Can sunspots be produced by equipartition magnetic fields residing at the bottom of the convection zone?

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Joy's law states that the line joining the two poles of a bipolar magnetic region (BMR) makes an angle with the latitudinal line, called the tilt, which increases with increase in latitude. If the solar dynamo operates at the bottom of the convection zone and the BMRs on the surface are produced by the fields generated there, then they should obey Joy's law. We give a theoretical model for these tilts, and show that the observations severely constrain the field strength at the bottom of the convection zone between 60 and 160 kG. For fields stronger than 160 kG, magnetic buoyancy dominates over Coriolis force and the tilts produced are very small compared to the observed. Whereas, for fields weaker than 60 kG, Coriolis force dominates over buoyancy and makes them emerge at very high latitudes, well above the typical sunspot latitudes.

Fields above 60 kG are an order of magnitude stronger than the fields that can be in energy equipartition with the velocity fields at the bottom of the convection zone. Such strong fields will severely inhibit dynamo action. In addition, we do not know how a dynamo could produce such a strong field. We propose a couple of mechanisms by which equipartition fields could possibly produce BMRs with the observed tilts: (a) Giant cells, if they exist, can dominate over Coriolis force and drag these equipartition fields in their updrafts, (b) Small scale turbulence can interact with the flux tube and exchange momentum with it, thus suppressing Coriolis force and making them emerge at the sunspot latitudes.

We show that these two mechanisms can make equipartition fields emerge at the sunspot latitudes with the proper tilts, provided their sizes are smaller than a couple of hundred kilometers. We also show that special anchoring mechanisms have to be invoked in order to make equipartition fields of any size produce BMRs with the observed tilts.

The Maintenance of the Sun's Differential Rotation and Its Temporal Variations

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The horizontal momentum balance equation has been solved to infer the strength of the meridional circulation and Reynolds stresses at the Sun's surface from the observed differential rotation. The meridional circulation and Reynolds stresses are important for maintaining the equatorial acceleration, which sustains the differential rotation. Our results indicate that the average value of the meridional circulation is around 1.1 m/sec\(^{-1}\), with circulation directed towards the poles in both hemispheres, and the average magnitude of the Reynolds stresses is 3.6 \times 10^{-7} m^2/s^2, with transport of angular momentum directed towards the equator in both hemispheres. This is in excellent agreement with observations. We also obtained estimates of yearly variations of the equatorial angular velocity, and our results are compatible with observations.

On Sound Generation by Turbulent Convection: A New Look at Old Results


We have revisited the problem of generation of acoustic waves by turbulent convection in an isothermal atmosphere. The theory of sound generated aerodynamically has been originally developed by Lighthill and later modified by Stein to include the effects of stratification. Lighthill and Stein's results have been extensively used to estimate the amount of acoustic wave energy generated in the solar and stellar convective zones. We have recently recognized that Stein's treatment of turbulence requires some corrections and that these corrections lead to significant changes in the obtained results. In this paper, we present the correct status of computing the acoustic wave energy fluxes by incorporating a physically meaningful description of the spatial and temporal spectrum of the turbulent convection. We show the dependence of the obtained wave fluxes on the nature of turbulence and discuss the efficiency of acoustic wave generation in the solar convective zone.

A Test of a Moment Technique for Vector Field Calculations

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Since last year, we have been using a moments technique to calculate the solar vector magnetic field from measurements of the Stokes profiles from the San Fernando Observatory Video Spectra-Spectrohellograph (SFU VS3H). As part of our evaluation of the accuracy of this technique, I have carried out simulations using analytic profiles. Let \( S_n \) be the nth moment of Stokes profile \( S(\lambda) \). That is:

\[
S_n = \int \lambda^n S(\lambda) d\lambda
\]

where \( \lambda = 0 \) is taken at line center and the integral is done over the line profile. We use the following approximations:

\[
\begin{align*}
Q_1 &= \frac{1}{2} B^2 \sin^2 \gamma \cos 2\chi \\
Q_2 &= \frac{1}{2} B^2 \sin^2 \gamma \sin 2\chi \\
V_1 &= B \cos \gamma
\end{align*}
\]

where \( B \) is the magnitude of the field, \( \gamma \) is its inclination to the line of sight, and \( \chi \) is its azimuth angle. These approximations are exact if the Stokes profiles are given by the Sears formula. We have applied them to profiles generated in the Unno-Rachkovskiy solution to the transfer equation, and show that they are a useful approximation for more realistic line profiles as well. The largest systematic errors are in the azimuth angle \( \chi \), with smaller errors in determination of the longitudinal component of the field and essentially no error in determining the magnitude of the transverse component.

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Observations of Changes in Sunspot Cooling

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The larger and more rapid changes in the total solar irradiance have been identified with the passage of large sunspot groups across the solar disk. These dips have been modeled by use of the PSI function which assumes a constant value of thermal contrast, \( \alpha \), from one spot to another. We present results from digital images of sunspot groups obtained at 672.3 nm using a photometric telescope with an aperture of 2.5 cm. In addition to a digital PSI, these data can also be used to determine the pixel-by-pixel photometric deficit, Def. The ratio of these two quantities, PSI/Def, is proportional to \( \alpha \). We define \( \alpha \) to be 0.2 \* (PSI/Def). This definition will differ by \( -15\% \) from that used in the PSI because our deficit measurement is monochromatic. For 18 spot groups, we find a mean \( \alpha \) of 0.34 ± 0.014, although extreme values range from 0.24 to 0.46. We find that \( \alpha \) for a particular sunspot