A&A 471, L47–L50 (2007)
DOI: 10.1051/0004-6361:20078071

Astronomy & Astrophysics

Letter to the Editor

The long-term stability of the visible F corona at heights of 3–6 $R_\odot$

H. Morgan and S. R. Habbal

Institute for Astronomy, University of Hawaii, 2680 Woodlawn Drive, Honolulu, HI 96822, USA
e-mail: hmorgan@ifa.hawaii.edu

Recieved 13 June 2007 / Accepted 3 July 2007

ABSTRACT

Context. CMEs can effect the distribution of dust grains in the corona. The brightness of the visible F corona is expected therefore to change as the frequency of CMEs varies with solar cycle.

Aims. We search for a variation in the F corona by comparing LASCO C2 observations from solar minimum and maximum.

Methods. An established inversion method is used to calculate the visible F corona brightness from LASCO C2 solar minimum observations made during 1996/10. Good agreement is found with the F corona brightness calculated from Skylab observations during 1973/05–1974/02 for heights of 3–6 $R_\odot$. The unpolarized brightness, which is dominated by the unpolarized F corona brightness at these heights, is obtained by subtracting many pairs of polarized brightness images from total brightness images and averaging over a solar rotation. We calculate the unpolarized brightness for both solar activity minimum and maximum.

Results. The unpolarized brightness, and therefore the F corona, remain virtually unchanged between solar minimum and maximum at heights above 2.6 $R_\odot$, despite the large change in the shape and activity of the corona. Using a simple density model, it is shown that the small variation in unpolarized brightness seen below 2.6 $R_\odot$ can arise from differences in the distribution of electron density, and therefore cannot be attributed to a variation in the F corona.

Conclusions. Despite the large rise in frequency of CMEs from solar minimum to maximum, the F coronal brightness, at heights of 3–6 $R_\odot$ in the visible, remains very stable.

Key words. Sun: corona – interplanetary medium – Sun: activity

1. Introduction

The total brightness (B) of the visible corona is dominated by two components, the K corona brightness (B_K) and the F corona brightness (B_F), with B_F becoming dominant at heights above ~3 $R_\odot$ (e.g., van de Hulst 1950). B_F is the emission of scattered sunlight from interplanetary dust integrated along a line of sight, first described by Grotrian (1934). B_K is Thomson-scattered emission from coronal electrons, also integrated along a line of sight (van de Hulst 1950). Isolating the F and K components of brightness from coronal observations is not a trivial matter, and is important in many ways:

- in studying the dynamic K corona, B_F is useful since it may be subtracted from total brightness observations to isolate B_K (e.g., Saito et al. 1977);
- B_F gives information on the composition and spatial distribution of interplanetary dust, and the influence of the Sun on the dust (e.g., Mann 1992). A comprehensive review of interplanetary dust and the F corona can be found in Gruen et al. (2001), and references within.

This paper uses observations by the Large Angle and Spectrometric Coronagraph (LASCO) C2 instrument (Brueckner et al. 1995), on board the Solar and Heliospheric Observatory (SOHO) to study some aspects of the F corona near the Sun (~2.2–6 $R_\odot$). This study is greatly facilitated by the high quality observations made by LASCO C2 over a solar cycle. An established inversion method to isolate the F coronal brightness (Saito et al. 1977), using LASCO C2 data collected near the minimum of solar activity, is presented in Sect. 2. The results are also compared to previously published estimates. In Sect. 3, measurements made by LASCO C2 near solar minimum (1996) and solar maximum (2000), are used to calculate unpolarized brightness (total brightness minus polarized brightness, to be described in more detail below). We describe the results and give conclusions in Sect. 4.

2. Estimate of F corona brightness

A composite image of the solar minimum corona of 1996/10/09 is shown in the left image of Fig. 1. The image combines observations by the Extreme-Ultraviolet Imaging Telescope (EIT/SOHO) (Delaboudiniere et al. 1995), the Mauna Loa Solar Observatory's MK III coronameter (MKIII) (Fisher et al. 1981), and LASCO C2. From LASCO C2 polarized brightness (pB) observations made on this date, we obtain profiles of pB and total brightness made along radial sectors within ±2° of position angles 0°, 90°, 180°, and 270° (north pole, east equator, south pole and west equator respectively), within a height range of 2.6 to 5.8 $R_\odot$. These observations were made using the "orange" filter of the C2 coronagraph, which has a nominal bandpass of 540−640 nm. The pB observations are calibrated using the standard LASCO procedures included in the Solar Software package, and the total and polarized brightness was calculated from each set of pB observations. The radial profiles of total and polarized brightness are shown in Figs. 2a and b respectively, along

