Long-Term Datasets for the Understanding of Solar and Stellar Magnetic Cycles
Proceedings IAU Symposium No. 340, 2018
D. Banerjee, J. Jiang, K. Kusano & S. Solanki, eds.

doi:10.1017/S1743921318001436

Study of Coronal Rotation using X-ray images observed by Hinode

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Abstract. Solar rotation is still one of the unresolved concern of solar physics. We performed time series analysis on the bins formed on equally separated latitude regions on the soft X-ray images. These images are observed with the X-ray telescope (XRT) on board the Hinode satellite. The flux modulation method traces the passage of X-ray feature over the solar disc and statistical analysis of the time series data of the SXR images (one per day) for the period extends from year 2015 to 2017 gives the coronal rotation period as a function of latitude. The investigation provided quite systematic information of the solar rotation and its variability.

Keywords. Sun: activity, Sun: corona, Sun: rotation, Sun: X-rays.

1. Introduction

In recent years our understanding of the rotation of the Sun has greatly improved due to availability of full disc images at X-ray and EUV wavelengths provided by solar satellites. In addition to photosphere, several recent studies on these images cast light on differential rotation in the chromosphere and corona as well. The Sun has large scale rotation which can be measured by tracking visible features across the solar disk, such as sunspots, or via spectroscopy, or via analyzing modulation in the solar radiation flux such as radio waves, X-rays and UV rays.

The differential rotation of the solar corona is still an open question. We cannot clearly ascertain whether the coronal rotation is rigid (Weber *et al.* (1999), Chandra *et al.* (2010)) or differential (Kariyappa (2008)), as we can say for the lower atmosphere, or whether the variation of the coronal rotation is independent of or dependent on a sunspot cycle.

2. Data Analysis

The X-ray Telescope (XRT) on-board the *Hinode* spacecraft is a grazing incidence X-ray imaging telescope. It is sensitive to plasmas with wide temperature range from < 1 MK to 30 MK (Kano *et al.* (2007)). We used daily SFD images of 512×512 pixel size, at cadence of one per day, obtained during the years of 2015, 2016 and 2017 from XRT. To produce time series, 17 latitude bins have been selected at interval of 10° on each SFD image from 80°N to 80°S. Averaged SXR flux of each latitude bins produces total 17 such time series. Then, an auto-correlation coefficient of such time series was obtained as a function of lag. The auto-correlation curves show clear rotation modulation with fair amount of correlation. The position of peaks on these curves can provide the synodic rotation period. We choose the farthest peak up to which curve shows smoothness and cyclic nature to attain maximum possible accuracy. The synodic rotation period so obtain is then converted to sidereal rotation period.

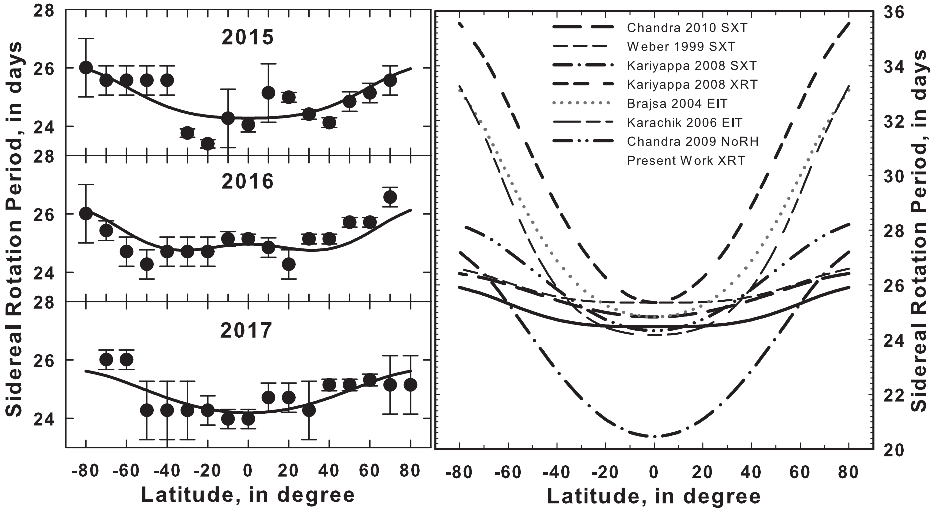

Figure 1. Left panel: Latitudinal variation in coronal rotation period obtained for the year 2015 to 2017. Right panel: Comparison between rotation period obtained from different data sources.

Table 1. Variation of the coefficients A, B and C and their standard errors.

Year	$A \pm \Delta A$	$B \pm \Delta B$	$C \pm \Delta C$	$Annual SSN$
2015	14.83 ± 0.18	-0.27 ± 1.01	-0.76 ± 1.05	69.8
2016	14.42 ± 0.15	$+0.89 \pm 0.82$	-1.60 ± 0.85	39.8
2015	14.88 ± 0.14	-0.67 ± 0.75	-0.19 ± 0.75	21.7
Average	14.71	-0.02	-0.85	43.8

3. Results and Discussion

The sidereal rotation periods are plotted against latitude in Figure 1 (Left panel). In spite of significant scatter the soft X-ray corona shows almost rigid rotation throghout the period of study (2015-2017). When the least square curve is fitted in these results, the coefficients A, B & C of each year are obtained (Listed in Table 1).

Our study suggest that the rotation profile of soft X-ray corona across the latitude is shallower than that of its lower atmospheric layers. The results (compared in Figure 1 (Right panel)) are in line with the results obtained by Weber *et al.* (1999) & Chandra *et al.* (2010) with *Yohkoh*/SXT data and Chandra *et al.* (2009) with 17 GHz radio flux data. But differs with finding of Kariyappa (2008) with SXT and XRT data. This may be because of the choice of different tracers, methods and time duration of the data. It is also found that near the equator SXR corona rotates at a speed close to the photosphere and chromosphere (Brajsa *et al.* (2004) & Karachik *et al.* (2006)).

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https://doi.org/10.1017/S1743921318001436 Published online by Cambridge University Press