THE GLOBAL ACTIVITY OF THE SOLAR CORONA

A. Llebaria\(^1\), P. L. Lamy\(^1\), S. Koutchmy\(^2\)

\(^1\) Laboratoire d'Astronomie Spatiale (CNRS), Marseille, France
\(^2\) Institut d'Astrophysique de Paris (CNRS), France

ABSTRACT

The question of the global activity of the solar corona, as a function of time and distance from the center of the Sun, is considered by analyzing long time-series of LASCO-C2 images. Polarized images are first considered to perform the separation of the K and F components. The F-corona images are used to construct a photometric model of the F-corona which reflects its annual variations resulting from geometric effects. This time-varying model is then subtracted from all corrected and calibrated unpolarized images to yield images of the K-corona. Synoptic maps are created at different distances between 2.7 and 6.5 solar radii. In order to conveniently quantify the temporal variation, the total white-light radiance is integrated first globally and then in zones of different latitudes to separate the streamer belt and the coronal holes. The results cover the first three years of SOHO operation i.e., from 1996 to 1998. The radiance of the polar regions remained remarkably stable. Temporal variations appear at mid-latitudes and are maximum in the equatorial belt. The total integrated radiance was approximately constant in 1996 and then progressively increased with the rising activity of the Sun, to reach a factor of 1.5 in early 1999.

Key words: solar corona; solar activity; synoptic-maps; SOHO

1. INTRODUCTION

In the present paper we adress three key questions about the temporal variation of the K-corona:

- what is the temporal variation of the total or integrated K-corona radiance?
- how does it relate to the solar cycle?
- can we distinguish differences between the streamer belt and the coronal holes?

Those questions were addressed as early as 1950 by Van de Hulst and Saito from total coronal observations (K+F corona). They found a cyclic variation correlated with the sunspot cycle with an amplitude of about 1.8. More recently Ficher and Sime (1984) found a factor of 2 from observations of the polarized K-corona, but Lebeq and all. (1985) found an even larger modulation, a factor 4.

We reconsider the problem on the basis of nearly three years of continuous observations from the LASCO/C2 coronagraph aboard SOHO. Its excellent photometric and polarimetric performances allow a rigorous separation of the K and F coronae, a crucial step to solve those problems. However the LASCO/C2 field of view is limited to the 2.5-6.5 R\(_\odot\) range, thus excluding the inner i.e., the brightest part, of the K-corona. Nevertheless we show below that the temporal variation of the radiance of the K-corona in the LASCO/C2 field-of-view shed some light on the above questions.

2. OBTAINING K-CORONA IMAGES

Obtaining correct images of the K-corona alone is the initial and crucial step of our analysis. We first consider the daily sets of three polarized images of the corona oriented at 60\(^\circ\), 0\(^\circ\), and -60\(^\circ\) and generate maps of the calibrated radiance, of the polarization and of the local angle of polarization. This angle provides a check of the quality of the polarimetric analysis and the histograms peak at 90\(^\circ\) as expected and have a FWHM of 25\(^\circ\) (Lamy et al. 1997). We then perform the extraction of the K-corona using the classical assumption that the polarization of the F-corona and of the straylight are null. This is indeed a valid assumption for the F-corona inside 6.5 R\(_\odot\). This analysis yields almost daily sets of images of the K-corona and of the F-corona mixed with straylight (F+S images). Fig 1 gives an example.

The second step of our analysis consists in separating the F and S components, a complex process whose details are beyond the scope of this article. The resulting images of the F-corona exhibit characteristic patterns of annual variation resulting from the motion of the SOHO spacecraft across the plane of symmetry of the zodiacal dust cloud and from the variation of its heliocentric distance.

The third step consists in constructing a synthetic photometric model of the F-corona as seen by LASCO/C2 for each day of the year as well as a
model of the stray light. In a final step, we process all unpolarized C2 images using the above models to produce calibrated images of the K-corona.