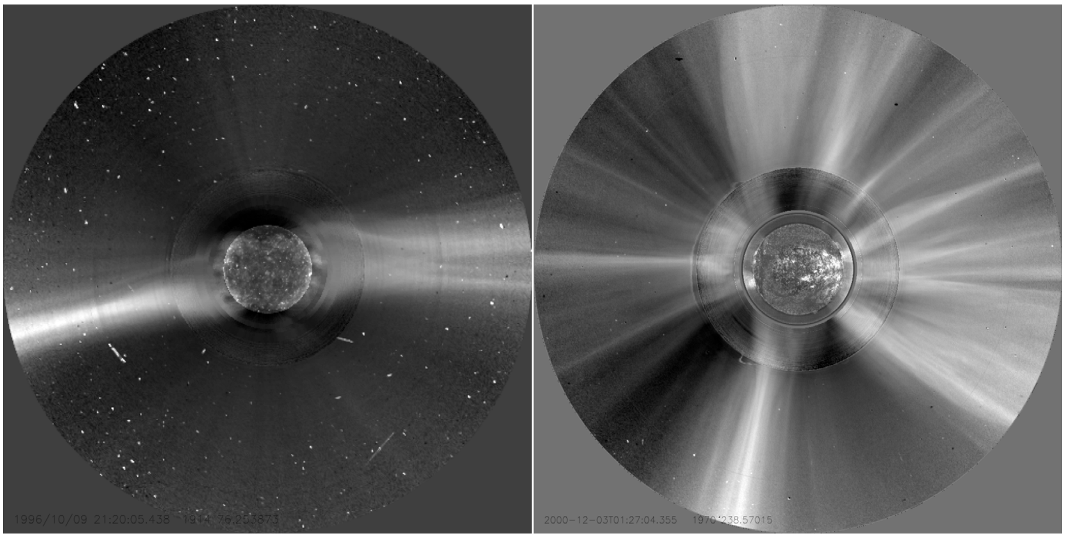

Fig. 1. Composite images of the corona observed during 1996/10/09 (*left*) and 2000/12/02 (*right*). The images contain observations by EIT, the MLSO coronameters (the MKIII instrument for 1996, MKIV for 2000), and LASCO C2. The whole field of view extends to 6 $R_{\odot}$. These images have been processed with a Normalizing Radial Graded Filter (Morgan et al. 2006).

with values found by Saito et al. (1977) for Skylab observations made during 1973/05–1974/02. The profiles found by LASCO in these figures show, as expected, a much higher brightness at the equators compared to the poles. The east and west equators have very similar total brightness at all heights, whilst in *pB* the west is brighter than the east. The poles have somewhat different radial profiles, with the North starting with a higher brightness at low heights, but decreasing faster with height than the South. This is probably due to the distribution of coronal structures (polar plumes, or even the projection of equatorial streamers at large distances along the line of sight).

We adopt a spherically symmetric model geometry, and invert the LASCO *pB* to determine a model electron density using procedures similar to those developed by Quémerais & Lamy (2002). The inversion result is shown in Fig. 2c. We integrate the density along appropriate lines of sight using well-known formulations (van de Hulst 1950) to determine radial profiles of $B_{\rm K}$ (Fig. 2d). These lines of sight are taken through the model density at heights and angles corresponding to the original *pB* observations. $B_{\rm K}$ is subtracted from the total brightness B to obtain an estimate of the F corona brightness $B_{\rm F}$, based on a spherically symmetric model, and dependent on the assumption that the F corona is largely unpolarized below 6 $R_{\odot}$ (Mann & MacQueen 1996). This is an established inversion method for estimating $B_{\rm F}$, described in detail by Saito et al. (1977). Values of $B_{\rm F}$ found by Saito et al. (1977) are compared with our estimates from the LASCO observations in Fig. 2e. Excellent agreement is found at heights of 3 $R_{\odot}$ and above.

Figure 3 shows our calculations of $B_{\rm F}$ for the east equator and south pole alongside equatorial and polar values found in other published works. As shown, we have good agreement with Saito et al. (1977). Values given by Blackwell et al. (1967), and Koutchmy & Lamy (1985), for the equator at heights above 5 $R_{\odot}$ are in good agreement, as are values found by Munro & Jackson (1977) for the pole at all heights (2.6–5.8 $R_{\odot}$). Values found by Koutchmy & Lamy (1985) for the pole are lower than our results at 4 $R_{\odot}$, with better agreement towards 5.8 $R_{\odot}$. Values found by Duerst (1982) are substantially lower for both equator and poles. The spread of values shown here are likely dominated by different observational equipment and observing conditions (i.e. absolute calibration uncertainties), and also possibly due to the different techniques used to derive $B_{\rm F}$.

