The Solar Cycle as Seen from the SOHO/UVCS White Light Channel

THE SOLAR CYCLE AS SEEN FROM THE SOHO/UVCS WHITE LIGHT CHANNEL

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ABSTRACT

The UVCS White Light Channel (WLC) is designed to measure the linearly polarized radiance (pB) of the extended corona, in the wavelength band from 450 nm to 600 nm. The pB is the most direct way to derive coronal electron densities. The WLC coronagraph has performed daily observations of the solar corona at several polar angles from 1.7 to 3 solar radii from April 1996 to April 2004. By using the UVCS synoptic program that provides almost daily measurements of the pB at the same locations in corona, it is possible to plot time evolution of this paramenter throughout the solar cycle. The WLC time evolutions are of particular interest between 1.75 to 2.4 solar radii because of their uniqueness, providing a link between ground based (Mauna Loa) and space borne (SOHO/LASCO C2) coronagraphic observations. The WLC pB data, with the up-to-date radiometric calibration, will be made available by means of a facilitated access provided by the UVCS Data Analysis Software (DAS) Catalog.

Key words: Solar corona; solar cycle, polarized brightness..

1. INTRODUCTION

The White Light Channel WLC of the Ultraviolet Coronagraph Spectrometer (UVCS) of SOHO is a coronagraph polarimeter operating in the wavelength range from 450 to 600 nm (Kohl et al., 1995). WLC measures the polarized brightness (pB) of the corona from 1.5 to 5 $\mathrm{R}_\odot$, with a spatial resolution of 14”×14”, in one single point at each time, which is coregistered with the field of view of the ultraviolet spectrometers of UVCS.
The pB is due to Thomson scattering of the photospheric continuum by free electrons in corona. The electron density in the extended corona can be inferred from different spectroscopic diagnostics (for example, from the collisional component of the UV emission lines), but this often requires the knowledge of other coronal parameters, such as temperatures, velocities and ion abundances. Under the assumption that the polarized component of the coronal continuum is due solely to electron–scattered K–corona and not to the dust–scattered F–corona, which is valid below 3 $\mathrm{R}_\odot$, the pB measurement provides a direct measurement of the electron density integrated along the line of sight, with no dependence on other plasma parameters.
The computation of the local electron density from the line–of–sight electron density requires an electron density model of the coronal structure, unless a spherical symmetry is adopted. In this case the electron density can be derived analytically.

Aim of this work is to provide a description of the WLC set of data that can be used to derive electron densities in the solar corona, and to give a view of the evolution of solar activity through solar cycle 23.

2. WLC MEASUREMENTS

The polarization brightness (pB) is measured by the WLC in a single point relative to the roll angle, PA, and to the heliocentric height, r, of the instrument pointing.

The polarimeter consists of a rotating half wave retarder plate (HWRP) and a fixed linear polarizer. The HWRP is rotated into three positions, which are separated by 30° one from each other. For each angle of the HWRP, α, the photon counting detector measures a countrate:

$$N(\theta) = k \cdot B(\theta) \tag{1}$$

with:

$$B(\theta) = \frac{I + Q\cos 2\theta + U \sin 2\theta}{2} \tag{2}$$

where: (I, Q, U) is the Stokes vector for linearly polarized brightness, normalized to the Sun center brightness; k is the radiometric factor, a constant that includes the efficiencies of the optical components, including detector, and the geometry of the optical system, all weighted by the Sun center specific brightness; and $\theta = 2\alpha$. In Eq. 1 the assumption is made that the normalized Stokes vector is wavelength independent.

