing is acceptable. It is only necessary to realign the HGA three times every 24 hours. These movements have to be smooth enough to prevent any significant spacecraft depointing ($< 0.7''$). A very low driver speed is used to do this (0.001°/s). The worst case depointing associated with this action is lower than 0.27". The halo orbit requires the

HGA pointing capability in any direction inside a ±32° cone around the spacecraft–Sun line.

3.7. DYNAMICS AND CONTROL

3.7.1. Attitude and Orbit Control System (AOCS)

SOHO is a 3-axis stabilized spacecraft. The Attitude and Orbit Control System (AOCS) provides the satellite with the means to

- point the spacecraft optical reference axis X_O accurately to the Sun
- control the roll angle around the Sun pointing axis
- perform orbit manoeuvres

The AOCS comprises three sensor units, actuators, electronics and software for attitude determination and control. The three sensor units comprise the Inertial Reference Unit (IRU) including three gyros, a Star Sensor Unit (SSU), and a Fine Pointing Sun Sensor (FPSS). Thrusters and four reaction wheels are used for actuation.

In the normal mode, pitch and yaw is measured by the FPSS and the spacecraft roll attitude is measured by the SSU. Reaction wheels are used for actuation. Every eight weeks an orbit maintenance maneuver will be performed by operating the thrusters. These maneuvers are coupled with wheel off-loading.

3.7.2. Pointing Performance

During the halo operational phase, in the nominal fine pointing mode, the spacecraft pointing performances are as follows (all 3σ values):

- *Absolute Pointing*

  The commanded absolute pointing will nominally be: The spacecraft optical X axis (X_O) pointing towards the photometric center of the Sun, and the spacecraft optical Z axis (Z_O) oriented towards the north ecliptic hemisphere such that the (X_O,Z_O) plane contains the Sun axis of rotation. As such the Y_O axis will be parallel to the solar equatorial plane pointing towards the east (opposite to the solar rotation direction). The maximum variation of the absolute pointing error of the X_{pi}-axis from on-ground alignment until end of the nominal mission will be less than 5 arcmin. The maximum variation of the absolute pointing error of the roll angle about the X_a axis will be less than 15 arcmin.
- *Relative Pointing Errors*

  The medium term absolute pointing error of the X_{pi} axis will be less than 10 arcsec over a time period of 6 months. In other words, SOHO will always point to Sun center with an accuracy better than 10 arcsec. The relative short term pointing error of the X_{pi}-axis will be less than 1 arcsec, over a time period of 15 minutes. In other words, the angular separation between the instantaneous absolute orientation of the X_{pi}-axis at any time t and the average over a 15 min time interval T, where t belongs to T, is less than 1 arcsec (3σ). The short term roll error about the X_a-axis will be less than 1.5 arcmin, also over a time period of 15 minutes.

3.8. CLEANLINESS

As several instruments, in particular the UV and EUV instruments, are very sensitive to contamination, cleanliness was of paramount importance in the whole SOHO programme. Therefore, several measures have been taken in order to assure clean environmental conditions for the sensitive experiments. Among these measures are:

- material selection according to low outgassing requirements
- use of clean rooms and clean benches (down to class 100 areas)
- baking ("space conditioning") of critical hardware (instruments, PLM structure, harness, MLI, OSR panels)
- careful venting and thruster position design
- conductive outer surfaces in order to avoid electrostatic attraction of ionized contaminants
- Nitrogen purging of the majority of the sensors throughout the AIV and pre-launch operations

The Thermal Balance/Thermal Vacuum (TB/TV) tests revealed very low levels of molecular contamination. One can therefore expect a fairly stable sensitivity of all instruments.

4. Orbit, Operations, Ground-Segment

As the SOHO ground-segment and operations concept is described in detail in a separate paper in this volume (St.Cyr et al., 1995), we give here only a brief summary.

4.1. OPERATION TIME

The SOHO spacecraft is scheduled for launch on an Atlas II-AS in late 1995. SOHO has been designed for a lifetime of two years, but will be equipped with sufficient on-board consumables for a mission duration of 6 years. It is worth noting that the SOHO mission will start operating during the minimum of the solar cycle, and that an extended mission would cover all the rising phase of activity well beyond the next activity maximum (Fig. 11).