3. Unpolarized brightness

Figure 2f shows our estimate of $B_{\rm F}$ alongside the calculated unpolarized brightness (*upB*). *upB* is a value we calculate by subtracting the polarized brightness *pB* from the total brightness *B*. In the context of LASCO observations, *upB* has been described previously by Llebaria et al. (1999). Since $B_{\rm F}$ is almost completely unpolarized at these heights (Mann 1992), we expect *upB* to contain $B_{\rm F}$, and also other contributions (for example, the unpolarized component of the instrumental stray light). Figure 2f shows that *upB* is strongly dominated by $B_{\rm F}$, and, as expected, *upB* is higher than $B_{\rm F}$ at all heights.

Unpolarized brightness profiles are shown in Fig. 4 for both equators and poles, for dates 1996/09/01-1996/11/07 (solar minimum) and 2000/12/02-2000/12/31 (solar maximum). The distribution of the coronal electron density structure changes enormously between these two time periods, as can be seen in Fig. 1. However, Fig. 4 shows that *upB* remains almost constant from solar minimum to maximum, which is strong evidence that the F corona remains unchanged with the solar cycle at these heights in the broad wavelength range of the LASCO C2 orange filter. *upB* can change somewhat from day to day, but in Fig. 4 an average *upB* is calculated from many observations made over the course of several weeks (or more than a solar rotation). This average value is almost identical at heights of 2.5−6 $R_{\odot}$ for both solar minimum and maximum.The usefulness of *upB* as a background for subtraction in coronagraphic image processing (due to its stability, among other reasons) has been noted by Morgan et al. (2006).

The difference in *upB* at heights below 2.5 $R_{\odot}$ seen between solar minimum and maximum can be explained by the different distribution of electron density along the line of sight. Using a simple density model, we show in Fig. 5 that different radial profiles of density can easily result in differences in the observed *upB*. Therefore the differences in *upB* at low heights seen in Fig. 5 cannot be attributed to any change in $B_{\rm F}$.

