DIFFERENTIAL ROTATION OF THE SOFT X-RAY CORONA OVER A SOLAR CYCLE

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ABSTRACT

The Yohkoh Soft X-ray Telescope has provided unprecedented, high spatial and temporal resolution of the solar corona in X-rays for a complete activity cycle. Building upon earlier work, we perform time-series analysis on latitude bins of the full-disk images (SFDs) to describe the differential rotation of the corona over latitude and cycle phase. The bins are formed by integrating over localized regions in heliographic longitude and latitude. Using techniques of Bayesian harmonic analysis, we find that the rotation signal in the data comprises several components, of which the solar activity cycle is dominant. Typically, there are several rotation components, but one is usually preeminent. We find evidence for rotation power in the corona which matches signals found in solar neutrino experiments.

INTRODUCTION

The differential rotation of the solar corona is an interesting subject, in part because the latitudinal profile of the rotation rate seems to vary less (i.e., is more "rigid") than that of the underlying photosphere. Although there has been a history of studies on the coronal rotation rate, including some of Soft X-Ray (SXR) data, today we benefit from resolved SXR data spanning an entire solar activity cycle, due to the *Yohkoh* Soft X-Ray Telescope (SXT; Tsuneta *et al.*, 1991). This study builds on earlier work (Weber *et al.*, 1999) by extending the dataset to ten years, and by using a fully Bayesian methodology instead of the earlier, more *ad hoc* approach.

DATA REDUCTION AND BAYESIAN HARMONIC ANALYSIS

The data used are derived from "SFD" images (the full-frame images of the sun which have been used as the frames of the famous SXT movie). Time-series are formed from the integrated flux from each of nine latitude bins located on the central meridian at {60S, 45S, 30S, 15S, equator, 15N, 30N, 45N, 60N}. (The data reduction techniques are discussed in more detail in Weber *et al.*, 1999.) For the results presented here, we only consider the data from the AlMg diagnostic filter. The total time studied runs from Sept. 1991 to Dec. 2000 (about 9.2 years). The dataset included 215,828 images, for a mean sampling rate of about 64 images per day.

Bretthorst (1988) has developed the groundwork for doing harmonic analysis of a time-series using Bayesian techniques. For this presentation, we utilized his approach. We presume that the time-series $d_i = d(t_i)$ (where $i = 1, \cdots, N$) can be described by the model

$$d_i = f_i + e_i = \sum_{j=1}^{m} [A_j \sin(\omega_j t_i) + B_j \cos(\omega_j t_i)] + e_i, \tag{1}$$

where $f = f(\{A_j\}, \{B_j\}, \{\omega_j\})$ and e_i is normally distributed noise with variance σ^2. The periodogram of the data $\overline{h^2}$ can be shown to be the "sufficient statistic" for optimally estimating the frequencies of the model. For a model with m harmonics, $\overline{h^2}$ is an m-dimensional periodogram.

Bretthorst (1988) also provides formulae and procedures for determining the moments of the frequency estimations (and hence, their uncertainties), as well as for the amplitudes and their uncertainties, the noise variance σ^2, and the relative likelihood of models with differing numbers of harmonic components.

Our procedure was to (1) locate the first component using a single-harmonic model; (2) subtract the estimated component(s) from the data; and (3) analyze the residual with a single-harmonic model to initially estimate the next component. (4) Starting from previous estimates, analyze the *total* data set with the multi-harmonic model. [This amounts to searching for max($\overline{h^2}$). To locate the maximum of $\overline{h^2}(\{\omega\})$, we used a "pattern-search" algorithm (Hooke & Jeeves, 1961).] (5) Repeat steps 2–5.

RESULTS

We have just begun to get results from this analysis, but there are a few things that can be said at this time.

Dominance of solar cycle modulation and rectification. From the harmonic analysis, we find a solar cycle component with a frequency of about 0.106 cyc/yr (~9.5 yr period). This component typically carries about 5× as much power as the dominant rotation component. On a smaller note, we observe that the time-series is rectified at solar minimum, as happens with the sunspot number.

Relatively rigid rotation of corona. We examined the differential rotation year by year of the dominant rotation components. A common characteristic is that the coronal rotation rate only matches the underlying photospheric rate near the equator, and rotates faster than the photosphere at higher latitudes; thus the rotation profile of the corona across latitude is shallower, i.e., more rigid than that of the photosphere.

Indication of connection to solar interior. We examined the power spectra across latitude, for the period 1991–2000. Low latitudes displayed a component at 13.6 cycles/yr, and high latitudes displayed one at 12.9 cycles/yr. These frequencies are noteworthy because they correspond to the dominant frequencies in the power spectra of the Homestake and GALLEX/GNO solar neutrino data. This correspondence is elaborated upon further by Sturrock & Weber (2002).

The Bayesian approach appears to be quite promising for time-series analysis of solar data. Even better would be to reimplement Bretthorst's work for wavelets in place of harmonic components.

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