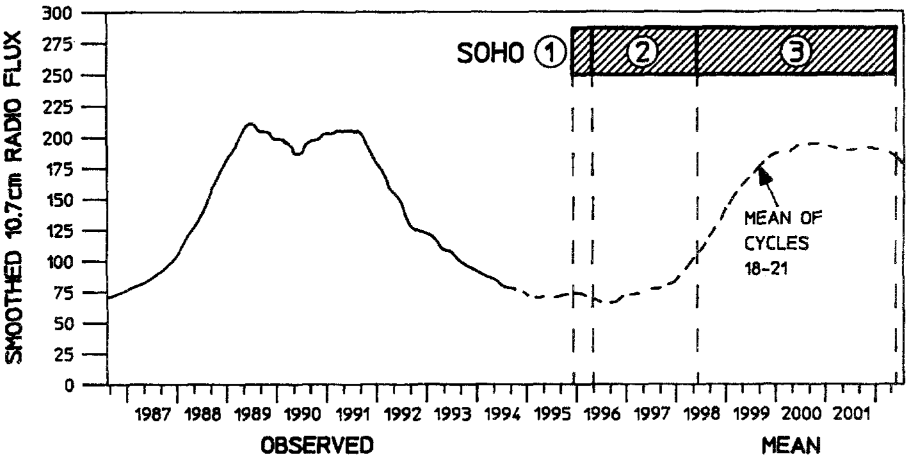

Fig. 11. The SOHO operation time versus the predicted solar activity cycle, represented as the mean of cycles 18-21 (Space Environment Service Center: Prediction of Smoothed 10.7 cm Radio Flux. Preliminary Report and Forecast of Solar Geophysical Data, 6 June 1995, SESC PRF 1031, p. 16, NOAA/ERL, Boulder). (1) Transfer to halo orbit, (2) nominal operation time, (3) expected operation extension.

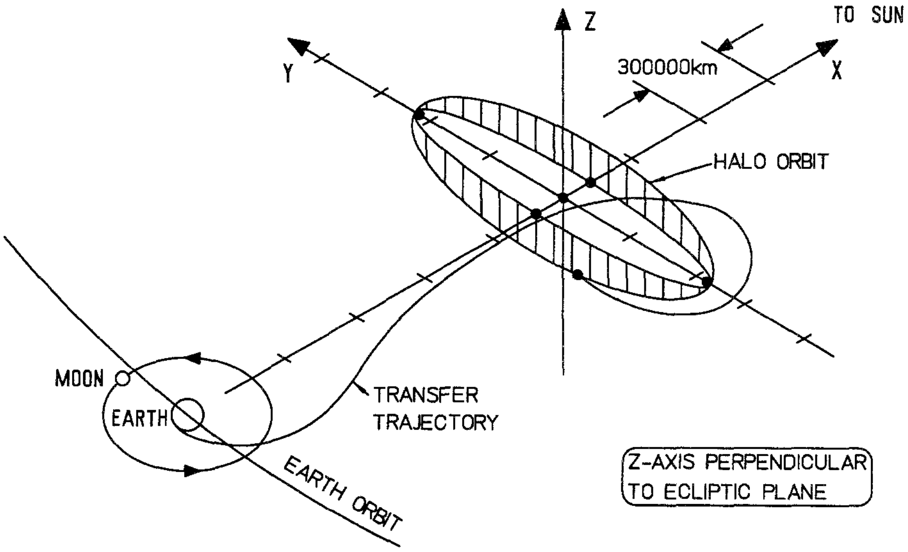

Fig. 12. SOHO orbit

4.2. ORBIT

SOHO will be launched by an Atlas II-AS, the most powerful version of the Atlas-Centaur family. Initially it will be injected into a low Earth parking orbit. After a short coast phase of at most 110 min, the Centaur stage will

