# SOHO, YOHKOH, ULYSSES AND TRACE: THE FOUR SOLAR MISSIONS IN PERSPECTIVE, AND AVAILABLE RESOURCES

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**Abstract.** Four solar observing spacecraft, now in operation, have obtained and continue to obtain data during the late phase of solar cycle 22 and hopefully most of cycle 23. The data are available for scientific analysis, practically in an unrestricted manner. A large pool of software suited for the processing and to help programming any data analysis is freely available. An almost random list of results that are being obtained with this data is presented as an example of what can be done by analysing the data from these spacecraft, either alone or combining results among them, with ground observatories, or with other spacecraft, such as those that measure particles and fields in interplanetary space or in geospace, to study solar physics or solar-terrestrial relations.

## 1. Introduction

The minimum of activity of solar cycle 22 and the solar cycle 23 offer a unique opportunity to study the Sun in many of its aspects simultaneously. The presence, besides the traditional ground-based observatories and several interplanetary plasma and particle investigating satellites, of four spacecraft specifically devoted to coordinated studies of the Sun has produced a large revival of solar science, and a plethora of data for further research of solar physics, most of it available in the public domain. Ulysses, Yohkoh, the Solar and Heliospheric Observatory (SOHO) and the Transition Region and Chromosphere Explorer (TRACE) are providing, thanks to the long duration and the complementarity of their observations, a new insight into many solar features.

Ulysses, launched in 1990, is producing the only observation so far of the solar wind structure in three dimensions, by sampling the solar wind fields and particles at near-all solar wind latitudes. It is now in its second rotation around the sun.

Yohkoh ('Sunbeam' in English) since 1991 studies the very hot solar atmosphere by producing solar images in X-rays and $\gamma$-ray wavelength bands of the electromagnetic spectrum. The acceleration sources of energetic particles in the active corona have been located by many observations of active coronal loops. All sizes of flares have been studied and an impressive statistical survey has been possible. Almost a complete solar cycle has already been observed and imaged by Yohkoh.

SOHO since 1996 carries on the most comprehensive space investigation of the Sun by a coordinated set of instruments that study the solar interior structure and

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dynamics by helioseismology (solar oscillations), the solar irradiance, the physical phenomena in the solar atmosphere that heat the corona and give rise to the solar wind (extreme UV images and spectra), the composition of the hot solar atmosphere and of the solar wind (mass and charge spectroscopy), the extension of the solar wind to form the heliosphere (H Lyman-$\alpha$ mapping of the sky).

TRACE since 1998 complements the SOHO observations of the solar EUV atmosphere by producing very high resolution images, at high cadence, at selected wavelengths.

SOHO, with the complementary TRACE, because of its comprehensive instrument array (photosphere, chromosphere, corona and solar wind observations) has produced a focusing effect in solar space research, and is particularly well suited for coordinated studies, among its own instruments, but also with the other spacecraft and with ground observatories.

A particularly important feature of this time is that now there is a general consensus among the scientist that provide space instrumentation and the space science administrations (particularly ESA and NASA) in that the best way to obtain maximum benefit of the experimental observations is to share the observations and measurements with the wide scientific community.

The data of many spacecraft are kept available in national or international data centers, and are generally open to access by any scientist that requests them. This is particularly true of the four spacecraft considered here, with the advantage that scientific and engineering teams that have designed them are still operating them and can help in the interpretation of the measurements. Also, their observations are coordinated among them and with earth-based observatories making the solar space data that has been obtained in the last several years, and being obtained now, the most challenging for solar investigations.

This article intends to give an indication of what observational material is available, information on the instruments that produce it, and some examples of the results that so far have been obtained from their analysis.

## 2. Space Solar Physics during Solar Cycles 22 and 23 – Yohkoh, Ulysses, SOHO, TRACE and Other Complementary Missions Observations and Achievements

Figure 1 shows a graphical display of the time span of the operation of the four mentioned mission. Ulysses, launched in 1990, is now in its second rotations about the Sun and over its high latitude regions. Yohkoh was launched on August 1991, today it continues to be operational and it is expected not to re-enter into the Earth atmosphere before late 2002. SOHO, launched in December 1995 and fully operational since early 1996, and TRACE, launched in April 1998, are both in operation. Although we will not describe them in this paper, there are a few other space missions, now operating, that produce essential complementary measure-

