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Study of solar rotation

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Abstract. The radio and X-ray emissions originate at different layers of solar corona. The study of such emission using flux modulation method produces valuable information about the solar rotation with respect to latitude of the corona. This paper summarizes the important results of our study on radio flux data at 2.8 GHz, radio images taken at *Nobeyama Radioheliograph* at 17 GHz and soft X-ray images observed through *Yohkoh/SXT* spacecraft.

Keywords : Sun: corona – Sun: rotation – Sun: radio radiation – Sun: X-rays

1. Introduction

The discovery of *solar rotation* immediately followed the advent of the telescope. Around 1610, Galileo Galilei, Johannes Fabricius, Christoph Scheiner and other astronomers saw sunspots move across the solar disc. Their early records also contain evidence that the sunspot passage took a little longer time at higher solar latitudes than near the equator, this phenomena being later interpreted in terms of the *differential rotation* of the Sun. This characteristic of solar rotation has attracted solar physicists up to this day. New details are being observed, and old puzzles, such as the origin of the solar differential rotation, remain unresolved.

2. Coronal rotation

The coronal rotation is characterized by its unique latitudinal and height profiles, temporal and spatial variations and variations between rigid to differential rotation profile. The coronal rotation rates have been estimated using solar radiation at various

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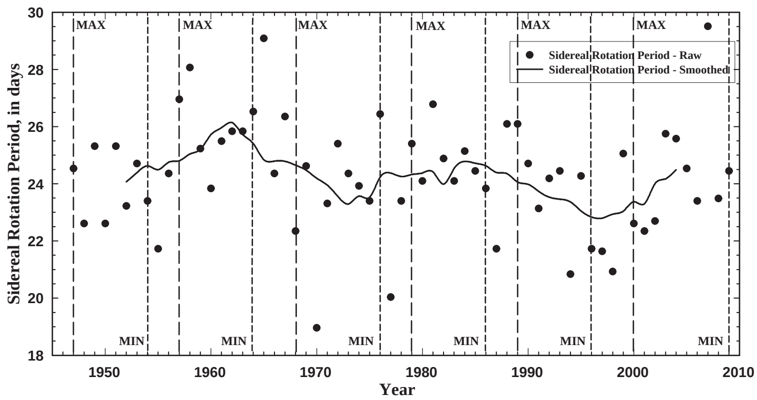

Figure 1. The temporal variation in sidereal rotation period (scatter plot) and its 11 yr running mean (smooth curve) (Chandra & Vats 2011).

frequencies. The radio or X-ray observations have the advantage over other observations, that it provides distinct resolution for altitudes in the corona (Vats et al. 1998a,b, 2001).

2.1 Coronal Rotation using Radio Flux at 2.8 GHz

The radio flux at 2.8 GHz monitored by the Dominion Astrophysical Observatory at Penticton, is an integrated emission over the entire solar disk, which originates from the lower solar corona near $\sim 6 \times 10^4$ km above the solar surface (Vats et al. 2001). The temporal variation in coronal rotation period, obtained through the autocorrelation analysis (Fig. 1), does not show any systematic periodicity. When the rotation period data is being smoothened (by taking an eleven years running mean) it shows the presence of a long term variation in the coronal rotation period, which is close to the 22-years periodicity. This may correspond to the 22-year Hale's cycle (Fig. 1). The autocorrelation curve (Chandra & Vats 2011) confirms this periodicity of 22-years. The cross-correlation analysis between the smoothened data of coronal rotation and the sunspots number not only reconfirms the correspondence to the 22-year cycle (Chandra & Vats 2011), but also shows that both of them are almost in phase to each other. The years of the minima of the 22-years cycle (shown in Fig. 1) coincide well with the years of minimum activity of the even numbered solar cycles (ENSCs), *i.e.* at the years 1954, 1976 and 1996. Whereas the years of the maxima of the 22-years cycle matches well with the years of minimum activity (at the years 1964 and 1986) of the odd numbered solar cycles (ONSCs). Our result is in agreement with the results reported by Javaraiah (2000).