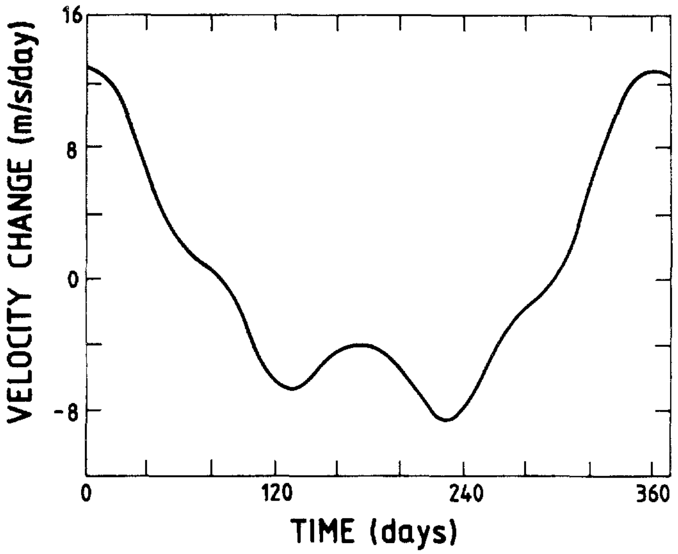

Fig. 13. SOHO velocity change in a typical halo orbit around the L1 Lagrangian point.

be restarted and will inject SOHO into a transfer orbit to the Sun-Earth L1 Lagrangian point, about 1.5x10^6km sunward from the Earth. After a transfer phase of ca. 4 months the spacecraft will be injected into a halo orbit (Fig. 12) around L1, where it will be continuously pointing to Sun center with an accuracy of 10". Pointing stability will be better than 1" over 15 min intervals. The halo orbit will have a period of 180 days. The semi-diameters of the halo orbit have typical dimensions of approximately 200,000 km in the ecliptic in the Earth-Sun direction, 650,000 km in the ecliptic perpendicular to the Earth-Sun direction, and 200,000 km out of the ecliptic. The L1 halo orbit has several particular advantages as compared to low Earth orbits: a) it provides a smooth Sun-spacecraft velocity change throughout the orbit, required to obtain accurate helioseismology measurements (Fig. 13), b) it is permanently outside of the magnetosphere, appropriate for the "in situ" sampling of the solar wind and particles, and c) it allows uninterrupted observation of the Sun, appropriate for all the investigations.

4.3. EXPERIMENT OPERATIONS FACILITY (EOF)

The diagram in Fig. 14 shows the basic data connections that will be present for SOHO science operations.

The SOHO Experiment Operations Facility (EOF), located at NASA's Goddard Space Flight Center (GSFC), will serve as the focal point for mission science planning and instrument operations. At the EOF, experiment PI representatives will receive real-time and playback flight telemetry data, process these data to determine instrument commands, and send commands

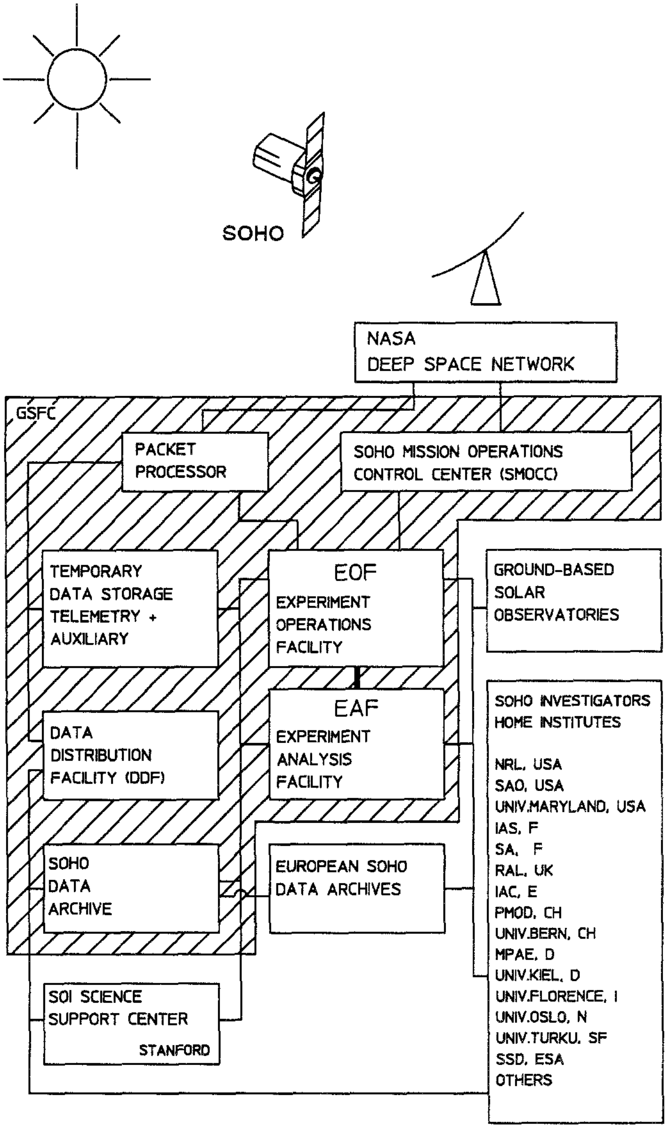

Fig. 14. SOHO ground system: basic data connections for science operations.