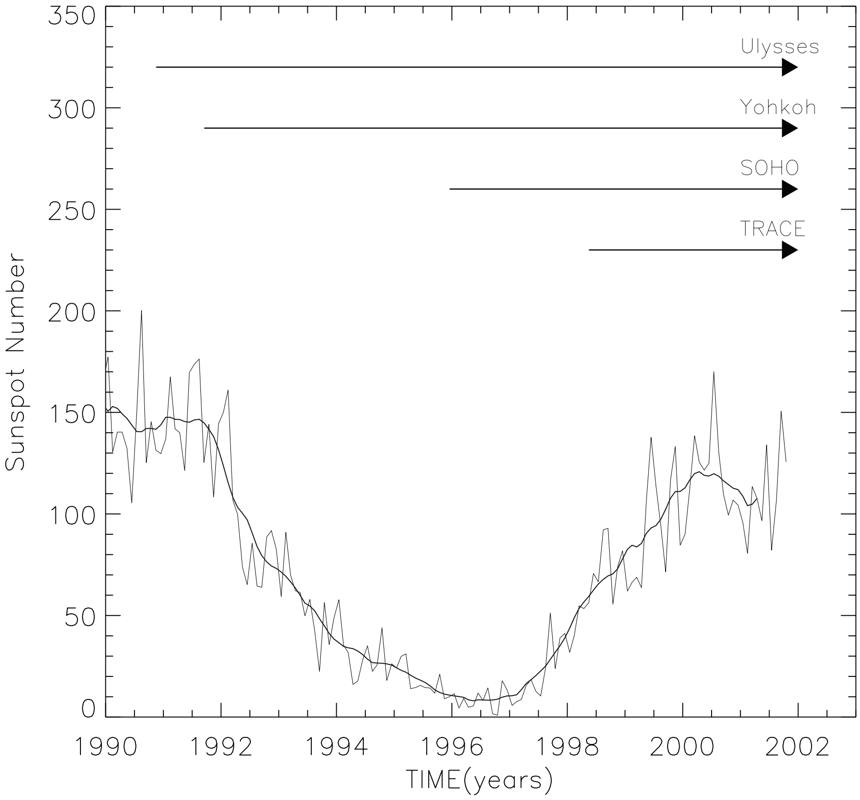

*Figure 1.* The life span of Ulysses, Yohkoh, SOHO and TRACE relative to the solar cycle represented by the monthly value of the sunspot number (original, thin line, and smoothed, thick line), from International Sunspot Number at http://www.oma.be/KSB-ORB/SIDC.

ments to this missions, notably: NASA's WIND and ACE, measuring particles and fields in the solar wind, and CLUSTER, the four spacecraft fleet that produces vector measurements of basic plasma parameters, either in the solar wind or in the magnetosphere.

### 2.1. ULYSSES

Ulysses has provided an excellent overview of the heliosphere during the solar minimum, because it has toured the sun, passing above the poles in its 5 year orbit, in coincidence with the declining phase of solar cycle 22 (see Balogh and Forsyth, 1998 for a short review and references; and Balogh, Marsden and Smith 2001, for a comprehensive review). The Instruments aboard Ulysses perform a comprehensive set of field and particles measurements (Table I).

Examples of the results obtained with Ulysses are:

TABLE I

Ulysses payload

| Instrument | Measurement range |
|---|---|
| Magnetometer (VHM/FGM) | magnetic field 0.01–44000 nT |
| Solar Wind Plasma Experiment (SWOOPS) | ions: 026–35 keV, electrons 0.8–860 eV |
| Solar Wind Ion Composition Instrument (SWICS) | elemental and ionic charge composition |
| Unified Radio and Plasma Wave Instrument (URAP) | plasma waves 0–60 kHz, radio 1–940 kHz, magnetic 10–500 Hz |
| Energetic Particle Instrument (EPAC) | ion composition: 80 keV–15 MeV/n |
| Interstellar Neutral-Gas Experiment (GAS) | neutral He |
| Low-Energy Ion and Electron Experiment (HISCALE) | ions: 50 keV–5 MeV, electrons: 30–300 keV |
| Cosmic Ray and Solar Particle Instrument (COSPIN) | ions: 0.3–600 MeV/n, electrons: 4–2000 MeV |
| Solar X-ray and Cosmic Gamma-Ray Burst Instrument (GRB) | 15–150 keV |
| Dust Experiment (DUST) | dust particles: $10^{-16}$–$10^{-7}$ g |
| Coronal-Sounding Experiment (SCE) | density, velocity and turbulence spectra |
| Gravitational Wave Experiment (GWE) | Doppler shift in spacecraft radio signal |

- Ulysses has confirmed that high solar wind velocities from the polar coronal holes are relatively uniform (between 750 and 800 km/s) with a small poleward gradient. The fast solar wind has a near uniform density of about 3 particles/cm$^3$ when scaled to 1 AU, using a 1/r$^2$ scaling law (e.g. Phillips et al., 1995).
- The polar solar wind appears significantly over-expanded when compared to the areas occupied by the polar coronal holes (Phillips et al., 1995).
- The characteristics fast and slow solar wind streams are clearly differentiated, as determined by ion composition and freezing in temperature measurements 1.2 MK for the fast solar wind and ($>$ 1.5 MK for the slow solar wind) the slow solar wind temperature could not be determined due to its level of fluctuation (Geiss et al., 1995).
- The radial component of the magnetic field frozen in the solar wind is independent of latitude, a significant constraint for solar wind models (Smith and Balogh, 1995; Forsyth et al., 1996a).
- The high speed wind streams present very high level of transverse fluctuations, mostly Alfvénic (Forsyth et al., 1996b).

