STELLAR ROTATION AND ACTIVITY

The Story of Solar-Type Stars

D. R. SODERBLOM
Space Telescope Science Institute
Baltimore MD, USA

Abstract. This review is limited to solar-type stars (late-F to early-K main sequence stars) and to recent developments in the study of the evolution of angular momentum in those stars. Observations of rotation in young clusters are discussed, together with the models that have been put forth to account for what is seen. One key question is whether or not the convective envelopes of solar-type stars decouple from the radiative cores when the stars near the Zero-Age Main Sequence. That question cannot yet be answered, but forthcoming observations are likely to address the issue. Another significant open question is the degree to which any one cluster of stars is typical of all stars at that age, and that too is near to being resolved as we reach deeper into the Galaxy at high spectroscopic resolution. Finally, some general properties of activity in solar-type stars are presented.

1. What is a Solar-Type Star?

What makes a star “solar-type” is the presence of a convection zone (CZ) in the surface layers, for the CZ lies at the heart of the many fascinating phenomena that we associate with the Sun. Most of those phenomena are related to “activity” in one form or another – sunspots, flares, the corona, etc. – and activity is an observable manifestation of the Sun’s magnetic field. The magnetic field exists because of the dynamo mechanism, and the dynamo arises because of the complex circulation patterns created by the interaction of convection with rotation, especially differential rotation. This simplified description is the current paradigm for studying and understanding the behavior of stars like the Sun.

So the essence of “solar-typeness” is the intimate connection between rotation and activity. That connection, and the nature of rotation and activity separately, have been the subjects of entire topical symposia, and

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cannot be recapitulated here. Instead I will dwell on a few recent developments. My goals are to use the Sun to understand the physics of other stars, and to use stars to place the Sun in context. In this way we can hope to know the past behavior of the Sun, and to understand the mechanisms that account for that behavior.

2. Recent Work on Rotation

Probably the most important observations of solar-type stars in recent years were made in 1981. A Dutch thesis student, Floor van Leeuwen, was surveying the Pleiades cluster and found periodic variations in the brightness of some of the K dwarfs (Alphenaar & van Leeuwen 1981). That in itself was not surprising, for the Pleiades is young (100 Myr old), leading us to expect its solar-type stars to be highly active and highly spotted. But the periods observed were as low as 0.25 day, corresponding to a rotation rate of 100 times the Sun’s.

Spectroscopy soon confirmed that these variations were indeed due to rotation (Soderblom et al. 1983) and that a significant fraction of Pleiades K and M dwarfs spin rapidly (meaning 20 times the solar rate or more) (Stauffer et al. 1984). Soon similar stars were found in the α Persei cluster (Stauffer et al. 1985), which, at an age of 50 Myr, was also Zero-Age Main Sequence (ZAMS). This confirmed that the Pleiades stars weren’t freaks, and that many ZAMS stars go through a stage where they are Ultra-Fast Rotators (UFRs).

Less clear was whether or not all stars go through a UFR stage. If so, the high proportion (about 80%) of slow rotators in the Pleiades meant that the transition from UFR to slow rotator had to take place within whatever spread in age exists within the cluster. Observations of stars forming regions indicate that the age spread within a cluster is at most a few million years. Going from rotating at 100 times the solar rate to, say, 10 times the solar rate in 5 Myr or less means losing angular momentum at an extremely high rate, higher than we believe solar-type stars can realistically achieve.

Two obvious alternatives exist to solve this problem. First, perhaps only a fraction of stars ever get enough angular momentum to go through a UFR stage at all. Recent studies of the distributions of rotation in star-forming regions (e.g., Choi & Herbst 1996) support that view. The second possibility is that only the surface of the star spins down within those few millions of years because the radiative core decouples from the CZ. This decoupling may occur, of course, whether or not the UFR phenomenon has its origins in the initial distribution of angular momentum.

The best way to understand this UFR phenomenon is to observe stars in open clusters, for there we have reasonably large samples of stars of the