to their instruments, both in near real-time and on a delayed execution basis. They will be able to perform data reduction and analysis, and have capabilities for data storage. To accomplish these ends, the appropriate experiment teams will use workstations that will be connected to an EOF Local Area Network (LAN). There will be connections from the EOF to external facilities to allow transfer of incoming data from GSFC support elements, remote investigator institutes, other solar observatories, and ESA facilities. There will also be connections for the EOF to interact with the SOHO Mission

Operations Control Center (SMOCC) and other required elements at GSFC for scheduling and commanding the SOHO flight experiments. The EOF consists of approximately 3200 square feet of space in Building 3 of GSFC. This space is contiguous to the SOHO Mission Operations Control Center where the Flight Operations Team (FOT) works.

While the EOF is the focal point for instrument operations, the Experiment Analysis Facility (EAF) is the focal point for science and data analysis. It is located in Building 26 of GSFC and provides workspace for resident PI team members as well as for visiting scientists. The EAF includes a conference area, and the SOHO Archive and the Solar Data Analysis Center (SDAC) will also be set up there. A high capacity data communications link between the EOF and the EAF is being implemented, but real-time experiment operations will not take place from the EAF.

4.4. TELEMETRY

The Deep Space Network (DSN) will receive S/C telemetry during three short (1.6 hrs) and one long (8 hrs) station pass per day (Fig. 15). Science data acquisition during non-station pass periods will be stored on-board and played back during the short station passes. The MDI high data rate stream (160 kbits/s) will be transmitted only during the long station pass. For 2 consecutive months per year continuous data transmission, including MDI high-rate data, will be supported by DSN. Whenever there is data transmission, the basic science data (40 kbits/s) will be available in near real-time at the EOF. From the EOF the SOHO investigators will control the operation of the instruments via near-real time commands. These will be verified and sent immediately to the spacecraft. It is a baseline requirement that the SOHO data will be acquired with a time continuity better than 96%.

The connections to the spacecraft instruments will be such that commands can be sent to the instruments for immediate execution. One will be able to decide on pointing targets, what sequence of operations is desired and send those commands to the instruments.

The data, when received on the ground, will be immediately forwarded to the EOF where scientists will be able to view the current data from their own experiment, other SOHO experiments, and certain ground-based observatories. It is anticipated that the ability to receive and view real time data will greatly facilitate our ability to optimize the scientific return from the experiments. The electronic connections will also greatly improve our ability to do joint research with ground-based observatories.

4.5. OPERATIONS

The Science Working Team (SWT) will set the overall science policy and direction for mission operations, set priorities, resolve conflicts and disputes,

