ASSESSING SOLAR CORONAL PARAMETERS BY DIFFERENTIAL ROTATION AND FRACTAL ANALYSIS

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ABSTRACT

Several approaches are still being used to track the revolution of the sun. Using radio measurements, we attempted to investigate coronal rotation. The change of coronal rotation with height in the solar atmosphere is investigated. We present the first measurement of differential rotation as a function of height in the solar corona in radio emission. This is calculated using disk-integrated daily observations of solar flux at 11 radio frequencies in the 275–2800 MHz range. At 275 MHz, the rotational modulation is difficult to distinguish, possibly because the turbulence in the intervening medium has a substantial impact on these emissions. It's difficult to establish if these periodic fluctuations in sidereal rotation period are partly attributable to the solar corona's latitudinal differential rotation because these studies are based on disk-integrated solar radiation at radio frequencies.

Keywords: Solar rotation; flux modulation; photosphere; image

I. INTRODUCTION

Galileo Galilee first saw sunspots in 1613, which led him to uncover the phenomenon of solar rotation. This discovery led to the invention of the telescope. Both the Earth's revolution around the Sun, which takes 365.25 days, and its rotation about its own axis, which takes 24 hours, take place every day. In a manner analogous, the Sun completes one revolution around the centre of the Galaxy every 4700 years while simultaneously completing one rotation around its own axis every 25 to 34 days. The axial tilt of the Sun is 7o 15', while the axial tilt of the Earth is 23o 30'. Due to the fact that the Sun is a gaseous globe, its rotational motion is not as precise as that of our planet. On Earth, the magnetic field is comparable to that of a bar magnet. On the other hand, the magnetic field of the Sun is not as consistently distributed. As a result, all of the inconsistencies in the magnetic field are being generated.

Both the Earth's revolution around the Sun and its rotation on its own axis both take exactly one year and one day, respectively. In a manner analogous to this, the Sun spins around its own axis while also rotating around the centre of the Galaxy at an angle of 34.7 degrees. Because the Sun is a ball of gas, its rotational motion is not quite as precise as that of our planet. On Earth, the magnetic field is comparable to that of a bar magnet. In a similar fashion, the Sun possesses a magnetic field as well. However, because of the gaseous environment, the magnetic field of the Sun does not have the same level of consistency as it does on Earth.

Because of the EVERSHED effect, the magnetic field is gradually becoming more spread out. Astrophysicist from Great Britain who worked at the British-Indian observatory under the name John Evershed (Madras in old time and currently observatory shifted to Kodaikanal). In 1909, he made the discovery that would be known as the Evershed effect. The following is an explanation of what is meant by the statement: "The Evershed effect is the radial flow of gas over the surface of the Sun (photospheric surface) of the penumbra of the Sunspots from inner border with umbra towards the outer boundary."

II. ROTATION ESTIMATION

The estimation of solar rotation may be carried out by mainly four methods listed as:

- **Tracer method**

One of the most used tracking technologies is the tracer. Full disc or totally covered solar pictures from SOHO/EIT, Nobeyama, GONG, and other sources are used in this approach. Now, utilizing the picture, a specific region/semi-permanent feature may be found for examination. The same region/feature is moved and compared to previous/next images. Thus, velocity may be determined by tracing the same location with several photos. The velocity may be used to calculate the synodic rotation period. This tracing approach may be used to determine the solar rotation of the photosphere above.

The division of a difference in angular position by a difference in time is required for tracer measurements of solar rotation. There are three methods for obtaining these differences. Either measure the time when the tracer reaches a certain place on the solar disc or cross-correlate the pictures separated by known times.

Carrington is credited with discovering differential rotation for the first time. As a result, he took the first method. He used the heliograph's longitude and latitude to calculate the rotation period based on daily Sunspot number data. The procedure necessitates a thorough understanding of an image's size, mapping, and resolution. It also needs continual measurements.

- **Spectroscopic method**

In the photosphere, the spectroscopic approach is employed for all latitudes except the poles. Because the optical depth can be determined, this approach provides a better estimate of solar rotation. Dopplerograms are used to determine the spectrum. The spectrometer is tuned to some specific frequencies and lines. The spectral lines shift due to synodic rotation, causing Doppler shift. The concentrated region is approaching closure if the spectrum line of the targeted area changes near the blue line. The concentrated region is passing away if the line changes towards the red line.

Because the optical depth of the spectral line can be measured, the Doppler shift of photospheric spectral lines reveals the rotation of plasma at the Sun's surface. In compared to the tracer approach, it gives a comprehensive measurement of solar rotation. The reason for this is that observations are taken at all latitudes (60 S to 60 N) during the solar cycle.

This procedure does have certain drawbacks. Because the observations are Earth-based, the dopplergram readings are skewed toward dispersed light. Furthermore, polarisation with the spectrograph fringes causes the instruments to be affected. As a result, the accuracy of the measurements is insufficient to determine the solar rotation rate or period.

- **Flux modulation method**

The flux modulation is primarily employed in this approach via the following mathematical analysis methods:

i autocorrelation analysis,

ii cross correlation analysis,

iii cross covariance analysis, and so on.