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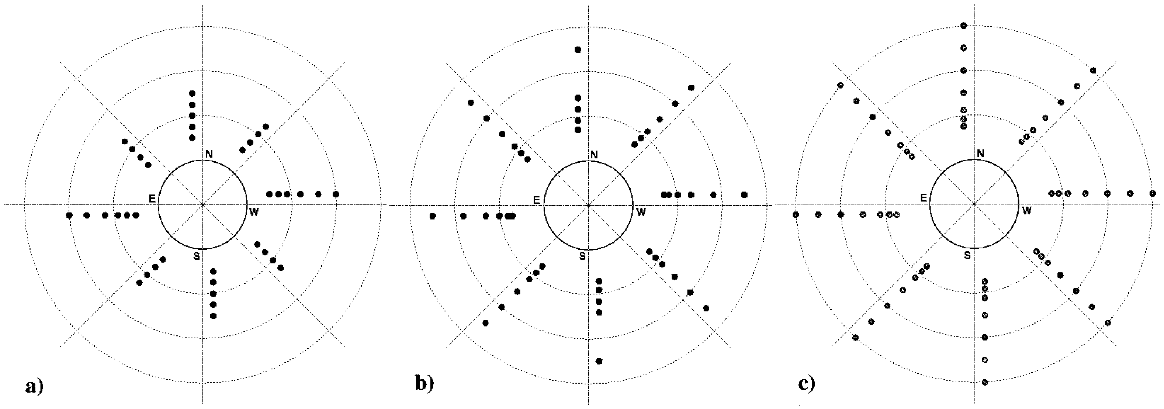

Figure 1. UVCS/WLC synoptic programs: a) from 5 April 1996 to 18 March 1999; b) from 19 March 1999 to 13 April 2000; c) from 14 April 2000 to 20 April 2004.

Table 1. Nominal heliocentric heights and rolls used during UVCS synoptic programs.

Position Angle	5 Apr 1996 - 18 Mar 1999	19 Mar 1999 - 13 Apr 2000	14 Apr 2000 - 20 Apr 2004
Polar (180°, 360°)	1.5, 1.75, 2, 2.25, 2.5 $R_\odot$	1.7, 1.9, 2.15, 2.4 $R_\odot$	1.75, 1.9, 2.1, 2.5, 3, 3.5, 4 $R_\odot$
Equatorial (90°, 270°)	1.5, 1.7, 1.9, 2.2, 2.6, 3 $R_\odot$	1.7, 1.8, 2, 2.3, 2.8, 3.5 $R_\odot$	1.75, 1.9, 2.1, 2.5, 3, 3.5, 4 $R_\odot$
Mid-latitude (45°, 135°, 225°, 315°)	1.5, 1.75, 2, 2.25 $R_\odot$	1.7, 1.9, 2.1, 2.5, 3 $R_\odot$	1.75, 1.9, 2.1, 2.5, 3, 3.5, 4 $R_\odot$

Finally, pB, normalized to the Sun center brightness, is derived by solving the set of linear equations obtained from Eqs. 1 and 2 for the three angles of the HWRP, relative to a reference system with the origin in the point of observation, the x axis directed radially from the center of the Sun and the y axis on the plane of the sky.

3. CALIBRATION AND SYNOPTIC OBSERVATIONS

Data are calibrated according to the most recent calibration described in (Romoli et al. , 2002):

- Radiometric calibration
- $pB = Q$, instead of $pB = \sqrt{Q^2 + U^2}$, under the assumption that the direction of the K–corona linear polarization is tangent to the limb, and the U polarization component is a spurious polarization due to fluctuation of the detector dark countrate.
  The stray light contribution to pB can be neglected.

The statistical error for each data point is small, compared to the scale of the plot. The uncertainty in the y-axis scale is ±10%, due to the radiometric calibration.

The UVCS synoptic program consists of a daily (or once every two days) observation sequence in which a mirror scan of the solar corona is performed at several heights for eight values of the position angle, listed in Table 1. The synoptic program has been periodically improved according to the status of the instrument and the progress in the solar cycle. Three different synoptic programs have been run from the beginning of the operation to the end of the WLC operations in April 2004, when the WLC detector has been switched off, because of a mulfunctionment of the same.

Figure 1 summarizes the synoptic observations for all 8 position angles as run in the three different synoptic programs. The filled circles show where the WLC measures the pB during the UVCS synoptic observation. Due to an offset in the pointing of the WLC ((231 ± 7) arcsec), shown in the Figure, the heliocentric heights of observation are slightly higher than nominal (from 0.01 to 0.02 $R_\odot$), and the actual position angle is increased in average by 7°.