TABLE II
Yohkoh instruments

| Instrument | Energy range | Measurement |
|---|---|---|
| Soft X-ray Telescope (SXT) | 1–2 keV | images in various wave-bands (selected by filters) |
| Hard X-ray Telescope (HXT) | 10–100 keV | Fourier-synthesis imaging in 4 energy bands |
| Bragg Crystal Spectrometer (BCS) | Fe XXVI, Fe XXV, Ca XIX and S XV line complexes | Spectral information |
| Wide Band Spectrometers (WBS) | soft X-rays, hard X-rays and $\gamma$-ray detectors | Spectral information |

- The measured latitude gradient of cosmic rays is significantly smaller than predicted by the established cosmic ray modulation models (Heber et al., 1996).

The Yohkoh observations during most of the first Ulysses orbit and later the observations by SOHO are an excellent complement to the Ulysses observations. The determination of some of the wind parameters as it leaves the corona, by SOHO, are not always consistent with the inferred parameters from the Ulysses measurements, indicating the need to improve the models.

A comprehensive review of the Ulysses results during solar cycle 22 can be found Balogh, Marsden and Smith (2001).

## 2.2. YOHKOH

Yohkoh is a satellite, in a low earth orbit, dedicated to high-energy observations of the Sun, specifically of flares and other coronal disturbances. The Yohkoh mission was launched, on August 30, 1991, from the Kagoshima Space Centre in southern Japan. The spacecraft carries a payload of four scientific instruments (Table II).

Together these instruments provide the most detailed record yet obtained of high-energy processes in solar flares and in other forms of solar coronal activity.

Detailed information on the Yohkoh instrumentation can be found in Tsuneta et al. (1991).

In its near full solar cycle observation of the hot solar corona Yohkoh has produced a major advance in the understanding of many of the energetic phenomena in the solar atmosphere (Culhane, 1998).

Some results are:

- Yohkoh's STX observations led to the discovery of the coronal X-ray jets and they have been thoroughly studied (i.e. Shibata et al., 1996). The jets are collimated plasma flows at temperatures of 2–20 × $10^6$ K. Typical sizes are $\sim 10^4$–$4 \times 10^5$ km, and translational velocities range from 400 to 1000 km/s.

Kinetic energies are in the range $10^{26}$–$10^{28}$ erg and masses $10^{9}$–$10^{11}$ kg. Lifetimes range from minutes to hours. Jets are often associated with flares in X-ray Bright Points, emerging flux regions or active regions. The jet phenomenon appears to be well explained by reconnection between emerging magnetic flux and pre-existing magnetic fields. Modeling the reconnection by two-dimensional MHD simulations (Yokoyama and Shibata, 1995) it is possible to explain many of the observed jet morphologies.

- Yohkoh has also discovered the phenomenon of Transient Active Region Brightenings (Shimizu et al., 1992). X-ray images of active regions frequently show small brightenings usually involving two or more loops. Energy release occurs when two loops either almost parallel to each other or in contact near one of the foot-points, simultaneously brighten. Temperatures range up to $10^{7}$ K while the thermal energy content can be as high as $10^{29}$ ergs. The frequency distribution with energy of the transient brightenings is a power law with index 1.4–1.7 over the energy range $10^{27}$–$10^{29}$ (Shimizu, 1995). The high energy end overlaps with the distribution of small flares which has also a similar slope. This is indicative of a common origin for both flares and transient brightenings.
- The observations of Yohkoh have led to important advances in the understanding of solar flares. Many examples of flares have been found which conform to a reconnection model with X-point symmetry and probably spontaneous reconnection occurring high in the corona (Tsuneta, 1996).
- Yohkoh observations have established soft X-ray coronal dimming as a signature of Coronal Mass Ejection (CME) occurrence and promise to provide in the future a method for recognizing those coronal magnetic field configurations that are likely resulting in launching CME's. Temperature measurements as function of height in large scale diffuse coronal structures have indicated a leveling off of temperature to just over 2 MK at 1.4 $R_{\mathrm{sun}}$, a value similar to that found by Ulysses observations of the solar slow solar wind (Foley et al., 1996). Investigation of the heating mechanism in the closed loops that also exist in the diffuse structures suggest that energy is deposited uniformly along the loops rather than at the foot-points (Priest et al., 1998).

