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Memorie della

Solar and stellar variability

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Abstract. The magnetic dynamo that is responsible for the variability of the solar atmosphere has functioned throughout the history of the Sun, as it does in the multitude of Sun-like stars. Combined solar and stellar observations provide insight into the variability of the Sun's energy output on time scales up to billions of years. This brief overview references select areas of current research.

1. Introduction

Stellar observations suggest that the Sun was magnetically active even before it became a hydrogen-burning star (see Schrijver and Zwaan 2000, for an introductory overview of solar and stellar magnetic activity). That activity has been smoothly declining over billions of years as angular momentum is lost through a magnetized solar wind (e.g., Schrijver et al. 2003). The associated spectral irradiance has decreased most dramatically in the hard X-ray domain, likely reaching a million-fold decrease by the end of the main-sequence phase as the dominant coronal heating shifts from flares to quiescent heating (e.g., Güdel et al. 1997, 2003; Guinan et al. 2003; Ribas et al. 2005). In contrast, the bolometric luminosity of the Sun will have slowly increased by a few tens of percent in response to the continuing conversion of hydrogen to helium in the core (e.g., Gaidos et al. 2000; Sackmann and Boothroyd 2003). The young Sun likely exhibited massive (clusters of) starspots, including polar spots, covering perhaps more than 50% of its surface (e.g., Schrijver 2002). The darkening by large spots apparently outweighs the brightening associated with the magnetic faculae in active, young stars, causing their activity and bolometric irradiance to vary in phase, contrary to what we observe in the present-day Sun (e.g., Lean 1997; Lockwood et al. 1997). The cyclic variability shown by the Sun is apparently not the most common pattern for a global stellar dynamo: observations reveal that stellar activity tends to vary erratically in young, active stars. Regular cyclic activity is observed only in relatively slowly rotating, old stars (e.g., Radick et al. 1998), but even there only for one out of every three Sun-like stars. Cyclic activity is most readily observed in, e.g., the chromospheric emission of stars like the Sun; it is curious that no definitive evidence of cyclic activity has been found in X-rays, with one possible exception (Favata et al. 2004). There is near consensus among dynamo theorists that the global solar dynamo operates primarily near the bottom of the convective envelope, involving an overshoot layer below it (e.g., Dikpati et al. 2005). There are authors, however, that argue that the dynamo operates throughout the convective envelope (Dorch and Nordlund 2001), perhaps involving a substantial near-surface turbulent dynamo (e.g., Bercik et al. 2005). A dynamo also operates in fully convective stars (e.g, Giampapa et al. 1996; Hawley et al. 1996), albeit with apparently a different dependence on rotation rate than found for warmer stars. The amplitude of the solar cycle varies significantly from cycle to cycle. The consequences of that the long-term behavior of the heliospheric field (and the associated cosmic-ray levels) were modeled by Schrijver and DeRosa (2003) and Wang et al. (2002). They succeed in matching, e.g., the records of the cosmogenic ^{10}Be isotope abundances observed in ice cores, but in order to do that they need to introduce ad hoc processes into their models. These processes involve poorly understood aspects of the dynamo, and suggest important roles for meridional circulation or 3D convective field transport (see also Baumann et al. 2004). The most extreme variation in the behavior of the solar cycle is the Maunder minimum, during which almost all activity disappeared. Sunspots and geomagnetic activity continued to be observed during that phase, suggesting that the sunspot cycle continued at a much reduced amplitude (e.g., Letfus 2000; Wang and Sheeley 2003). There have been reports of stars in states like the Maunder minimum, but recent studies find that these stars either have evolved off the main sequence or have activity levels comparable to the average Sun despite the lack of long-term modulation in their activity (e.g, Wright 2004). The solar mass loss and the energetic-particle fluxes evolve with stellar activity. Mass loss can be inferred from the long-term evolution of stellar rotation owing to the associated loss of angular momentum, but that indirect measurement is also sensitive to the magnitude and geometry of the coronal-asterospheric magnetic field (e.g., Schrijver et al. 2003). Another method to evaluate mass loss in Sun-like stars involves modeling the observed signatures of asteropauses where stellar winds and the interstellar medium collide (Wood et al. 2002). Energetic particle fluxes have been measured for several decades, but long-term evolutionary changes have yet to be subjected to empirical validation.

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