2.2 Differential Rotation of Corona using X-ray and Radio Images

The soft X-ray images (observed by *Yohkoh*/SXT during 1992-2001) and radio images at 17 GHz (*Nobeyama Radioheliogram* observed during 1999-2005) are used to obtain the rotation period with respect to the latitude (Chandra, Vats & Iyer 2010; Chandra 2010). The images of one year block are chosen and latitude bins, at interval of 10 degree are defined along heliocentric latitude lines in each image. The average intensity variation in each latitude bin is reduced to a time series of one year. The coronal differential rotation period at each latitude is then calculated by the autocorrelation analysis of such time series for all the years (Chandra, Vats & Iyer 2009). The results are found to agree qualitatively with the earlier investigations of the corona. A curve is fitted to each set of derived values of a particular year by the least square method, and coefficients A, B and C, are evaluated from this. The differential rotation profiles as a function of latitude vary considerably throughout the period of the study, but their mean gradient is less in comparison to most of the previously published results (see Fig. 2). It implies that the differential rotation profile of the soft X-ray corona and radio corona, across latitudes is shallower than that of the chromosphere and the photosphere. Fig. 2 also shows that the equatorial rotation rate obtained from the radio images are lower than those obtained from the X-ray images. But the differential rotation is opposite of this, i.e., higher when obtained from the radio images than that obtained from the X-ray images. The X-ray images suggest that the equatorial rotation rate (A) is anti-correlated with the sunspot activity, except in the year 2000 (Chandra, Vats & Iyer 2010). The radio images at 17 GHz show that the equatorial rotation rate and the sunspot number have a lag of 3 years. The B coefficient representing the differential part is almost in phase with the sunspot number (Chandra 2010). The space-time plots of sidereal rotation period obtained from radio images and X-ray images shows that the NS asymmetry is real and significant (Vats & Chandra 2011). Moreover, the southern hemisphere rotates faster than the northern hemisphere in odd solar cycles. Whereas, in even solar cycles the northern hemisphere rotates faster than the southern hemisphere. The asymmetry seems to change its sign from odd to even solar cycles. Thus, our study supports the finding of Gigolashvili et al. (2005), who investigated the H_α filaments and showed the existence of NS asymmetry in the chromosphere.

3. Conclusion

The analysis of disc integrated radio flux observed at 2.8 GHz for the period of six solar cycle shows the presence of long term variation in the coronal rotation period. The periodicity is close to the 22 year periodicity of the magnetic reversal cycle known as Hale's cycle. This also indicates that the ascent or descent in the rotation period is initiated in the years of solar minima. The soft X-ray images (for the period 1992-2001) and radio images at 17 GHz (for the period 1999-2005) of the corona are also analysed to determine the latitudinal variation of the solar rotation. The analysis shows that the corona, at the height of these emissions, rotates differentially as in case of the pho-

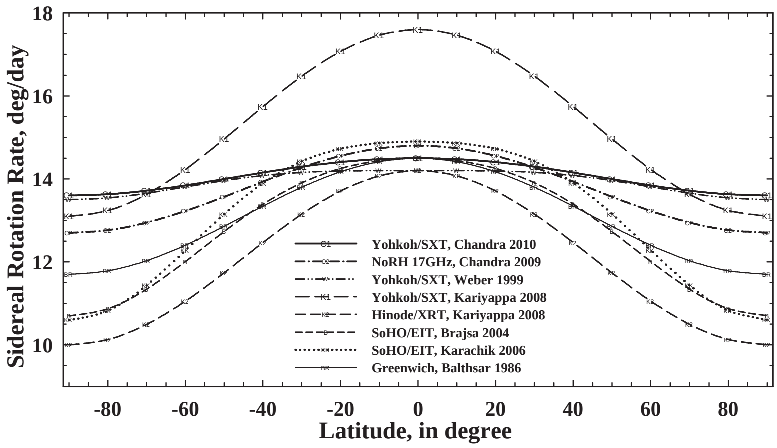

Figure 2. The coronal rotation profiles of different data sources are compared with each other.

tosphere and the chromosphere; but the gradient is significantly lower. The coronal equatorial rotation rate and its latitude dependent differential rotation rate show their strong dependency on the phases of the solar cycle. The space-time plots of sidereal rotation period, obtained by X-ray and radio images, display clear evidence of NS asymmetry. This asymmetry changes its sign in odd and even solar cycles.

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References

Chandra S., Vats H. O., Iyer K. N., 2009, MNRAS Lett., 400, L34
Chandra S., Vats H. O., Iyer K.N., 2010, MNRAS, 407, 1108
Chandra S., 2010, Ph. D. Thesis, Saurashtra University, Rajkot, India
Chandra S., Vats H. O., 2011, MNRAS, 414, 3158
Gigolashvili M. S., Japaridze D. R., et al., 2005, Solar Phys., 227, 27
Javaraiah J., 2000, J. Astrophys. Astr., 21, 167
Vats H. O., Deshpande M. R., et al., 1998a, Earth, Moon & Planets, 76, 141
Vats H. O., Deshpande M. R., Shah C. R., Mehta M., 1998b, Solar Phys., 118, 351
Vats H. O., Cecatto J. R., Mehta M., Sawant H. S., et al., 2001, ApJ, 548, L87
Vats H. O., Chandra S., 2011, MNRAS Lett., 413L, 29