Reduction of Spatially Resolved Magnetic Fields by Scattered Light.

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Other authors to be added

During the first two years of observations at WSO (1976-1977) the mirrors (and lenses) were often very dirty giving rise to significant amounts of scattered light (several percent). It is well known that scattered light has a dramatic influence (reduction) on Doppler measurement values of solar rotation (DeLury, *J.R.A.S. Canada*, 1939; Scherrer *et al.*, *Ap.J.*, 1980). It is, perhaps, less appreciated that scattered light also has a dramatic influence (reduction) of the values of magnetic fields measured with spatial resolution on the disk, although, in retrospect that should have been obvious. Here we report on experiments at WSO to quantify the magnitude of the reduction as a function of the amount of scattered light. The reduction has implications for values of the polar fields used in predicting the size of the solar cycle.

The initial observations (reported in Svalgaard et al., *Proc. Workshop Solar Rotation*, Catania, 1979) were made in September of 1978 (a period of high solar activity, R_z = 138) by dusting the mirrors with fine chalk dust from felt-erasers for blackboards and recording magneto/Doppler/intensity grams with progressively larger amounts of scattered light, measured 2 arc minutes outside the limb. These observations are included here for comparison. A new series of observations has been made (and might be extended – see later) in May, 2009 using Johnson & Johnson Baby Powder with essentially the same result, as we report in detail below.

The analysis was made on data from a 21x21 grid with 369 data points inside the limb [*question: made how, I thought we had 11x21*]. The 369 corresponding data points from two magnetograms taken as closely as possible in time [typically two hours] are plotted against each other, the abscissa for a magnetogram with no or minimal scattered light (less than 1%) and the ordinate for a magnetogram with considerable scattered light:

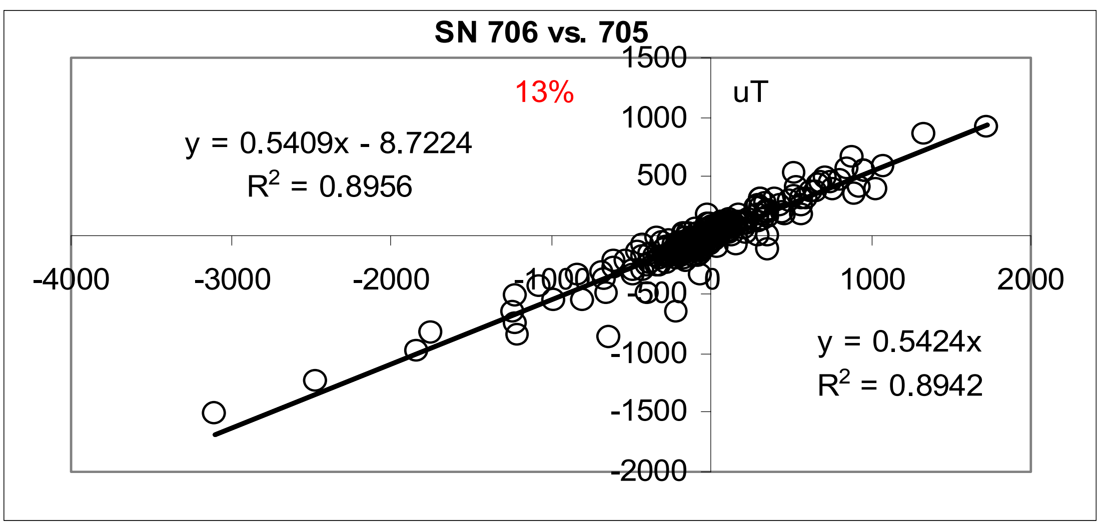

Figure 1: Comparison from 16 Sept. 1978, serial number 706 (13%) versus 705 (1%).

Two regression lines are shown [at times indistinguishable], one forced through the origin. In Figure 1 it is clearly seen that 13% scattered light reduces the readings by a factor of 0.5424 rather uniformly over the disk and for both low and high field strength. Figure two shows a comparison from the new series:

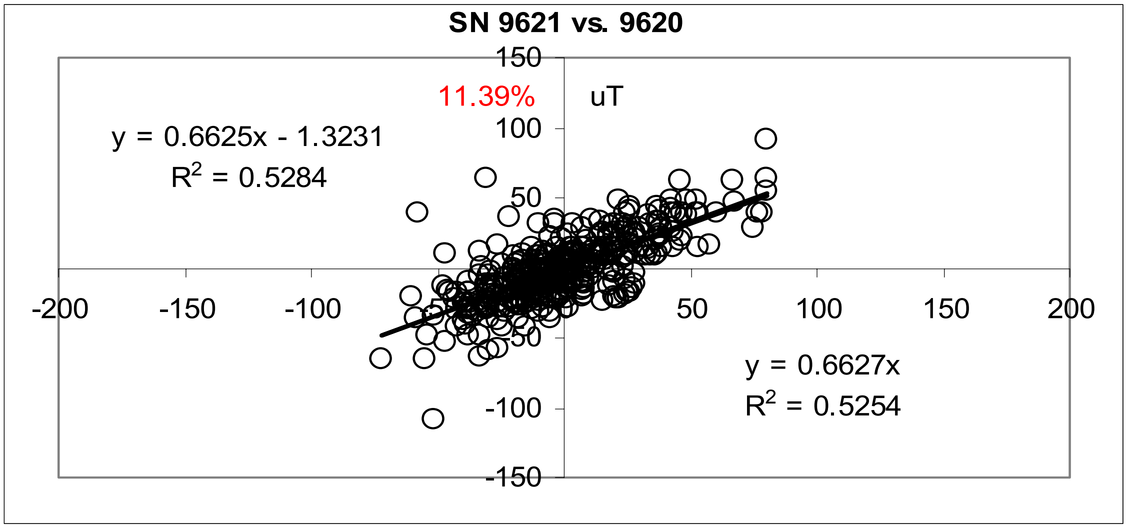

Figure 2: Comparison from 8 May 2009, serial number 9621 (11.39%) versus 9620 (0.18%).

The field is an order of magnitude weaker, but still the comparison shows a good correlation with a reduction of a factor of 0.6627. Figure 3 shows yet another example with somewhat higher field strength and corresponding improved correlation:

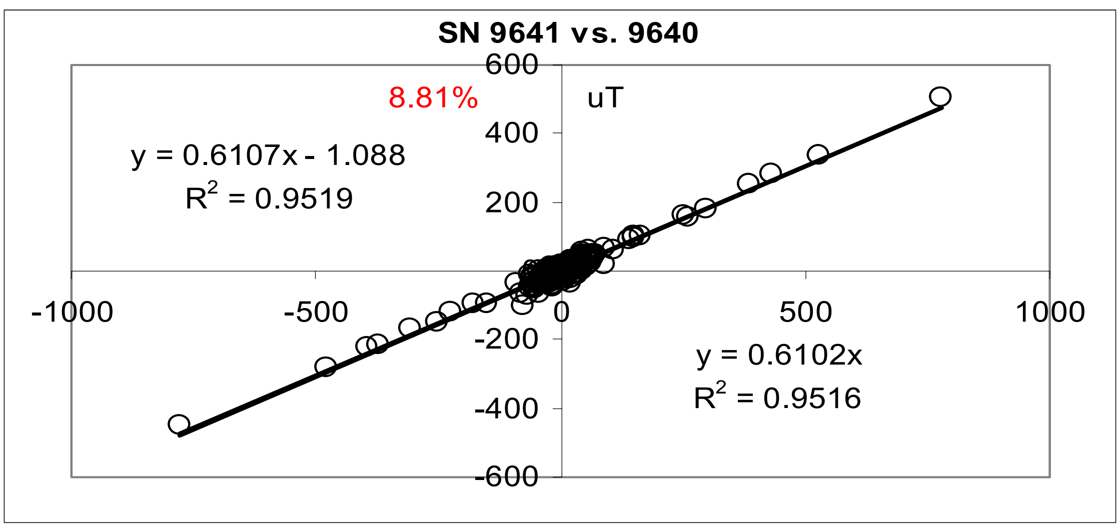

Figure 3: Comparison from 16 May 2009, serial number 9641 (8.81%) versus 9640 (0.22%).

A little bit of activity instantly improves the correlation, but in all cases we see a consistent pattern: increasing reduction with increasing scattered light, and the effect is large. Even over a time duration of two hours there is some difference to be expected between two magnetograms due to rotation and active region development. We can get a measure of how serious the difference is by comparing magnetograms with little or no scattered light. Figure 4 shows a typical case:

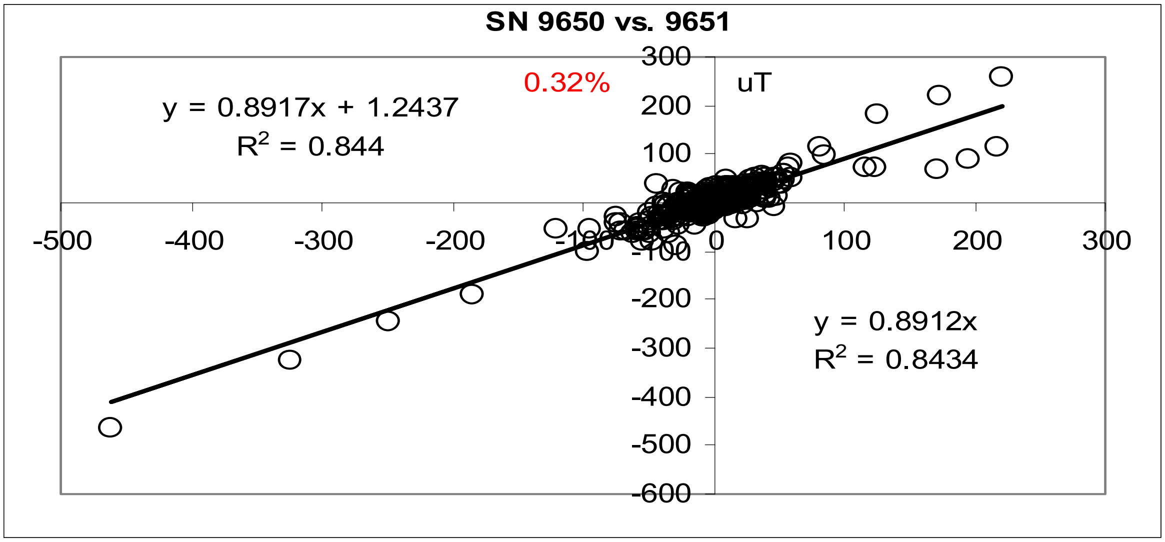

Figure 4: Comparison from 21 May 2009, serial number 9650 (0.31%) versus 9651 (0.33%).

Plotting all comparisons we get Figure 5:

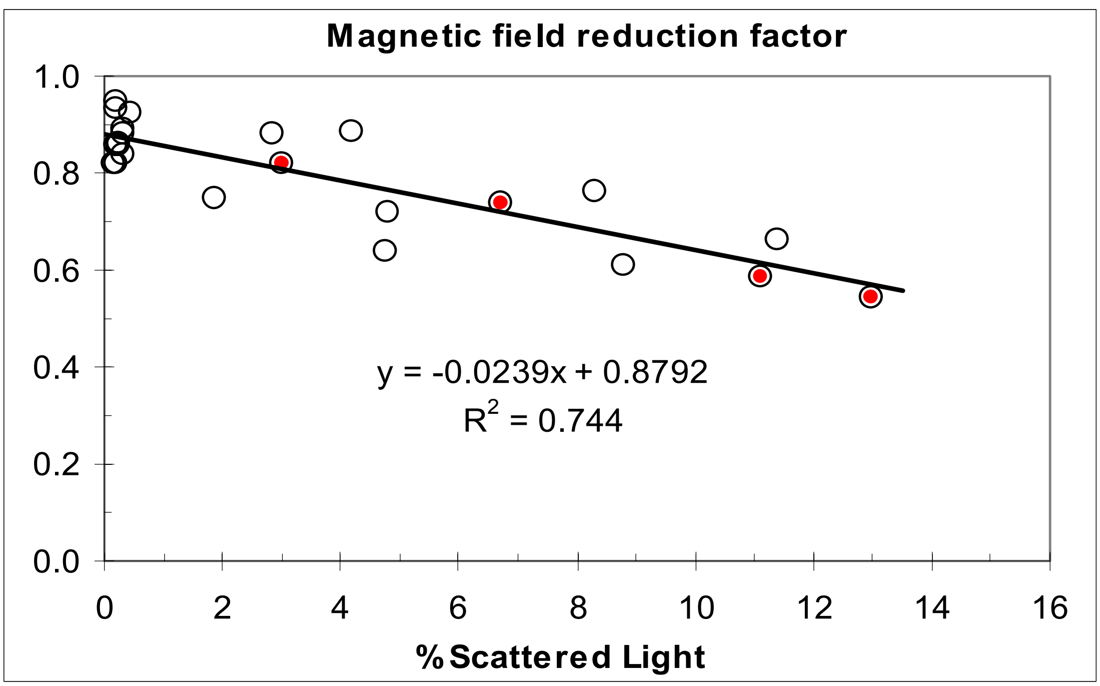

Figure 5: Reduction factor as a function of scattered light. 1978 series marked with red dots.