### 2.3. SOHO

Since its launch on 2 December 1995, the Solar and Heliospheric Observatory (SOHO) has provided an unparalleled breadth and depth of information about the Sun, from its interior through the hot and dynamic atmosphere. SOHO is located around the L1 Sun-Earth Lagrangian point, and operates, observing the sun, continuously.

The instrumentation aboard SOHO (Table III) is oriented toward studying:

TABLE III

SOHO instruments and the measurements that they perform

| Instrument | Measurement |
|---|---|
| CDS (Coronal Diagnostics Spectrometer) | EUV light 15–80 nm, spectral res. 1000–10000, pixel angle 3 arc sec |
| CELIAS (Charge, Element, and Isotope Analysis System) | Ions 0.1–1000 keV. Solar wind '*in situ*' composition |
| COSTEP (Comprehensive Suprathermal and Energetic Particle Analyzer) | Ions (p, He) 0.04–53 MeV/n,<br>electrons 0.04–5 MeV |
| EIT (Extreme ultraviolet Imaging Telescope) | Full disk images, HeII, Fe IX, Fe XII, Fe XV lines |
| ERNE (Energetic and Relativistic Nuclei and Electron experiment) | Isotopic composition, ions (p-Ni)<br>1.4–540 MeV/n |
| GOLF (Global Oscillations at Low Frequencies) | Global sun velocity oscillations |
| LASCO (Large Angle and Spectrometric Coronagraph) | White light images 1.1–30 $R_{\mathrm{sun}}$ |
| MDI/SOI (Michelson Doppler Imager/Solar Oscillations Investigation) | Velocity oscillations (harmonic degree up to 4500), intensity, longitudinal mag. field – images 1024 $\times$ 1024, pixels 2 and 0.7 arc sec |
| SUMER (Solar Ultraviolet Measurements of Emitted Radiation) | EUV light 50–160 nm, spectral res. 20000–40000, pixel ang. 1.3 arc sec |
| SWAN (Solar Wind Anisotropies) | H Ly-$\alpha$ light, $4\pi$ scanning |
| UVCS (Ultraviolet Coronagraph Spectrometer) | EUV spectra (lines Ly-$\alpha$, O VI, etc) between 1–10 $R_{\mathrm{sun}}$ |
| VIRGO (Variability of Solar Irradiance and Gravity Oscillations) | Irradiance oscillations low degree ($l \leqslant 7$), total solar irradiance, irradiance at 402, 500, 862 nm |

* *The Solar Interior* – GOLF and VIRGO both perform long and uninterrupted series of oscillations measurements of the full solar disk, respectively in velocity and in the irradiance domain. In this way, information is obtained about the solar nucleus. SOI/MDI measure oscillations on the surface of the Sun with high angular resolution. This permits us to obtain precise information about the Sun's convection zone – the outer layer of the solar interior.

* *The Solar Atmosphere* – SUMER, CDS, EIT, UVCS, and LASCO constitute a combination of telescopes, spectrometers and coronagraphs that observe the hot atmosphere of the Sun, the corona, extending far above the visible surface. SUMER, CDS and EIT observe the inner corona. UVCS and LASCO observe both inner and outer corona. They obtain measurements of the temperature, density, composition and velocity in the corona, and follow the evolution of the structures with high resolution.

* *The Solar Wind* – CELIAS, COSTEP and ERNE analyze *in situ* the charge state and isotopic composition of ions in the solar wind, and the charge and isotopic composition of energetic particles generated by the Sun. SWAN makes maps of the hydrogen density in the heliosphere from ten solar diameters outwards. It uses telescopes sensitive to a particular wavelength of hydrogen, allowing the large-scale structure of the solar wind streams to be measured.

A comprehensive description of the SOHO mission and instruments is found in Fleck et al. (1995)

The following are some examples of the research that one does with SOHO data:

*On Global Structure and Dynamics of the Solar Interior*

- The nearly uninterrupted data from the Michelson Doppler Imager (MDI) yield oscillation power spectra with an unprecedented signal-to-noise ratio that allow the determination of the frequency splitting of the global resonant acoustic modes of the Sun with exceptional accuracy. The inversions of these data have confirmed that the decrease of the angular velocity $\omega$ with latitude seen at the surface extends with little radial variation through much of the convection zone, at the base of which is an adjustment layer, called the 'tachocline', leading to nearly uniform rotation deeper in the radiative interior (e.g. Kosovichev et al., 1997; Schou et al., 1998).
- One of the consequences of the precision that helioseismology has reached with SOHO is that it provides a clear indication of the fact that the so called 'solar neutrino problem' is not a problem of the general solar (or stellar) model, but of the physics of neutrinos. A recent model of the solar interior (Turck-Chièze et al., 2001) is able to describe the sound speed profile throughout the sun's interior, but still predicts 2 to 3 times the electron neutrino fluxes observed by various detector methods. Early results of the Sudbury Neutrino Observatory, recently published, tend to prove that, effectively it appears that solar neutrinos change properties in flight from the Sun to the Earth.
- By applying a tomographic technique to high resolution MDI data, Duvall, Kosovichev and co-workers were able to generate the first maps of horizontal and vertical flow velocities as well as sound speed variations in the convection zone just below the visible surface. They found that in the upper layers, 2–3 Mm deep, the horizontal flow is organized in supergranular cells, with outflows from the cell centers. The characteristic size of these cells is 20–30 Mm and the cell boundaries were found to coincide with the areas of enhanced magnetic field. The supergranulation outflow pattern disappears at a depth of approximately 5 Mm, i.e. only about a small fraction of the characteristic horizontal size of the cells (20–30 Mm) (e.g. Kosovichev et al., 2000).