4. DESCRIPTION OF DATA

Figure 2 shows some examples of the pB temporal behaviour throughout the solar cycle as measured during the UVCS synoptic program. The Figure displays pBs at

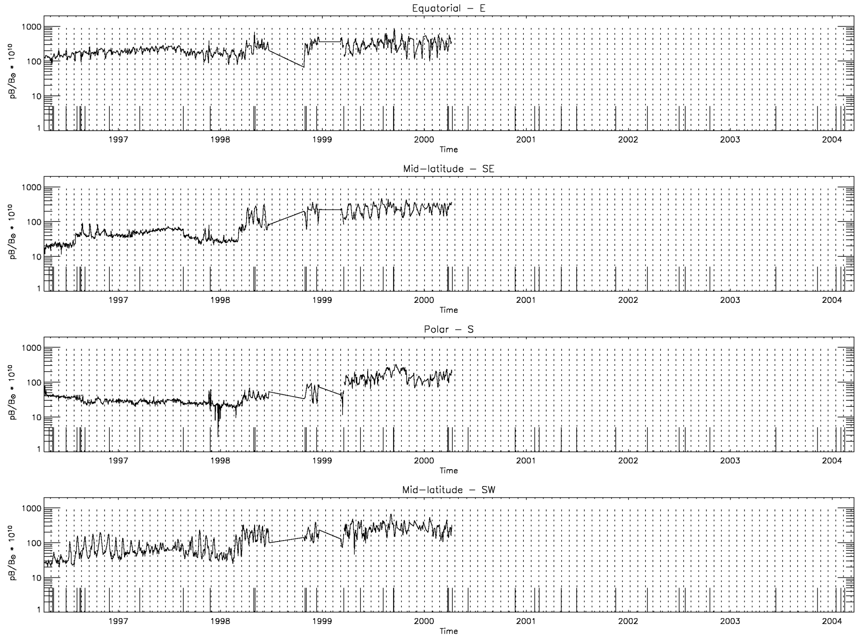

Figure 2. Example of time behaviour of the synoptic observations at four position angles (NE, S, NW, E), for the whole period of WLC operations. In color are the three different synoptic programs, that can differ in height by about 0.1 R$_\odot$. The vertical dotted lines mark the beginning of each Carrington rotation. The long ticks above the x axis corresponds to the UV channel grating position change, that affect slighly the pointing, as shown in Figure 2 (Enlarged version of the figure available on CDROM).