Because it simply employs the flux value, flux modulation is the best approach for estimating the solar rotation for all layers. The hallmark of the solar rotation may be found before using flux modulation, but measuring the exact rotation time is challenging. The mathematical functions stated all (i) Auto - Correlation, (ii) Cross - Correlation, and (iii) Cross

- Covariance can minimize the unpredictability of the data. In this case, the autocorrelation function is applied. The synodic rotation period is the autocorrelogram's first secondary maximum. The following is the definition of the autocorrelation function:

$$P_x(l) = P_x(-l) = \frac{\sum_{k=0}^{n-1}(x_k - \bar{x})(x_{k-1} - \bar{x})}{\sum_{k=0}^{n-1}(x_k - \bar{x})^2}$$

where, l = Lag,

n = No. of observations,

k = 0, 1, 2, 3, 4…

P_x (l) = Auto correlation at lag l.

III. OBSERVATIONS

The study relied on daily solar radio flux measurements taken at noon at the Learmonth observatory in Australia. 245 MHz, 410 MHz, 610 MHz, 1415 MHz, 2695 MHz, 4995 MHz, 8800 MHz, and 15400 MHz have data availability.

The measurements at 245 MHz and 15400 MHz were determined to be noisy, thus they were excluded from the research. For the rest of the frequencies, radio flux data is practically continuous (with a very few gaps). Interpolation using linear regression is used to fill in the gaps. Because additional data gaps were discovered in 1996, the fractal dimension for the year was estimated using linear regression using 1995 and 1997 data. Similarly, data breaks are more prevalent in the years 2005 and 2008, and they are addressed accordingly.

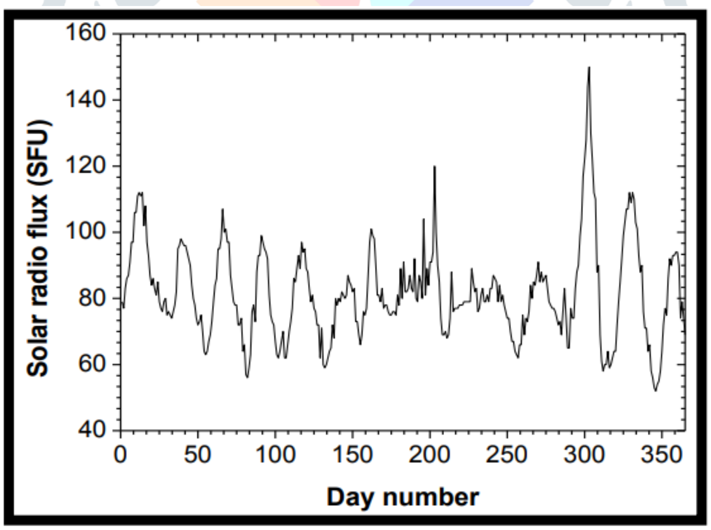

Figure 1: Sample plot for2012-solar radio flux at 1415 MHz

Figure 1 depicts a typical example of daily solar radio flux for the year 2012 at 1415 MHz, which demonstrates moderate modulations owing to solar rotation. The radio flux at 1415 MHz has a fractal dimension of 1.4 in 2012 (the method to determine fractal dimension will be detailed in the following section). The periodic fluctuations in the data cause the fractal dimension to be smaller.

IV. ANALYSIS AND RESULTS

Higuchi established the fractal analysis approach and proved that fractal dimensions are 2 and 1, respectively, for random and periodic time series.

Watari and Vats et al. utilised this approach to calculate solar radio flux. A time series must be provided for fractal analysis.

X (1), X (2), X (3)…..X (N)

From this it is possible to construct a new time series

X (m), X (m+k), X (m+2k),……………., X(m + [(N -m)/k] k)

where, ( ) are Gaussian notations and m (m = 1, 2, 3 . . . k) is an integer.

m and k are initial time and time interval, respectively.

In this way k sets of new time series are obtained.

$$L_{\langle k\rangle} = \frac{\left\{\left(\sum_{k=0}^{\frac{N-m}{k}} \left|(x(m+ik) - x(m+(i-1)k)\right|\right) \frac{N-1}{\left[\frac{N-m}{k}\right]_k}\right\}}{k}$$

Length L of the curve of the new time series can be defined as

$\langle(k)\rangle \sim k^{-D}$ +c

Where, D is the fractal dimension and

$\langle(k)\rangle$ Represents average value over k sets of Lm(k) and

c is a constant

V. CONCLUSION

Despite a considerable amount of scientific and theoretical investigation, the solar rotation has numerous difficulties and peculiarities that are not simply explained. Howard spoke through some of his previous research on solar rotation in the photosphere, chromosphere, and corona. The observed rotation characteristics throughout height are challenging to reconcile with models and our knowledge of the Sun in that work. It is now recognized that the Sun's interior revolves faster than the photosphere. The time series of solar radio flux has a fractal dimension that clearly shows fluctuations. During periods of high solar activity, the average fractal dimension is large, whereas during periods of low solar activity, it is small. This might be related to an increase in the solar corona's unpredictability. In general, the fractal dimensions get larger as the frequency rises. During low solar activity, this rise is much greater than during high solar activity.

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