*On Corona and solar wind*

- Several types of transient events have been detected in the quiet Sun. High-velocity events in the solar transition region, also called ‘explosive events’, were first discovered in the early eighties based on UV observations with HRTS. They have large velocity dispersions, $\sim \pm 100$ km/s, i.e. velocities are directed both towards and away from the observer causing a strong line broadening.
- Explosive events have been studied extensively by a number of authors using SUMER data and some results support the magnetic reconnection as the origin of these features. Innes et al. (1997) reported explosive events that show spatially separated blue shifted and red shifted jets and some that show transverse motion of blue and red-shifts, as predicted if reconnection was the source. Comparison with MDI magnetograms and magnetograms obtained at Big Bear Solar Observatory provided evidence that transition region explosive events are a manifestation of magnetic reconnection occurring in the quiet Sun. They are preferentially found in regions with weak and mixed polarity, and the majority of these events occur during ‘cancellation’ of photospheric magnetic flux.
- Harrison et al. (1999) presented a thorough and comprehensive study of EUV flashes, also known as ‘blinkers’, which were identified in quiet Sun network as intensity enhancements of order 10–40% using CDS. They have identified blinker spectral, temporal and spatial characteristics, their distribution, frequency and general properties, across a broad range of temperatures, from 20,000 K to 1,200,000 K. The blinkers are most pronounced in the transition region lines O III, O IV and O V, with modest or no detectable signature at higher and lower temperatures. A typical blinker has a duration of about 1000 s. Comparison to plasma cooling times led to the conclusion that there must be continuous energy input throughout the blinker event. At any one time there are about 3000 blinker events in progress. The authors estimate the thermal energy content of an average blinker at $2 \times 10^{23}$ erg.
- Using the two SOHO spectrometers CDS and SUMER, David et al. (1998) have measured the electron temperature as a function of height above the limb in a polar coronal hole. Temperatures of around 0.8 MK were found close to the limb, rising to a maximum of less than 1 MK at 1.15 $R_{sun}$ then falling to around 0.4 MK at 1.3 $R_{sun}$. In equatorial streamers, on the other hand, the temperature was found to rise constantly with increasing distance, from about 1 MK close to the limb to over 3 MK at 1.3 $R_{sun}$. With these low temperatures, the classical Parker mechanism cannot alone explain the high wind velocities, which must therefore be due to the direct transfer of momentum from MHD waves to the ambient plasma. Notice the discrepancy of this result with the solar wind ‘freezing in’ temperature calculated from the Ulysses observations, quoted above.

- Coronal hole outflow velocity maps obtained with the SUMER instrument in the Ne VIII emission line at 770Å show a clear relationship between coronal hole outflow velocity and the chromospheric network structure, with the largest outflow velocities occurring along network boundaries and at the intersection of network boundaries (Hassler et al., 1999). This can be considered the first direct spectroscopic determination of the source regions of the fast solar wind in coronal holes.
- Time-lapse sequences of LASCO white-light coronagraph images give the impression of a continuous outflow of material in the streamer belt. Density enhancements, or ‘blobs’, form near the cusps of helmet streamers and appear to be carried outward by the ambient solar wind. Sheeley et al. (1997), using data from the LASCO C2 and C3 coronagraphs, have traced a large number of such ‘blobs’ from 2 to over 25 solar radii. Assuming that these ‘blobs’ are carried away by the solar wind like leaves on the river, they have measured the acceleration profile of the slow solar wind, which typically doubles from 150 km/s near 5 $R_{sun}$ to 300 km/s near 25 $R_{sun}$. They found a constant acceleration of about 4 $m/s^2$ through most of the 30 $R_{sun}$ field-of-view. The speed profile is consistent with an isothermal solar wind expansion at a temperature of about 1.1 MK and a sonic point near 5 $R_{sun}$.
- Proton and O VI outflow velocities in coronal holes have been measured by UVCS using the Doppler dimming method. The O VI outflow velocity was found to be significantly higher than the proton velocity, with a very steep increase between 1.5 and 2.5 $R_{sun}$, reaching outflow velocities of 300 km/s at around 2 $R_{sun}$. While the hydrogen outflow velocities are still consistent with some conventional theoretical models for polar wind acceleration, the higher oxygen flow speeds cannot be explained by these models. A possible explanation is offered by the dissipation of high-frequency Alfvèn waves via gyro-resonance with ion cyclotron Larmor motions, which heat and accelerate ions differently depending on their charge and mass (Cranmer, Field and Kohl, 1999; Cranmer, 2000 and references therein).

