STELLAR ANALOGUES OF THE SOLAR CYCLE AND ACTIVITY*

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Abstract. The past two decades have seen a rapid increase in our understanding of the phenomenology of stellar activity. This has happened principally as a result of new instrumentation which has allowed studies at X-ray, EUV, visible and radio wavelengths in ways hitherto impossible. From this work has emerged a tentative description of a connection between activity, rotation, convection, and stellar structure and evolution, linked through pervasive electrodynamic processes. Although most manifestations of stellar activity studied to date occur with far greater amplitudes than the apparently analogous phenomena on the Sun, there is clear support for the notion that the 'two-way street' between studies of solar and stellar activity – the so-called solar-stellar connection – represents a useful path to improving our understanding of activity in general. In this paper we review the phenomenology of stellar activity with a special emphasis on those aspects that seem to be relevant in understanding the origin of activity cycles. We point out that the labile character of theories of solar activity makes it hard to synthesise a common account of activity in the Sun and other stars. Nevertheless, we show how the stellar data suggest that some aspects of activity (such as the rotation-activity connection and the non-linear correlations between different activity indicators) might be incorporated from the start into models of solar activity.

1. Introduction

The promise of a fruitful synergy between solar and stellar physics has been recognized since the birth of astrophysics, late in the nineteenth century. The essence of the promise has been enunciated often: the Sun lets us study phenomena in detail on account of its proximity, but for only a limited range of stellar parameters, since the mass, age and many other factors are fixed. The stars on the other hand are too remote to permit studies of great detail, but they do offer a wide range of physical conditions which allow conjectures and speculations to be tested more thoroughly than is possible on the Sun alone.

There are several examples of the successful exploitation of this synergy. Techniques used in the observation and analysis of photospheric spectra, non-LTE (non-local thermodynamic equilibrium) spectroscopic diagnostics, the chromosphere-corona-wind paradigm, and increasing interest in the similarities and differences between solar and stellar activity are all cases where cross-fertilisation has been fruitful. The intriguing complexity of the picture of solar activity which is emerging from recent research is bound to contribute to a re-examination of some of our fundamental notions regarding stellar activity. The prospects for the reverse process are less obvious at present (since

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the solar work is in such a state of flux) but some advances will undoubtedly occur with
the passage of time.

In this paper we review the observed phenomenology of four important aspects of
stellar activity: magnetic fields, activity indicators, stellar rotation, and stellar mass and
age. We are particularly concerned with connections between these phenomena. We
then discuss some of the theoretical interpretations of these phenomena, concentrating
on two areas: (i) the mechanisms which excite activity indicators and relate them to
atmospheric electrodynamics, and (ii) the more deep-seated processes which are
responsible for the structure and evolution of the magnetic fields and related phenomena.

2. Observations

If the first parts of this section we summarize common techniques used to study stellar
activity, and present what appear to be the more significant results. In the final part we
address the crucial question of the relationships between different manifestations of
activity.

2.1 MAGNETIC FIELDS

Although it has long been thought that magnetic fields play the central role in the
atmospheric electrodynamics of active stars, it is only in recent years that the first
tentative direct measurements of fields have been made. Almost all positive detections
in late-type stars are based on the application of variants of a method first described
by Robinson, Warden and Harvey (1980), in which the Zeeman signature in the intensity
(not the polarisation) profile of a magnetically sensitive line is identified by comparison
with a similar line that is not magnetically sensitive.

Applications of this method to active stars (e.g., Marcy, 1984; Gray, 1984; Saar,
1987) have yielded estimates of the flux, field strength and the surface area covered by
magnetic field in a number of stars. Fields strengths of 1–2 kG are usually reported, with
coverage in the range 20–80% (lower coverages cannot be detected). Whilst field
strengths of this order are probably not surprising in view of the conditions which
would be obtained were the fields in transverse magnetostatic equilibrium (e.g., Zwaan
and Cram, 1989), the area coverage is enormous when compared to that of the Sun.
Hartmann (1987) has offered a number of cautions regarding possible systematic
uncertainties of errors in the application of this technique, and suggested that some of
the reported trends deduced from such measurements may need to be revised. Never-
theless, the existing results present a most important step in building the solar-stellar
connection.

2.2. ACTIVITY INDICATORS

A wide range of spectroscopic features known to be associated with solar activity can
be observed in stellar spectra, and invariably they offer strong evidence for the presence
of activity in various kinds of stars. However, it is important to recognize that most of
these activity indicators (e.g., X-rays, radio emission, photometric variability) can be
seen in stars only because the degree of activity is substantially higher than that of the