3. SYNOPTIC MAPS

Synoptic maps of the radiance of the K-corona are constructed from large sets of images by extracting profiles along circles centered at the Sun and piling them in rectangular arrays where the horizontal axis is time and the vertical axis is solar latitude. Our circles have radii of 2.7, 4., 5.5 R_⊙ and are sampled every 0.5° starting at the south pole, thus producing 720 pixels along a column. Fig 2 illustrates such a synoptic map at 2.7R_⊙ generated from 550 consecutive images of K-corona resulting from the analysis of polarized images. In this case, the sampling in time is not uniform.

In order to alleviate this problem and to normalize the temporal evolution on a fixed meridian, we introduce a regular sampling with a step equals to half a synodic rotation, that is 13.6 days. The extraction of the circular profiles is done alternatively clockwise and counter-clockwise in order to correctly track the coronal features on consecutive images. This method is applied to a long time series of unpolarized images from which the F-corona and the straylight are subtracted as described in section 2. The time coverage extends from March 1996 to January 1999, that is nearly three years. The resulting synoptic maps obtained at three heliocentric distances are shown in Fig 3. Note that those maps simultaneously display the east and west sides since the extractions are performed along the full circles. The streamer belt is conspicuous and remains close to the equatorial region during the minimum of solar activity and then broadens as the level of activity increases. The large gap in late 1998 corresponds to the inactive period of SOHO.

4. TEMPORAL EVOLUTION OF THE INTEGRATED RADIANCE

In order to synthesize and quantify the temporal evolution of the K-corona, we perform an integration of its radiance in an annular region extending from 2.7 to 4. R_⊙, to yield the total integrated radiance (IR) as displayed in Fig 4. Note a nearly constant phase extending over about one year followed by an increase which tends to steepen as the solar activity develops, reaching a factor 1.5 in early 1999.

A more detailed view of this evolution is offered by considering 12 sectors of equal angular extent (30°) and centered at the equator and at latitude of ±30°, ±60°, and ±90°. The radiance is first integrated in this sectors and the results for pairs of sectors of equal latitudes are then summed to reveal its variation in 7 zones defined by their mid-latitudes. Fig 5 shows that the poles undergo little temporal evolution and that this situation progressively changes as the latitude decreases. A global increase is perceptible as the solar activity rises with a considerable "random" fluctuations especially in the equatorial zone.

5. CONCLUSIONS

Although LASCO-C2 does not offer access to the inner K-corona, it proves to be a useful tool to quantify the global activity of the solar corona. The total integrated brightness remained constant in 1996 during the minimum of solar activity but then progressively increases as the level of activity rises to reach a factor 1.5 in early 1999. The analysis in zones of various latitudes reveals however a complex situation where the polar regions stay stable while most of the variations take place at lower latitudes with considerable fluctuations in the equatorial region. This work will be pursued these coming years to reveal the activity of the corona over the rising part of the solar cycle.

REFERENCES

Figure 1. Polarized (left) and unpolarized (right) components of the solar corona during the solar minimum of activity. The first is mostly produced by $K$-corona, the second is a combination of $F$-corona and straylight. (from the LASCO/C2 observations performed in December 1990).

Figure 2. Synoptic maps at $2.7R_\odot$ from 550 consecutive images of the $K$-corona. The horizontal scale represents the frame number (i.e., a non uniform time scale). The vertical scale represents the position angle, counter-clockwise from the south pole.)
Figure 3. Synoptic maps of the radiance of the K-corona at three heliocentric distances constructed from polarized (left) and unpolarized (right) images. The time is expressed in "Julian days - 2450000" and extends from March 96 to January 99.
Figure 4. The total integrated radiance as function of time, from March 1996 to January 1999
Figure 5. The integrated radiance of the K-corona in different zones. The crosses correspond to the southern hemisphere and the triangles, to the northern hemisphere.