### 2.4. TRACE

TRACE, the Transition Region and Coronal Explorer, in low Earth sun-synchronous orbit since April 1998, observes the photosphere, transition region and corona nearly simultaneously with a spatial resolution of one second of arc. It provides a unique complement to SOHO studies of the solar atmosphere.

TRACE produces images in a choice of wavelengths, designed to get thermal and dynamic information on the interface between chromosphere and the corona (Table IV).

SOHO has found that the solar atmosphere is at all times full of activity, even during the minimum of the cycle. TRACE, especially designed to observe in high resolution and cadence the solar atmosphere, has obtained unprecedented images

TABLE IV

TRACE Channel Characteristics

| Wavelength (Å) | Ion identification | Bandpass (Å) | Temperature (log K) |
|---|---|---|---|
| 5000 | Continuum | broad | 3.6–3.8 |
| 1700 | Continuum | 200.0 | 3.6–4.0 |
| 1600 | C I, Fe II + continuum | 275.0 | 3.6–4.0 |
| 1550 | C IV + continuum | 20.0 | 4.8–5.4 |
| 1216 | H Ly $\alpha$ | 84.0 | 4.0–4.5 |
| 171 | Fe IX | 6.4 | 5.2–6.3 |
| 195 | Fe XII | 6.5 | 5.7–6.3 |
| 284 | Fe XV | 10.7 | 6.1–6.6 |

and movies of the solar atmosphere: loops of all sizes are seen in continuous movement and evolution. Among findings by TRACE we quote a few, extracted from related publications.

- TRACE finds that the solar corona is comprised of thin loops that are intrinsically dynamic, and that continually evolve. These very thin strings are heated from some minutes to tens of minutes, after which the heating ceases , or changes significantly in magnitude. There are upward moving pulses of hot material that suggest that the low-altitude heating is in fact strongly modulated or is intermittent on time scales of minutes or less. EUV observations show that not only material at coronal temperatures moves upward from as low as a few thousand kilometers above the photosphere, but also cool material, not hotter than about 20,000 K (Schrijver et al., 1999).
- The analysis of the density and temperature structure of many coronal loops, observed by TRACE at EUV wavelengths, have for the first time led to a localization where the energy is dissipated heating the solar corona to 1–2 million degrees. The data included coronal loops that were as small as 4000 km and as large as 240,000 km in height. It was found that the energy deposition in these loops occurs always in the lowest heights of 10,000–20,000 km, regardless of the loop size, based on energy balance calculations. The fact that the loops are heated at their foot-points excludes many mechanism theories for loop heating. It does not exclude such theories as magneto-acoustic waves, shocks or direct up-flows of heated chromospheric plasma (Aschwanden, Nightingale and Alexander, 2000).
- A statistical study of nanoflares observed with TRACE, shows that they are small versions of the large flares, and arrives to the conclusion that the energy that the flaring activity brings to the corona can only be a small part of the energy needed to heat the corona (Aschwanden et al., 2000).

- Aschwanden (2001) reports how the observations with Yohkoh, SOHO and TRACE establish important observational constraints for coronal heating models, such as that coronal loops in active regions have an over-density that can be supplied only by upflows of heated chromospheric plasma. Upflows of chromospheric material have been observed frequently in coronal loops, the coronal heating function has been localized in the lower corona within a range of less than about 10,000 km above the photosphere.

A review of progress in coronal physics obtained with TRACE can be found in Schrijver et al. (1999).

## 3. Data Archives

### 3.1. ULYSSES ARCHIVE

The ESA archive for Ulysses Data provides an on-line facility to browse and download selected measurements made by the scientific instruments flown onboard Ulysses to study the heliosphere in three dimensions.

Data files in the archive are zipped into a single file for each year. The naming convention of the plot and data files employs a five digit number, the first two of which denote the start year, and the remaining three, the start day of year. Direct access to the plots, data files and documentation can be obtained by FTP to the ESA anonymous FTP server helio.estec.esa.nl/ulysses/archive (131.176.17.136). The data in this archive have been provided by the Ulysses experiment teams. When using data from the Ulysses archive for scientific analysis, you are requested to inform the Principal Investigator(s) concerned.

