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A record low in solar activity inspires theorists about grand minima (News & views on the paper by Choudhuri & Karak on the Maunder minimum)

Axel Brandenburg

Abstract No Abstract for News and Views

In the past few months, many have been wondering whether the time for the next grand minimum has come. We know it is long overdue, and, more cautiously, Jürg Beer and collaborators (Abreu et al. 2009) have estimated that the current grand *maximum* should soon come to an end. Nevertheless, the idea of us facing a new grand minimum just like the one after the time of Galileo is hard to imagine. In 2007, NASA reviewed predictions for Cycle 24 in order for them to judge the cost-efficiency of another maintenance mission to the Hubble space telescope before it has to be ditched. A strong Cycle 24 would imply an elevated ionosphere, and thus more friction for nearby satellites orbiting the Earth. Indeed, none of the 45 predictions included the possibility that the next sunspot maximum might not come back at all.

In this situation, the latest work of Choudhuri and collaborators comes as a timely reminder of an important and yet unsettled issue: what causes grand minima to occur? The realization that the Maunder minimum between 1645 and 1715 was real, and not just a gap in the observations, goes back to John A. Eddy (Eddy 1976) just over 30 years ago. That was the time when chaos theory was being developed. Reza Tavakol (Tavakol 1978) was perhaps the first to spell out the possibility that the Sun might be chaotic and that grand minima may be associated with intermittency. Soon afterwards, Alexander Ruzmaikin (Ruzmaikin 1981) and later Nigel Weiss and collaborators (Weiss et al. 1984) showed that a truncation of the solar dynamo equations takes the form of the famous Lorentz equations — a prototype for chaos.

Later, another possibility for chaotic dynamo solutions was discussed: stochastic noise. There are good physical reasons why there should be noise. The dynamo equations considered in this context are mean field equations where averaging is performed over a finite number of turbulent eddies. Peter Hoyng showed that such an average will not be completely steady, but it must fluctuate (Hoyng 1988). He already predicted that “It is to be expected that models studying the effect of fluctuations ... will nevertheless appear in the literature, but the difficulty ... is clear: F will be chosen essentially arbitrarily...”. Indeed, Choudhuri (Choudhuri 1992) did include the effect of noise and estimated the resulting variations in the cycle length, but then Spiegel and collaborators (Platt 1993) also discussed such noise in the context of explaining grand minima. They pictured that noise might literally turn the dynamo on and off if the dynamo is close to being marginally excited. Hence, they called it on/off intermittency.

Until recently, there were no good ideas about what is the most physical way of implementing such noise. This is where help came through recent attempts to use dynamo models to predict the next cycle maximum. In order to use a model for prediction, one must somehow synchronize it with the actual Sun. Different ideas have been put forward. One school of thinking suggests using the past record of sunspot counts to adjust the efficiency of the dynamo effect (Dikpati et al. 2004; 2006). One good reason for doing it this way is that sunspot numbers are available for a very long time now. Another school suggests using what is called the Sun’s dipole moment (DM). This idea goes back to Svalgaard and collaborators (Svalgaard et al. 2005), and, in a more rudimentary form, to Schatten and collaborators (Schatten et al. 1978). The DM value is determined essentially by the magnetic field near the poles and it is also loosely related to the poloidal field. The polar field is strongest 1-2 years after the solar maximum and it is also much less noisy than the field at lower latitudes where sunspots emerge. Another good thing about using the DM value is that the physical process leading to the next maximum is the winding up of the poloidal field, of which DM is a good proxy. So, obviously, a strong poloidal field or a large DM should lead to a strong maximum and a weak one or small DM should lead to a weak maximum (Choudhuri et al. 2007).

In their new paper, Choudhuri and Karak used a similar procedure to either induce a grand minimum in their model, or otherwise to use it as a predictor for the likelihood that one is imminent in our Sun. This is, of course, just a logical extension of their earlier work. If one accepts that the DM value at the solar minimum is the main indicator about the future activity of the Sun, it ought to also contain information about a complete shut-down of sunspot activity. Unfortunately, DM values are only available for cycles 20, 21, 22, and 23. However, the trend of those DM values is dramatic: both cycles 20 and 21 had a relatively healthy value of about 250 and $245\mu\mathrm{T}$, respectively; cycle 22 was somewhat weaker with a DM of $200\mu\mathrm{T}$, but then for cycle 23 the DM dropped to $119\mu\mathrm{T}$. So, the question is whether this last DM value is already so low that one must fear a complete collapse in the sunspot number. The calculations of Choudhuri and Karak suggest that the answer is probably *no*, and that it would need to be lower than that for a real grand minimum to occur.

But, even if the DM values were somewhat less, this would still only be about one third of the largest DM measured so far. So why should that already be dangerously low? This depends on the relation between the actual magnetic field in the Sun and the resulting sunspot number. It has long been speculated that this may require some kind of threshold behavior. This became quite evident when Jürg Beer and collaborators announced that the solar cycle continued throughout the Maunder minimum (Beer et al. 1998). Their result was based on the beryllium 10 record from the Greenland ice cores. Unlike the carbon 14 record from tree rings, the beryllium record has a high enough time resolution to resolve not just the past few grand minima, but also individual cycles. The beryllium record reflects the strength of galactic cosmic rays on Earth which, in turn, signifies the shielding effect of the magnetic field in the Heliosphere and thus, ultimately, the strength of the dynamo. Given that the beryllium record suggests only a relatively small reduction during the Maunder minimum, it is clear that the relation between field strength and the emergence of sunspots must be extremely sensitive. This is also clear by looking at the synthetic field strength in the paper of Choudhuri and Karak, where one would have hardly expected anything dramatic to happen based on their trace of the field strength alone.

With all this new insight in mind, one may even ask, how come the sunspot record has been as persistent as it was over the past 260 years? We may not be able to decipher the answer from past data, but it is already now clear that this unexpectedly huge dynamical range of sunspot variability displayed by the sunspot record during our life time will provide unique insight to understanding essential pieces in the solar dynamo puzzle.

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