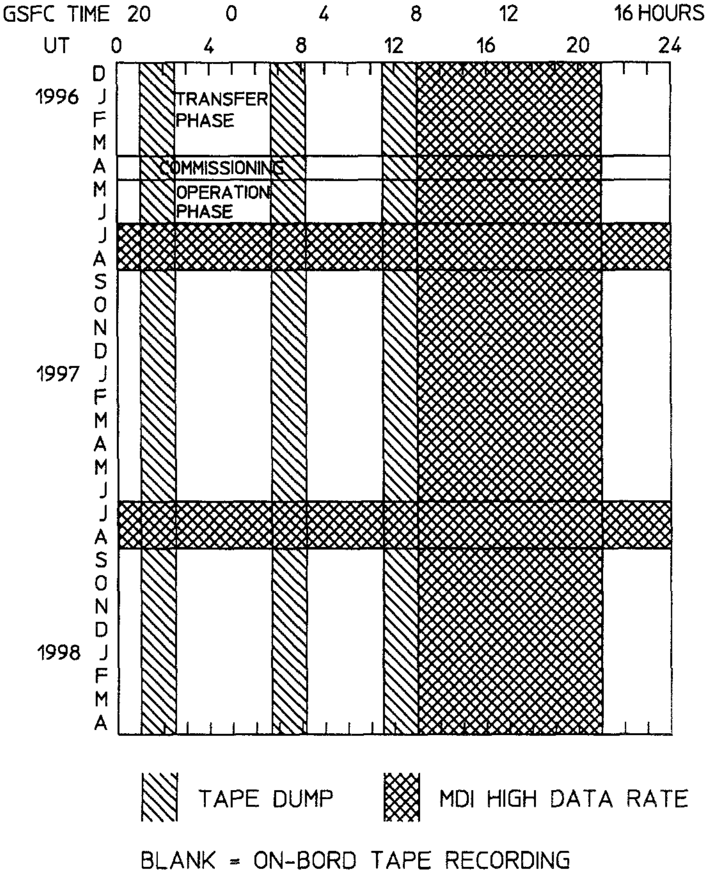

Fig. 15. SOHO telemetry and real time operation plan

and consider Guest Investigator observing proposals. During SOHO science operations, the SWT will meet every three months to consider the quarter year starting in one month's time and form a general scientific plan. If any non-standard DSN contacts are required, the requests must be formulated at this quarterly meeting. The three-month plan will then be refined during the monthly planning meetings of the Science Operations Team (SOT), composed of those PIs or their team members at the EOF, which will allocate observing sessions to specific programs. At weekly meetings of the SOT, coordinated timelines will be produced for the instruments, together with detailed plans for spacecraft operations. Daily meetings of the SOT will optimize fine pointing targets in response to solar conditions and adjust operations if DSN anomalies occur.

During agreed periods one or several experiment teams and, if agreed, teams from other spacecraft or at ground-based observatories will run, in collaboration, observation campaigns to address specific topics. The periods of two-months continuous near real-time observation may be the most convenient for campaigns that require continuous observation during more than 8 hours, or that require coordination with ground observations only feasible from particular observatories around the world.

Since the acceleration and heating processes in the solar atmosphere most likely relate to discrete activities within small-scale magnetic structures of the atmosphere, which may be seen as microflares, high velocity events, discrete ejecta etc., our understanding of these processes may be critically dependent on our ability to detect and observe highly transient events in the solar atmosphere. In order to be able to respond to short time-scale transient activity, such as the build-up of a bright point, the onset of a flare or eruption, an inter-instrument flag system has been implemented in the OBDH system, MDI and the coronal instruments SUMER, CDS, EIT, LASCO and UVCS. The flag concept works as follows: one of the instruments, designated the master, recognizes a solar event and records its location; it sends the event type and location to the spacecraft computer; the spacecraft computer sends the event type and location to all the receiver instruments; the master and receiver instruments change their observing programs using pre-stored commands to respond to the event. The master and receivers are assigned from the ground. In order to limit the complexity and potential clashes, at any one time only one pre-defined instrument may flag one predefined event in response to a specified observation, defined through planning at the EOF, and this will only have one potential reaction by the receiving instruments.

4.6. DATA

NASA will immediately forward real-time science data to the EOF over the LAN to the PI workstations. Playback data will be sent to the EOF in the same manner with transmission delays from DSN (less than 3 hours) and processing delays to turn the data around (approximately 2 hours).

4.6.1. Summary Data

The summary data will be used both to plan observations at the EOF and to provide an overview of the observations that have been obtained from SOHO. The summary data will consist of three classes of data. The first two classes will consist of a representative image from each of the imaging experiments, and key parameters from the non-imaging experiments. The third class will be a list of observing programs and start/stop times of data sequences. Together these data will provide a synopsis of solar conditions and the science programs that have been carried out by the observatory. The summary data will greatly enhance the capability for joint research with scientists throughout the community. These data will be available to the public electronically on a daily basis.

4.6.2. SOHO Data System

A SOHO Data System is being built to provide access, visualization, and analysis tools for solar data available in electronic form. This data system will have the following features:

- Provides network access to all solar data archive centres
- Holds on-line data for SOHO planning (updated through daily ftp)
- Reads several data formats (FITS, CDF, Yohkoh, and others)
- Query: graphical interfaces (both IDL widgets and Mosaic forms) for data searches with all common parameters (time, position, wavelength, etc.)
- Visualisation: tools for display, overlays, movies, grids, zoom, forward rotation, limb determination, image enhancement, etc.
- On-line library of SOHO campaigns (descriptions and data)
- User-library, on-line with uniform documentation

All SOHO data will be available in FITS format.