Ulysses data submitted to the ESA archive by the Ulysses investigator teams for the first phase of the Ulysses mission (from launch up to the end of the second polar pass, on September 30, 1995) are now available as a collection of eight CD-ROMs in an ESA Special Publication, ESA SP–1230. The disks contain the following measurements:

Disk 1: magnetic field data from the Vector Helium / Flux Gate Magnetometer (VHM/FGM), solar wind ion and electron data from the Solar Wind Observations Over the Poles of the Sun (SWOOPS) experiment, solar wind ion composition data from the Solar Wind Ion Composition Spectrometer (SWICS), ion and electron data from the Energetic Particle Composition (EPAC) experiment and sky maps from the Interstellar Neutral Gas (GAS) experiment.

Disk 2: ion and electron data from the Heliosphere Instrument for Spectra, Composition and Anisotropy at Low Energies (HI-SCALE) and the Cosmic Ray and Solar Particle Investigation (COSPIN), dust impact data from the Cosmic Dust Experiment (DUST) and radio sounding data from the Coronal Sounding Experiment (SCE).

Disks 3 and 4: radio and plasma wave data from the Unified Radio and Plasma Wave (URAP) investigation.

Disks 5, 6 and 7: solar X-ray and cosmic $\gamma$-ray data from the Gamma Ray Burst (GRB) experiment.

Disk 8: Ulysses data from the Jupiter encounter (collected by PPI/PDS).

The CD-ROMs also contain documentation, data plots of selected parameters and IDL plotting software, trajectory data, a list of publications and a collection of images (photographs and artwork) relating to the different stages of the Ulysses mission.

This ESA Special Publication is available through the ESA Publication Division at a nominal cost.

### 3.2. YOHKOH DATA

All the Yohkoh data is immediately opened to the world science community without any delay except for a short time (3 to 4 months) for reformatting the data.

The data archives are at Institute for Space and Astronautics Science (ISAS), Japan, Mullard Space Science Laboratory (MSSL), UK, and Goddard Space Flight Center (GSFC). USA, and can be accessed by the web at

http://www.darts.isas.ac.jp/solar/index.cgi
http://surfwww.mssl.ucl.ac.uk/surf
http://umbra.nascom.nasa.gov/

Daily SXT full-field images in FITS format, starting with 1993 January 1, can be accessed at
ftp://umbra.nascom.nasa.gov/pub/yohkoh/data/daily_images via anonymous ftp.

Yohkoh STX movies from the daily FITS format images are now available directly via the Web, at
http://www.lmsal.com/YPOP/ProjectionRoom/latest_STX.html

Analysis software is available at the data centers. An up-to-date Yohkoh Analysis Guide (YAG) is available in hypertext form as the User's Guide, 'the Reference Guide, and the Instrument Guide, at the Yohkoh Archive Centre (http://ydac.mssl.ucl.ac.uk/ydac/) at MSSL (UK), mirrored at the other Yohkoh data centers.

#### *Yohkoh Data Files*

The Yohkoh re-formatter produces a file for each instrument for every orbit, with a start time corresponding to the (predicted) first minute of Sun of the orbit (spacecraft dawn); for the SXT, two files corresponding to full and partial frame images are produced. All the files are simple byte streams that are interpreted into IDL structures when the files are read in. Each file is broken into a number of sections, the ones of principal interest are the roadmap, index and data sections. For each instrument mode (image, spectral or other integration), there is an index and a data record; the roadmap is a short summary of all the index records.

From the reformatted instrument files, a number of secondary files are produced. These include the observing logs and other synoptic files, and also a number of files relating to instrument performance and calibration. One secondary file per type per week is produced. There are also a few files produced on a monthly basis, e.g. the SXT Full Frame Images monthly file.

The following institutions hold Yohkoh data, and supporting ground-based observatories data:

- ISAS, Planning and Information Center, Sagamihara, Japan.
- Solar Group at Lockheed-Martin, Palo Alto.
- Solar Group at Montana State University
- Solar Data Analysis Center, at NASA's Goddard Space Flight Center.
- SOHO Synoptic Image Archive, at NASA's Goddard Space Flight Center.

### 3.3. SOHO ARCHIVE

All the SOHO data is, in principle, openly available one year after retrieval. Some instrument teams provide the data earlier than that, but there is some delay in the delivery of data by other instruments. The archive catalogue shows the status of availability of the different instrument's data in its first page.

The SOHO Archive holds the science processed data sets acquired by all twelve SOHO instruments. In general terms, the most basic unit of information that the archive distributes is a data file, which we also call an observation. Observations sometimes are grouped into studies. The definition of a study is somewhat loose: It's a collection of observations (or data files) that were taken by the same instrument. Observations can also be grouped into campaigns. The difference between campaign and studies is that, while studies are defined by an instrument team, observations are coordinated among several instrument teams with the possible participation of other observatories, both ground and space-based. Campaigns are well defined and have an unique number identifying them.