The scatter of the 2009 series is larger than for the 1978 series as we would expect from the 6 times smaller RMS value of the magnetic field over a magnetogram, but the trend is clear enough. The crowded points near zero percent scattered light show clean-mirror magnetograms compared to the following one and give an indication of the uncertainty and of the effect of rotation and evolution. [Because of the larger scatter I would like a few more points here, especially up near 10% scattered light – much more than that is impossible to get because the image becomes too faint for reliable limb-finding and guiding].

A second method that is less sensitive to rotation is to compute the root-mean-square value of the magnetic field over the magnetogram and form the ratio of the two rms values for a case of large scattering compared to adjacent magnetogram of little or no scattering (Figure 6):

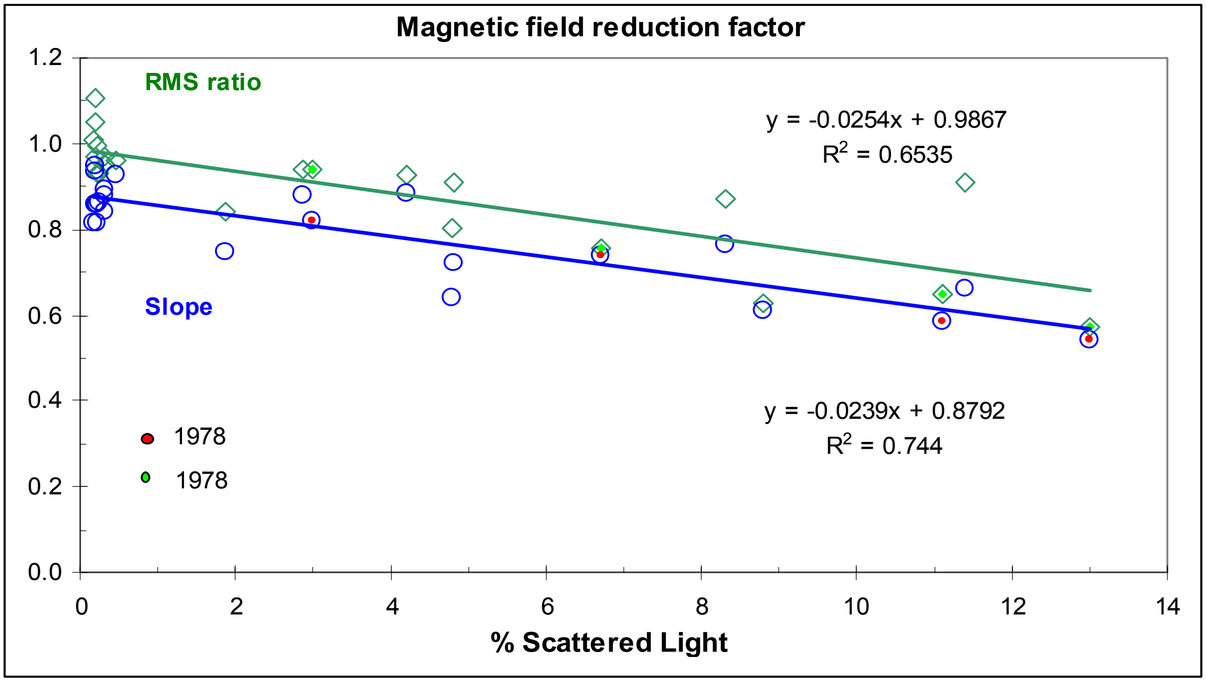

Figure 6: Magnetic field reduction factor as a function of scattered light. The 1978 series are marked with colored dots in the center of the plotted symbols. The upper data points (green diamonds) show the variation of the ratio of the rms of the fields over the two magnetograms.

The RMS ratio is much closer to one for no scattered light and generally lies above the slope points for all values of scattered light. A preliminary estimate of the reduction due to scattered light seems to be ~2.5% reduction of the field for each percent scattered light.

The next step is to determine the amount of scattered light for each magnetogram during the 1976-1978 interval. From September 1978 on, the mirrors were generally [although not always] kept clean enough that scattered light could be ignored. Measurements of scattered light started only after the problem had been identified in 1978, so we have to use the method described in Scherrer *et al.* [1980] and derive the amount of scattered light from the reduction in image brightness. A variation on this method is to assume a constant equatorial rotations rate ond compute the scattered light from the difference between the assumed rate and the observed Doppler rate. Figure 7 shows the values designated 'a0' and 'a1' for the first dozen years of observations. The decrease in rotation rate during 1976-1978 due to scattered light is clear. [Q*uestion: what exactly are a0 and a1? Need to read up on that Different differential rotation laws?*]. The relationship found by Scherrer *et al.* [1980] was: V_{obs} = 2030 – 32 S, allowing the percentage of scattered light, S, to be calculated from V_{obs}, at least in a statistical sense. Figure 8 shows the result.