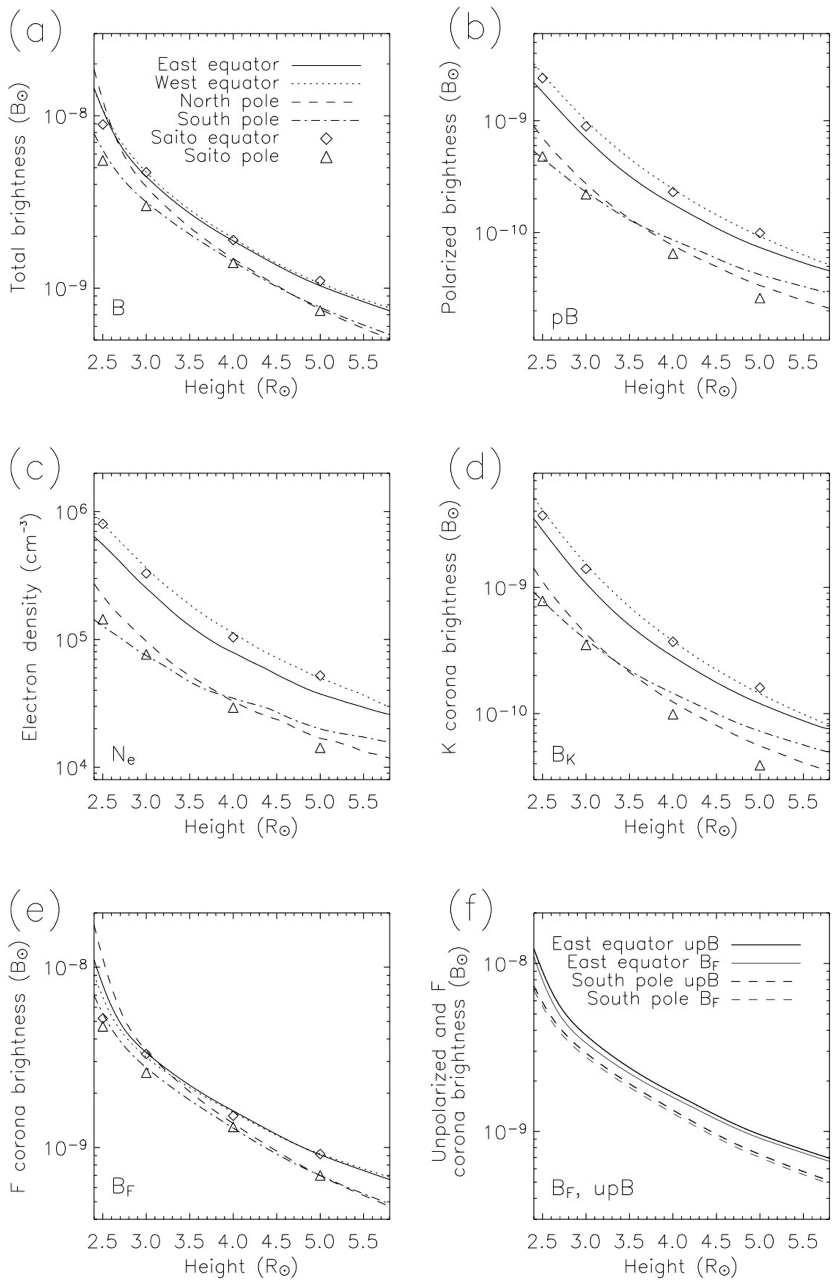

Fig. 2. Radial profiles at the poles and equators of **a)** B and **b)** pB as observed for the solar minimum corona of 1996/10/09 by LASCO C2. **c)** Electron density obtained by a spherically symmetric inversion of pB. **d)** B_K, calculated from the electron density. **e)** B_F, calculated by subtracting B_K from B. Values from Saito et al. (1977) are also shown. **f)** Unpolarized brightness ($upB = B - pB$) compared to B_F for the east equator and south pole.

4. Discussion and conclusions

In visible wavelengths at heights of 3–6 $R_\odot$, the unpolarized brightness observed by LASCO C2 remains unchanged from solar minimum to maximum. If we were to observe a change in upB, it would be difficult to attribute the variation to a genuine variation in the F corona, since it may be caused by other means, for example a variation in the instrument over time. However, since no appreciable change is observed, this is strong evidence of the long-term stability of the F corona. This has important implications for the effects of CMEs on interplanetary dust near the Sun. Such effects have been considered by Ragot & Kahler (2003), who consider in detail the forces acting on dust particles due to CMEs. B_F in the visible has a higher contribution from small dust grains compared to infrared (MacQueen & Greeley 1995). Ragot & Kahler (2003) place an upper limit of around 10% variation in B_F with solar activity (due to the higher frequency of CMEs at solar maximum compared to minimum, see Gopalswamy 2006). We calculate upB by averaging over a solar rotation, and it may be possible that disturbances in the dust distribution caused by CMEs occur at smaller time scales. However, it is surprising that our findings suggest hardly any variation in B_F between solar minimum and maximum.

A similar study can be applied for a larger set of LASCO observations covering a whole solar cycle, and should be extended to other observed wavelengths. In principle, a more detailed study may reveal systematic variations in upB due to the changing geometrical configuration of the observations, as the

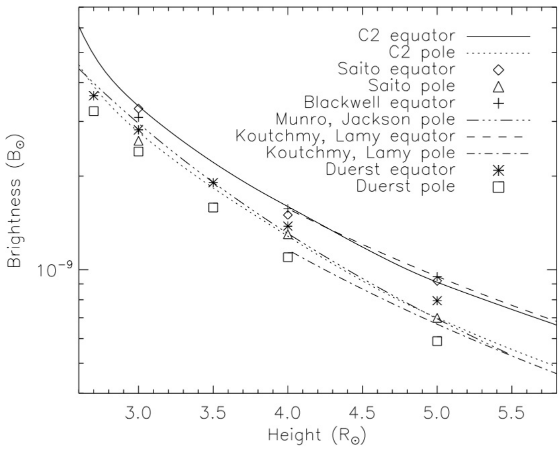

Fig. 3. Comparison of calculated B_F (as shown in Fig. 2e) with other published values (see text).