5. SOHO and the Community

5.1. DATA ACCESS

The intent of the SOHO data access policy is to provide data to as wide a community as possible and as soon as possible. From the beginning of the operational mission, the scientific community is welcomed and encouraged to participate in the analysis of the SOHO data in collaboration with the PI teams. The goal is to make fully calibrated data available for public use through ESA and NASA archives one year after reception by the PIs.

5.2. GUEST INVESTIGATORS

A SOHO Guest Investigator Programme has been envisaged from the onset of the STSP program. To ensure the maximum exploitation of the SOHO data in order to extract the best scientific output from the mission, and to attract special capabilities and expertise from outside the SOHO teams, selected Guest Investigators (GIs) will have the opportunity to acquire and/or analyze specific data sets, or, for some experiments, to become part of the PI teams.

Each approved SOHO GI will be attached to a SOHO experiment team, with whom to interact during the Guest Investigation. Two types of GI participation are foreseen, depending upon the nature of the SOHO experiment involved. For the coronal experiments (CDS, EIT, LASCO, SUMER, SWAN, and UVCS), GI participation will be of a traditional nature (like for SMM or Yohkoh): GIs will have priority rights for the analysis of certain datasets (either newly acquired, or from the archive), or priority rights for a certain type of analysis of datasets otherwise available to the whole SOHO experiment team. An example of the first is the study of a specific event, for example a CME, and an example of the latter is a statistical study, say a study of the magnitude of redshifts as a function of position on the solar disc.

The data from the helioseismology (GOLF, VIRGO, MDI), and from the particle experiments (CELIAS, COSTEP, ERNE) are of a totally different nature; they do not lend themselves to being split up into "events", or time intervals, each of which could be studied by different investigators. Hence the mode of participation of GIs attached to these instruments will be different. It is envisaged that, possibly for a limited period of time, approved GIs will be included as members of the PI team with the same rights and obligations as regular Co-Is.

Currently, it is planned to have the first Announcement of Opportunity (AO) issued one month after launch and the first round of GI investigations beginning about 1 year after launch. Further, it is planned that the AO for the SOHO GI programme will be renewed every year, until several years after the end of the mission, with a similar review cycle each time. The duration of a GI investigation is in principle one year, but the experiment teams are free to extend this time.

5.3. COORDINATED RESEARCH

The SOHO payload has been conceived as an integrated package of complementary instruments, such that their measurements would produce a complementary set of data for the study of the phenomena in the solar atmosphere, in the solar wind, and in the solar interior. Therefore, to achieve the scientific aims of the mission, it is essential to operate the instruments in a coordinated programme and analyse the data in a correlative and cooperative spirit. Further, to reach an adequate and sound understanding of the dynamics of the solar corona and its mass and energy balance, it is essential to know the magnetic field topology and the velocity field (both flows and waves) in the photosphere and chromosphere with the highest spatial and temporal resolution achievable. At present, these data can only be supplied by ground-based observatories. Therefore, to have a successful mission, it is vital to have a close cooperation and coordination between SOHO and ground-based solar observatories (both optical and radio). Finally, it should be emphasized that SOHO is part of STSP and that there is a large fraction of space science and plasma physics that may benefit from a coordinated approach between "in situ" observations such as obtained by Cluster, Ulysses, Geotail, Interball, Wind, or Polar and the remote and "in situ" measurements taken by SOHO.

6. Summary

SOHO is a large complex satellite designed to study the Sun from its deep interior through the solar wind in the heliosphere. The helioseismology experiments will provide data that will allow us to deduce the solar structure from the surface through the deep core. The two extremes of this data, the deep core and the outermost layers of the convection zone, are unobtainable except from space.

The EUV and UV imagers and spectrographs will give us our first comprehensive view of the outer solar atmosphere and corona. For the first time we will be able to observe the temperature, density and velocity evolution of the solar atmosphere from the photosphere out through the far corona ($>6R_\odot$). Not only will these observations have high spatial and temporal resolution, but they will be uninterrupted by a day/night cycle. The observations will be continuous.