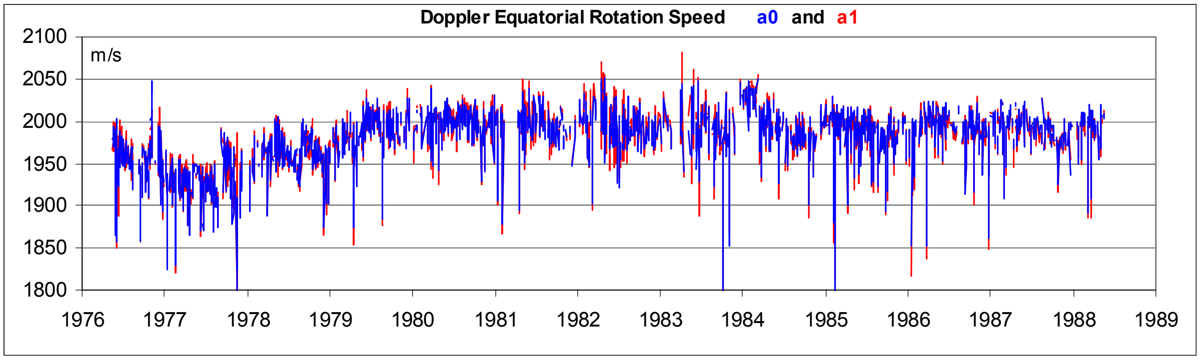

Figure 7: Doppler equatorial solar rotation rates *a0* (blue) and *a1* (red) observed at WSO

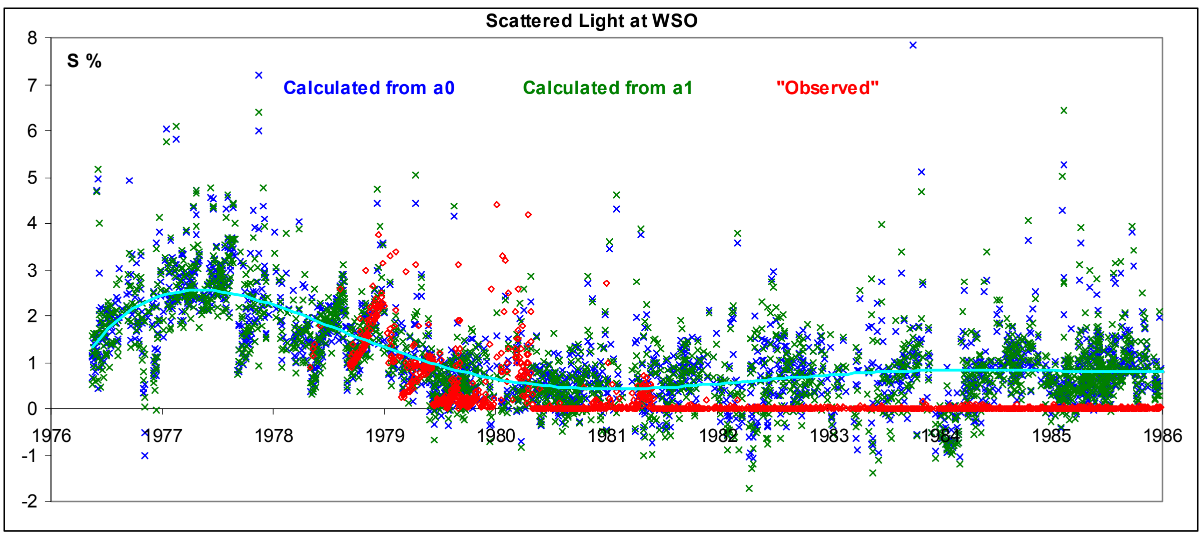

Figure 8: Calculated and 'observed' percentage of scattered light as WSO. Observations with 'too many' Trouble Bits have been omitted.

The 'agreement' between calculated *S* and *S* as stored in the WSO data files ("Observed") is reasonable up to and including observation serial number 1230. From 1231 on [2 May 1980] this is no longer the case, the 'observed' S being essentially zero. One could adopt various approaches to this: 1) ignore the problem since we are only concerned with 1976-1978, 2) investigate what happened and if the 'observed' values can be corrected or recovered. I have not made any decision on this and not brought the analysis up to the current date, pending some discussion of this.