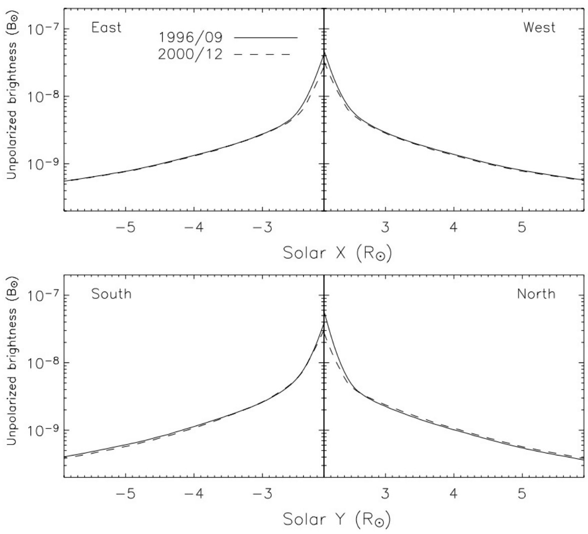

Fig. 4. Unpolarized component of white light averaged from 42 LASCO C2 total brightness and *pB* pairs observed during 1996/09/01-1996/11/07 (solid line) and 42 pairs observed during 2000/12/02-2000/12/31 (dashed line). The only significant difference is seen below ~2.5 $R_\odot$, where the solar minimum unpolarized component is brighter for the east and west equators and the north pole.

position of SOHO varies relative to the ecliptic. A more comprehensive study could also give insight on CME-dust interactions.

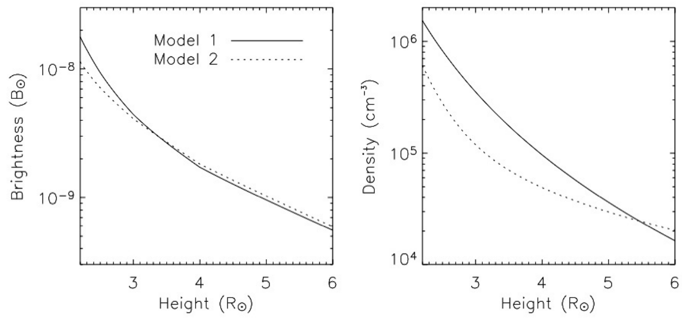

Fig. 5. *Left* – synthetic unpolarized brightness for two different coronal density models. *Right* – radial profiles of density used in the two models. These densities are used to calculate B_K and pB along many lines of sight at various heights. B_F is given by the values calculated from observations shown in Fig. 2. pB is subtracted from the total brightness ($B_K + B_F$) to give the unpolarized brightness.

Acknowledgements. The authors wish to thank the anonymous referee for suggestions which greatly improved this paper. The coronal data used in this work are courtesy of the LASCO/SOHO consortium. SOHO is a project of international cooperation between ESA and NASA. This work was supported by NSF grant ATM0457099 to the University of Hawaii at Manoa. Huw Morgan conducted part of this work while visiting the Institute of Maths and Physics at the University of Wales, Aberystwyth, and he is grateful for their support.

References

Blackwell, D. E., Ingham, M. F., & Petford, A. D. 1967, MNRAS, 136, 313
Brueckner, G. E., et al. 1995, Sol. Phys., 162, 357
Delaboudiniere, J.-P., et al. 1995, Sol. Phys., 162, 291
Duerst, J. 1982, A&A, 112, 241
Fisher, R. R., Lee, R. H., MacQueen, R. M., & Poland, A. I. 1981, Appl. Opt., 20, 1094
Gopalswamy, N. 2006, Space Sci. Rev., 124, 145
Grotrian, W. 1934, Z. Astrophys., 8, 124
Gruen, E., Gustafson, B. A. S., Dermott, S., & Fechtig, H. 2001, Interplanetary dust, ed. Eberhard Grun et al. (Berlin: Springer), Astron. Astrophys. Library
Hayes, A. P., Vourlidas, A., & Howard, R. A. 2001, ApJ, 548, 1081
Koutchmy, S., & Lamy, P. L. 1985, Astrophys. Space Sci. Library, 119, 63
Llebaria, A., Lamy, P., & Koutchmy, S. 1999, ESA Special Publication, 446, 441
MacQueen, R. M., & Greeley, B. W. 1995, ApJ, 440, 361
Mann, I. 1992, A&A, 261, 329
Mann, I., & MacQueen, R. M. 1996, Adv. Space Res., 17, 53
Morgan, H., Habbal, S. R., & Woo, R. 2006, Sol. Phys., 236, 263
Munro, R. H., & Jackson, B. V. 1977, ApJ, 213, 874
Quémerais, E., & Lamy, P. 2002, A&A, 393, 295
Ragot, B. R., & Kahler, S. W. 2003, ApJ, 594, 1049
Saito, K., Poland, A. I., & Munro, R. H. 1977, Sol. Phys., 55, 121
van de Hulst, H. C. 1950, Bull. Astron. Inst. The Netherlands, 11, 135