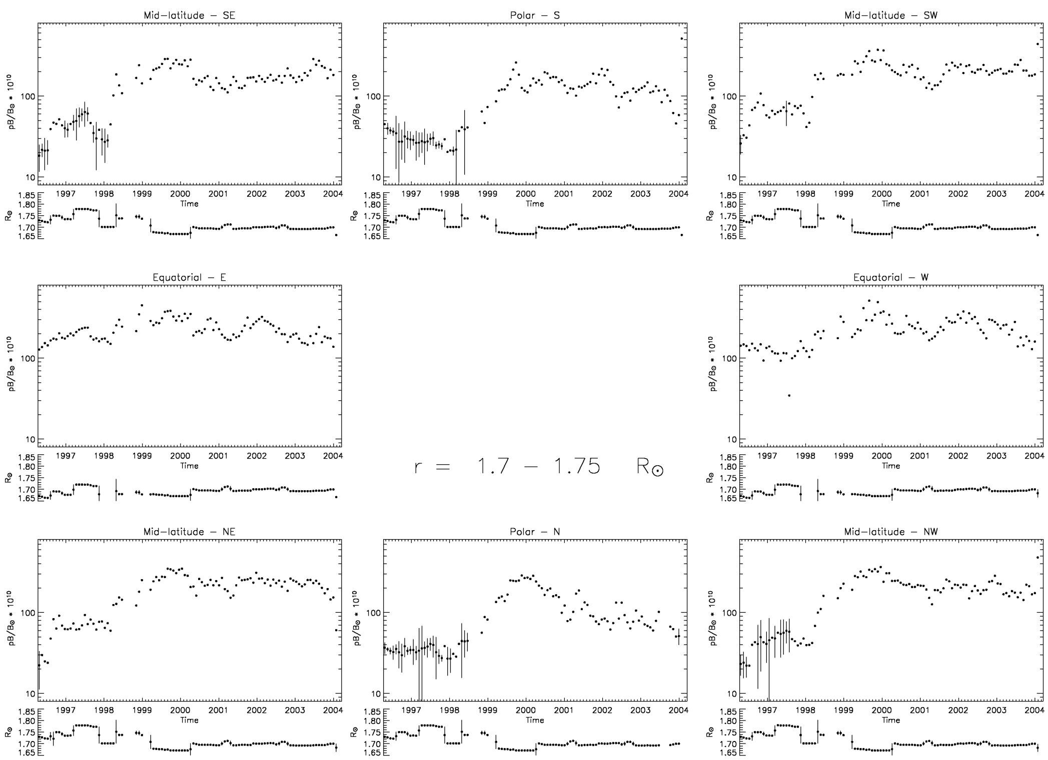

Figure 3. Mean pB time behaviour across solar cycle 23 at 1.7 - 1.75 R$_\odot$. Each plot displays one of the eight position angles. The data are averaged across a Carrington rotation, and the standard deviation is computed and shown in the plot. The narrow plot below each position angle shows how the heliocentric height varies with time (the vertical bars take into account the variation of height inside each Carrington rotation) (Enlarged version of the figure available on CDROM).

four position angles (NE, S, NW, E), for the whole period of WLC operations, for a nominal height range that goes fron 1.7 to 1.75 $R_\odot$. In different color are shown the three different synoptic programs, described in the previous section. The vertical dotted lines mark the beginning of each Carrington rotation. Depending on the position angle, the pBs have been measured at slightly different heights in the three synoptic programs, that can differ in height by about 0.1 $R_\odot$. In addition to that, because of a cross talk between the spectrometer grating mechanism and the mirror pointing mechanism, there are minor height pointing variations, as shown in Figure 2. The long ticks above the x axis corresponds to the UV channel grating position changes, that affect slighly the pointing.

Two mid-latitude sets are shown, because, due to the offset pointing of the WLC, one of them (SE) displays data closer to the pole and there is no evidence of streamers in the minimum phase. On the contrary, the other set (SW) has data closer to the equator and displays streamer passage at every solar rotation.

Figure 2 gives the mean pB time behaviour across solar cycle 23 at 1.7 – 1.75 $R_\odot$. Each plot displays one of the eight position angles. The data are averaged across a Carrington rotation, and the standard deviation is computed and shown in the plot. The narrow plot below each position angle shows how the heliocentric height varies with time (the vertical bars take into account the variation of height inside each Carrington rotation).

5. CONCLUSIONS

- Synoptic data represent a coherent set of data to study the coronal properties throughout the solar cycle.
- Solar cycle 23 displays a sharp increase of brightness, visible in both polar and mid-latitude regions, between the end of 1998 and the beginning of 1999.
- A peak of brightness in both poles is reached at the end of 1999, and the pole average brightness increase from minimum to maximum is a factor 10.
- Equatorial regions display an increase in brightness of a factor 3 between minimum and maximum of the cycle.
- The solar activity has not completed its cycle in 2004, therefore the brightness levels have not reached the levels of 1996.

Future work:

- Additional data analysis needs to be done in order to synthesize the pB behaviour through the solar cycle at all observed heliocentric height. A correction of the height effects has to be implemented.
- The Data Analysis Software (DAS) of UVCS will be updated to facilitate the access to WLC data. A simple routine to compute electron densities using a spherically symmetrical model will be included in the DAS.
- UVCS/WLC pB data will be compared where possible with pB data from literature, UVCS/LASCO and ground based coronagraphs.
- Determination of solar corona rotation and other periodical effects on the different coronal white light features.

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REFERENCES

Kohl, J.L., et al. 1995, Solar Phys., 162, 313.

Romoli, M., et al. 2002, The Radiometric calibration of SOHO, ISSI/ESA SR-002, 181.