8th Asia-Pacific Conference on Plasma Physics, 3-8 Nov, 2024 at Malacca

Dynamo modelling for cycle variability and occurrence of grand minima in Sun-like stars: Rotation rate dependence

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Many solar-type stars with spectra types early F to M produce cycles in their magnetic fields with varying properties. Like the solar cycle, stellar activity cycles are also irregular[1]. Observations reveal that rapidly rotating (young) Sun-like stars exhibit a high level of activity with no Maunder-like grand minima and rarely display smooth regular activity cycles. On the other hand, slowly rotating old stars like the Sun have low activity levels and smooth cycles with occasional grand minima. We, for the first time, model these observational trends using flux transport dynamo models. Following previous works[2], we[3] build kinematic dynamo models of one solar mass star with different rotation rates. Differential rotation and meridional circulation are specified by computing them using a mean-field hydrodynamic model. We include stochastic fluctuations in the Babcock-Leighton source of the poloidal field to capture the inherent fluctuations in the stellar convection. Based on extensive simulations, we find that rapidly rotating stars produce highly irregular cycles with strong magnetic fields and rarely produce Maunder-like grand minima, whereas the slowly-rotating stars (with a rotation period of 10 days and longer) produce smooth cycles of weaker strength, long-term modulation in the amplitude, and occasional extended grand minima (Figure 1). The average duration and the frequency of grand minima increase with decreasing rotation rate (Figure 2). These results can be understood as the tendency of less supercritical dynamo in slower rotating stars to be more prone to produce extended grand minima. We further conclude that even in rapidly rotating stars for which the star spots appear at high latitudes, the Babcock-Leighton dynamo operates[3].

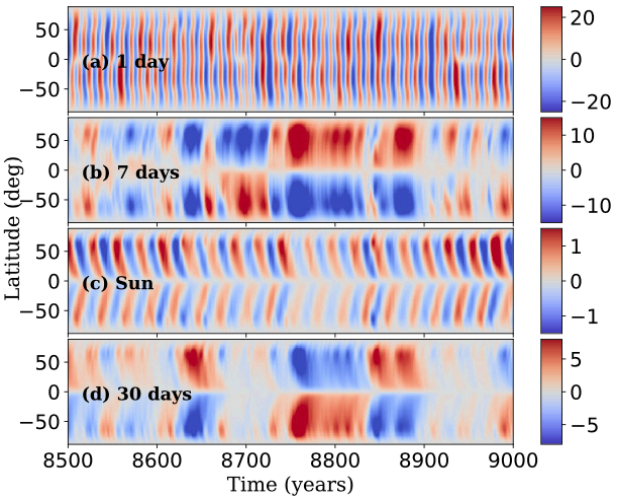

Figure 2. Time–latitude distributions of the toroidal field at the base of convection zone for different stars with rotation period of (a) 1 d, (b) 7 d, (c) the solar value (i.e. 25.38 d), and (d) 30 d from our dynamo model..

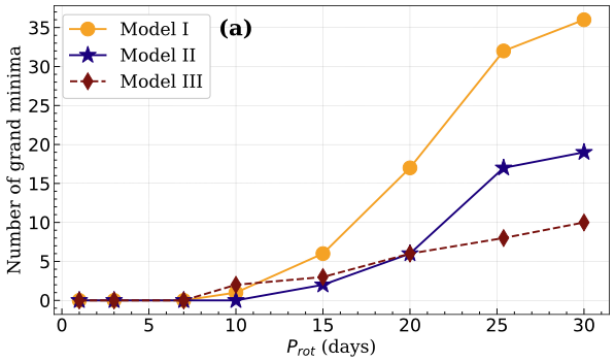

Figure 2. The number of grand minima produced in different stars vs the rotation period of the star produced in three different dynamo models. This figure implies that stars with rotation periods similar to the Sun (rotation period ~ 25 days) produce frequent grand minima.

References

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