The observations described above will give us the data to understand the mass, energy, and momentum flow of the solar wind through the solar atmosphere. These remote observations will be complemented with in-situ observations of the composition and energy of the solar wind particles. Together these observations will provide reliable boundary conditions and observables for computer models that will help us better understand the physics of the solar atmosphere.

Appendix

A. List of Acronyms

ACU	Attitude Control Unit
ANTS	Antenna Subsystem
AIT	Atomic International Time
AIV	Assembly-Integration-Validation
AO	Announcement of Opportunity
AOCS	Attitude and Orbit Control System
ATM	Apollo Telescope Mount
CDMU	Central Data Management Unit
CDS	Coronal Diagnostic Spectrometer
CELIAS	Charge, ELement and Isotope Analysis
CEPAC	COSTEP - ERNE Particle Analyser Collaboration
COBS	Central On Board Software
COSTEP	COmprehensive SupraThermal and Energetic Particle analyser
DHSS	Data Handling Subsystem
DSN	Deep Space Network
EAF	Experiment Analysis Facility
ECS	EOF Core System
EGSE	Electrical Ground Support Equipment
EIT	Extreme-ultraviolet Imaging Telescope
EM	Engineering Model
EOF	Experiment Operations Facility
EPHIN	Electron Proton Helium INstrument
EPSS	Electrical Power Subsystem

ERNE	Energetic and Relativistic Nuclei and Electron experiment
ESA	European Space Agency
ESR	Emergency Sun Reacquisition
FM	Flight Model
FOT	Flight Operations Team
FPSS	Fine Pointing Sun Sensor
FTP	File Transfer Protocol
GI	Guest Investigator
GOLF	Global Oscillations at Low Frequency
GONG	Global Oscillation Network Group
GSFC	Goddard Space Flight Center
HED	High Energy Detector
HPA	High Power Amplifier
HGA	High Gain Antenna
IRU	Inertial Reference Unit
ISTP	International Solar-Terrestrial Physics Program
LAN	Local Area Network
LASCO	Large Angle Spectroscopic COronagraph
LED	Low Energy Detector
LGA	Low Gain Antenna
LION	Low Energy Ion and Electron Instrument
LOI	Luminosity Oscillations Imager
MDI	Michelson Doppler Imager
MLI	Mulit-Layer Insulation
NASA	National Aeronautics and Space Administration
NRT	Near Real-Time
NSI	NASA Science Internet
OBDH	On Board Data Handling
OBT	On Board Time
OSR	Optical Surface Reflector
PACOR	Packet Processor
PDU	Power Distribution Unis
PLM	Payload Module
PI	Principal Investigator
POCC	Payload Operations Control Center
PROS	Propulsion Subsystem
PTCS	Payload module Thermal Control Subsystem
R/T	Real-Time
RAAD	Roll Attitude Anomaly Detection
RF	Radio Frequency
RTU	Remote Terminal Unit
S/C	SpaceCraft
SAS	Solar Acquisition Sensor
SDAC	Solar Data Analysis Center
SEM	Solar Extreme-ultraviolet Monitor
SGSS	Solar Generator Subsystem
SHSS	Structure and Harness Subsystem
SM	Structural Model
SMM	Solar Maximum Mission
SMOCC	SOHO Mission Operations Control Center
SOC	Science Operations Coordinator
SOHO	SOlar and Heliospheric Observatory
SOI	Solar Oscillations Investigation
SOL	Science Operations Leader
SOP	Science Operations Plan

SOT	Science Operations Team
SSU	Star Sensor Unit
STCS	Service module Thermal Control Subsystem
STSP	Solar-Terrestrial Science Programme
SUMER	Solar Ultraviolet Measurements of Emitted Radiation
SVM	Service Module
SWAN	Solar Wind ANisotropies
SWT	Science Working Team
TAI	Temps Atomique International
TB/TV	Thermal Balance/Thermal Vacuum
TC	TeleCommands
TCS	Thermal Control Subsystem
USO	Ultra Stable Oscillator
UTC	Universal Time Code
UVCS	UltraViolet Coronagraph Spectrometer
VIRGO	Variability of solar IRradiance and Gravity Oscillations

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