Bull. Astr. Soc. India (1998) **26**, 207-209

Comparison of rotation frequencies of sunspot groups with the radial gradient of Sun's plasma rotation frequency

J. Javaraiah and M.H. Gokhale
Indian Institute of Astrophysics, Bangalore 560 034, India

Abstract. For sunspot groups occurring in latitude bin 10°-20° and living 10-12 days, we find that the mean variation, $\omega(t)$ of the rotation frequency with age, has the same trend as the radial variation, Ω(r), of the rotation frequency of the solar plasma across the convective envelope in the same latitude bin. For spot groups in given latitude intervals, which live for 2-12 days, the mean variation of the *initial* rotation frequency, $\omega_{ini}(\tau)$, of a spot group, with respect to its life span, τ, also has a trend similar to that of $\Omega(\tau)$. We have estimated depths of origin and rate of emergence of the magnetic structures of spot groups in latitudes 10° - 15°.

1. Introduction

Using the compilation of Greenwich sunspot data during 1874-1939, provided to us by Dr.Balthasar, we have investigated in detail how the rotation frequency, $\omega(t)$, of a spot group varies with its age 't' and what is the relation between the 'initial' rotation frequency, $\omega_{ini}(\tau)$, of a spot group and its life span 'τ'. We compare computed variations of $\omega(t)$ and $\omega_{ini}(\tau)$ with the radial variations $\Omega(r)$, of the plasma rotation frequency across the Sun's convective envelope. Here $\Omega(r)$ is determined using values of the coefficients of differential rotation in Figs 3a-c of Dziembowski et al.(1989), which were based on the helio-seismic data of 1986 (Libbrecht 1989). Here we give a brief summary of the results and their interpretations.

2. Results, interpretations and discussion

We find that for spot groups living 10-12 days, in each of the latitude intervals (0° - 10°), (10° -20°) and (20° - 30°), the *range* of values of $\omega(t)$ is approximately same as that of $\Omega(r)$ across the convective envelope. Importantly, in the interval 10° - 20° even the *trend* of $\omega(t)$ is found similar to that of $\Omega(r)$ across the convective envelope at 15°. This may be interpreted as follows : In this latitude interval the magnetic structures of spot groups living for 10-12 days rise across the convective envelope as the spot groups grow older. In each of the other two latitude intervals we do not see the similarity of trends between $\omega(t)$ and $\Omega(r)$. This may be due to larger non-uniformity of spot group data in these intervals. The lack of similarity in the interval 20° - 30° may also be due to higher uncertainties in $\Omega(r)$.

[We believe that the 'decreasing' trend of rotation rate with age of spot groups, reported by earlier authors (e.g. Ward 1966; Godoli & Mazzucconi 1979; Gokhale and Hiremath 1984; Balthasar et al. 1986; Zappala & Zuccarello 1991; Zuccarello 1993) was due to mixing of shorter and longer lived groups in the data sample for each given age.]

We also find that in all the three latitude intervals, $\omega_{ini}(\tau)$, as a function of τ, has trends similar to the trend of $\Omega(R_\odot - r)$, where $R_\odot$ is the radius of the Sun. This similarity of trends suggests that the spot groups with life spans of 2 to 12 days are born in successively deeper layers of the Sun.

We have determined the relation between the radial position 'r' of the magnetic structure and age, t, of the spot group as follows. First we maximize the correlation $\omega(t)$ in latitudes 10° - 15° with $\Omega(r)$ at 12°.5 by choosing horizontal and vertical scales appropriately. We then determine the coefficients of linear relation between r and t by least square fitting of $\omega(t)$ with $\Omega(r)$. Similarly, we also obtain the relation between the radial location 'r' of the generation of the spot group, and its life span τ. From these relations (i.e., from the values of intercepts and slopes) we estimate the following :

(1) The magnetic structures of spot groups in latitudes 10° - 15°, and of life spans 10-12 days, originate at r~ 510000 km (i.e. near the base of the convective envelope) and rise across the envelope at the rate of ~ 17 Mm/day (i.e., ~ 200m/s).

(2) The magnetic structures of spot groups of life spans $\leq$ 2 day are formed at $r\sim$ 700 Mm, (i.e near the Sun's surface) and those of spot groups with successively longer life spans between 3 and 9 day are formed at successively increasing depths at the rate ~ 21Mm/day (ie., ~240m/s). This also confirms that spot groups with $\tau > 9$ days originate at $r \leq$ 510000km.

The result (2) is consistent with the conventional belief that the 'main' mechanism of solar activity (e.g., the one that generates spot groups living longer than 10 days), operates near or below the base of the convective envelope. Result (1) is consistent with the conclusion of Howard and LaBonte (1981) that the magnetic flux of an active region rises on a time scale of 10 days. Incidentally, in the model of Choudhuri and D'Silva (1990) the 10 day rise flux tube would correspond to initial strength ~ 10^5 G.

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