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On the behaviour of sunspots in solar plasma: sunspot decay

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Abstract
There are two main fundamental achievements in connection with statistical studies of solar sunspots and sunspot groups. One of them is that the mean decay rates of sunspot groups are lognormally distributed, the other one is that the decay rate of sunpots is proportional to the relative radius of the spot. The preceding study is based on the Greenwich Photoheliographic Results (GPR), the latter one is based on the Debrecen Photoheliographic Results (DPR). Now the Debrecen Photoheloigraphic Data (DPD) will be used to verify the above achievements and discuss the usefulness of DPD for such statistical studies.
Keywords: *Sun, sunspots, sunspot groups, decay*

1 Introduction

Sunspots are very spectacular features. They appear in the solar photosphere as dark areas compared to their environment. It is commonly known that this is caused by their much larger magnetic field which originates from the bottom of the Sun's convective layer. In this layer a magnetic flux tube of some $10^5 G$ is situated. Some perturbation can lead to arising magnetic flux that can form a pair of sunspots in the photosphere after about one month. It has been shown that just before these appear, the flux tube takes a tree-shape: this is called a magnetic tree. Therefore, sunspots usually appear in groups. After its birth, a sunspot begins to grow, it reaches a maximum area, then it starts to decay and finally disappears. The latter phase is in the focus of our investigation. A review on sunspots can be found in Solanki (2003). Several papers studied the decay law of sunspots. There are two fundamental questions: what is the decay law and why is *that* the decay law.

The first paper on the form of decay curve was Bumba (1963). He concluded that there are two types of curve. One of them is a rapid, exponential curve for the decay phase and typical of non-recurrent groups. The other type is when the rapid decay phase is followed by a linear phase. Later Moreno-Insertis et al. (1988) showed that no such differences exist between recurrent and non-recurrent spot groups and a parabolic decay law is more likely. In these two studies the Greenwich Photoheliographic Results (GPR) was used. Most recently Petrovay and van Driel-Gesztelyi (1997) found evidence for a particular parabolic decay law, specifically the decay rate is proportional to the relative radius of the sunspot. They processed the very detailed Debrecen Photoheliographic Results (DPR) that contains data not only for spot groups but also for individual spots, but unfortunately only for the years 1977 and 1978.

The answer for the second question is an appropriate model that reproduces the fundamental requirements. The spot boundary has to be sharp during the decay phase; this is an obvious observational fact. The relation between the lifetime and the maximum area of a sunspot group is linear (Gnevyshev, 1938; Waldmeier, 1955). The central magnetic flux density has to be more or less constant in time. And finally, the model has to reproduce the decay law. In Petrovay and van Driel-Gesztelyi (1997) Table I. shows the predictions of different sunspot decay models. Among them the turbulent erosion model (Petrovay and Moreno-Insertis, 1997) can satisfy all of the above requirements.

Another interesting achievement is that the average decay rate of sunspot groups follows a lognormal distribution. Assuming a parabolic decay law, this distribution shape comes naturally (Martínez Pillet et al., 1993).

The goal of this paper is to detect the lognormal shape of decay rate distribution and the decay law, using the DPD catalogue. This is a preliminary work, hence we will invoke only some basic statistics in order to decide whether this catalogue is suitable for such an investigation or not. In Sec. 2 the catalogue will be introduced, and selection criteria will be presented. Then we will describe the methods applied to test the lognormality (Martínez Pillet et al., 1993) and to try the parabolic decay curve in Sec. 3. Finally, in Sec. 4 we will give a short discussion.

2 Data

DPD is a catalogue that will contain sunspot data from 1986 up to now. Now the processing of daily solar white-light plates is partly completed: data are available for the years 1986-1988 and 1993-1996 (Győri et al., 2003).[1] Incomplete data are also available for years 1989, 1997 and 1998. In the catalogue, areas and positions of sunspots can be found for every day. This study invokes areas and corresponding observational times in order to determine the decay rates. Because of the lack of day-by-day sunspot identification, we could only use sunspot group data. It has to

[1] ftp://fenyi.solarobs.unideb.hu/pub/DPD

be noted that the catalogue uses NOAA number that corresponds to an *active region* which is not necessarily the same as a *sunspot group*.

Some selection has been made on the database. It was demanded that at least 3 observations had to exist for a group. This is the minimum number of data that is required to calculate the instantaneuos and the average decay rate. Commonly, there is a requirement for the position, because near the solar limb the foreshortening effect causes a large error even if it is eliminated. In this study the absolute value of the distance in longitude from the central meridian (LCM) is less than 65°. Lastly, only those spot groups have been included whose areas reach the value of 10 MSH[2] at least once.

3 Methods

3.1 Lognormality

The density function of a lognormal distribution is

$$\frac{1}{\sqrt{2\pi}\sigma' D} e^{-\frac{(\log D-\mu')^2}{2\sigma'^2}}.$$

Here D is the average decay rate of a sunspot group, derived from a linear fit to area and time data. μ' and σ' are the mean and the standard deviation of $\log D$, respectively. Three methods have been used to test the hypotesis of lognormal distribution.