At the SOHO archive home page opens a Database Search window, where data can be searched for: INSTRUMENT/DETECTOR, DATE, WAVELENGTHS, OBSERVATION TYPE, SCIENTIFIC OBJECTIVE, OBSERVER, OBJECT, STUDY, CAMPAIGN

Here is how a data request works:

Once the user supplies an e-mail address, a request is queued in the system. This queue is examined every 15 minutes for requests to be processed. Once a request is found, the system looks for every file the user asked for, and makes a tar or zip file with them. This last one is copied to an area where it can be downloaded, and then the user receives an e-mail notification with the URL where the data can be retrieved. Expect a delay of about 20 minutes between the time of a data request placement and the e-mail notification for actual retrieval.

The SOHO Archive is based at GSFC, USA, and is mirrored into two European sites, the SOHO Archive at Rutherford Appleton Laboratory (RAL), UK, and the

SOHO Archive at the Institute d'Astrophysique Spatiale, Orsay (F). The archives can be accessed via the web at:

http://sohowww.nascom.nasa.gov/
http://trace.solararchive.ral.ac.uk/soho/
http://www.medoc-ias.u-psud.fr/archive/

The SOHO archive contains only the essential data for synoptic activities from the MDI instrument. Because of its size, the bulk of the MDI data is at a separate archive located at the instrument home at Stanford University, and it is readily available through its home page
http://soi.stanford.edu/

### 3.4. TRACE

All TRACE data is equally available to everyone on the World Wide Web.

The TRACE instrument data are blocked into hour-long FITS files. The files contain in-line JPEG compressed images, as down-linked from the spacecraft. The data files are stored under directories that hold a week worth of files each. If data are requested from the TRACE archive on the Web, the Multiple eXtension FITS (.mxf) files that are returned cover a specific time interval, and contain images that are already decompressed. Detailed TRACE analysis need certain ancillary data files, including the dark current files. What observations have been made by TRACE can be determined from the catalog files. The location of the spacecraft, attitude, etc. can be found from the ephemeris files.

The TRACE archive is based at the TRACE Data Center at Lockeed Martin Solar and Astrophysics Labs (LMSAL), and is mirrored at Goddard's Solar Data Center, USA, at RAL's Solar Data Center, UK, and at the Kiepenheuer Institut für Sonnenphysik (KIS), Freiburg, D. Their addresses are

http://vestige.lmsal.com/TRACE/
http://penumbra.nascom.nasa.gov/TRACE/Data/trace_cat.html
http://trace.solararchive.rl.ac.uk/trace/home.html
http://trace.kis.uni-freiburg.de/

A convenient TRACE Analysis Guide (TAG) may be viewed as a Web document on the URL's:

http://www.lmsal.com/$\sim$bentley/guides/tag/
http://surfwww.mssl.ucl.ac.uk/guides/tag/

The TAG is available as a PostScript document.

## 4. Software

In the data archives of all four missions one finds information about the software that is available for the processing and analysis of the data. Ulysses CD-ROMs incorporate the necessary software.

For the analysis of Yohkoh, SOHO and TRACE data the most convenient tools are found in the SolarSoft software package. The SolarSoft system is a set of integrated software libraries, data bases, and system utilities which provide a common programming and data analysis environment for solar physics. The SolarSoftWare (SSW) system is built from Yohkoh, SOHO, SDAC and Astronomy libraries and draws upon contributions from many members of those projects. It is primarily an IDL based system, although some instrument teams integrate executables written in other languages. The whole package is freely available from the LMSAL at http://www.lmsal.com/solarsoft/ where one finds:

* SolarSoft Concepts – Coordinated analysis concepts and tutorials
* SolarSoft Installation (UNIX / PC-FreeBSD, PC-Linux)
* SolarSoft Under Windows
* SolarSoft Upgrades
* SolarSoft Setup – Running SSW IDL

There are links to the LMSAL address at all the web addresses quoted for Yohkoh, SOHO and TRACE archives.

The fact that SolarSoft is based on the IDL language may be a drawback for researchers with tight funds, as IDL is only commercially available. Also at LMSAL is available ANA (ANA stands for ‘A Non Acronym’). ANA is a free, extensive, interactive data and image processing software package and language for 32-bit computers. A description of ANA, together with installation information, can be found on one of the Lockheed-Martin Web sites on URL <http://ana.lmsal.com/>.

## 5. Conclusions

The presently operating solar observatories, SOHO, Yohkoh, TRACE and Ulysses, through their active data archives offer an exceptional opportunity for anybody to conduct solar physics research with first rate data. The amount of data generated by these spacecraft is much larger than what the experiment teams can digest. The advantage of these data respect to data from previous, older, missions, is that the instrument builders and operators are still there operating the instruments, and can be approached to clarify doubts about technical aspects of the measurements. Another major bonus is the existence of an extensive software package collected by the experiment teams, freely and readily available to help analyze the data.

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