First, the skewness and the kurtosis of the distribution has been estimated:

$$g_1 = \frac{1}{n}\sum_{i=1}^{n}\left[\frac{(\log D)_i - \mu'}{\sigma'}\right]^3,$$

$$g_2 = \frac{1}{n}\sum_{i=1}^{n}\left[\frac{(\log D)_i - \mu'}{\sigma'}\right]^4 - 3.$$

In the precise form of g_1 and g_2, they are multiplied by a factor that depends on the sample size (n), but as we have $n = 886$, this factor is close to 1 with 10^{-3} error. If a random variable is lognormally distributed, it means that the logarithm of the variable is normally distributed. The skewness and the kurtosis of a normal distribution are equal to zero. The variance of g_1 and g_2 can be estimated from $\text{var}(g_1) = \frac{6}{n}$, and $\text{var}(g_2) = \frac{24}{n}$. Another way is to generate similar samples with Monte Carlo (MC) simulations and calculate the "real" variances of them. Here we have used 250 simulations with sample size $n = 900$. The correspondig values are in Tab. 1. Considering those values, $g_1 = -0.067 \pm 0.082$ and $g_2 = 0.201 \pm 0.16$, so we say the test is positive.

[2] 1 MSH $= 10^{-6} A_{1/2\odot}$

Table 1: *Estimation of skewness and kurtosis.*

	value	var	var_{MC}
g_1	-0.067	0.007	0.007
g_2	0.201	0.027	0.023

However, higher moments of a distribution are not robust estimators, especially in the case when we have significant outlier points in the sample. Hence, another standard method has also been invoked. The χ^2-test for goodness of fit leads to $\chi^2 = 22$. For 95% significance level, the corresponding χ^2 value is 27.6 (for 17 degrees of freedom), therefore this test is positive, too. The observed and the estimated density functions are shown in Fig. 1.

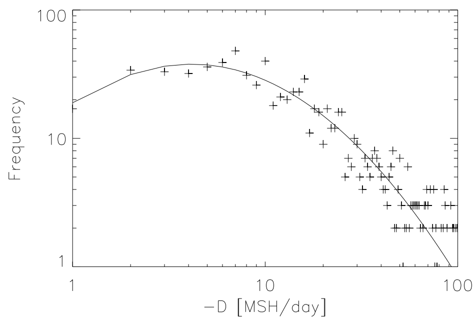

Figure 1: *The observed and the estimated density function: the crosses show the observed histogram of decay rates; the solid line shows the estimated density function scaled up with number of data. Both axis are logarithmic.*

3.2 Decay law

The form of the decay law according to Petrovay and van Driel-Gesztelyi (1997) is

$$D = C_D r / r_0,$$

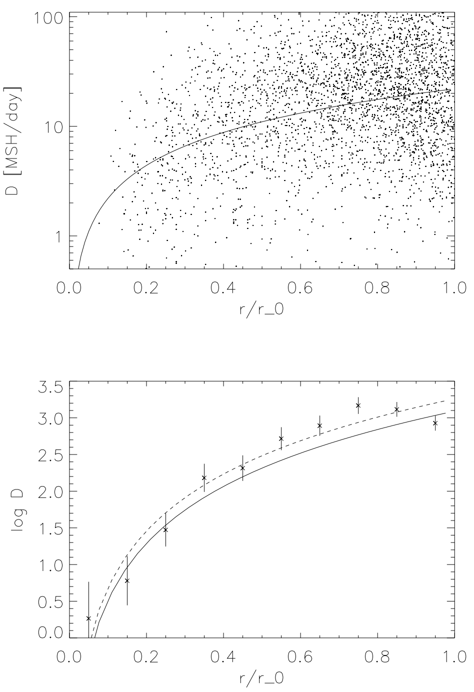

Figure 2: *Calculated instantaneous decay rate via relative equivalent radius are indicated with points for the original (left) and with crosses for the binned (right) data. The dashed line shows the linear fit to the data. The solid line comes from the turbulent erosion model (Petrovay and van Driel-Gesztelyi, 1997).* 2σ *error bars for the mean are shown.*

where r is the equivalent radius of the spot, r_0 is the maximum equivalent spot radius, and $C_D = 32.0 \pm 0.26$. Here, D means the instantaneous decay rate. This result was derived for individual sunspots using binned data from DPR. We have calculated the intantaneous decay rates with the same method as described in the latter paper but for spot groups using DPD. The results are depicted in Fig. 2. After binning the data, we can fit 3.2 to the data. This resulted in $C_D = 26.0 \pm 1.12$. The errors show that the relative error for our study is larger than for the previous study. However, our value for C_D is a bit closer to that value, which comes from the turbulent erosion model.

4 Discussion

Two statistical investigation has been made using DPD: the lognormal distribution of decay rates and the decay law of sunspot groups. The hypotesis of lognormal distribution was accepted, because both statistical studies led to positive results. This confirms a previous achievement of Martínez Pillet et al. (1993), which was made with GPR. The other investigation was to try the parabolic decay law. From this study, we can conclude that using sunspot group area data of DPD, the parabolic decay law - where the instantaneuos decay rate is proportional to the relative spot radius - can be verified.

We come to the conclusion that DPD is suitable for such statistical investigation. However, previously it has been shown that if we would like to get reliable information about the decay law, we have to use sunspot data. Hence, further effort will intent to identify sunspots day-by-day in the DPD catalogue. Another notable and relevant factor that sunspot groups and active regions (i.e., NOAA regions) are not necessarily the same and mixing them can lead to further errors in statistical studies.

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