with the highest value of the “normal” coronal density \((10^9 \text{ cm}^{-3})\). On the other hand, if we combine the highest value of the “fast electron” density with the lower values of the “normal coronal density”, then we see that essentially 100% of the normal electrons must have been accelerated to high energies during an outburst. This is a remarkable and novel result if it can be confirmed. In a solar flare, only a very small fraction of the coronal electrons is actually accelerated to “flare” energies. Something quite different from a solar flare may therefore be occurring in the RS CVn outbursts: the “something” can apparently force a large fraction (maybe even 100%) of the electrons in the corona to “run away” to energies which are at least 10 times larger than “normal”.

This conclusion is unexpected in the sense that it has been widely assumed that radio outbursts on RS CVn stars were quite similar in physical properties to the bursts which occur in solar flares, and also to the bursts which occur during flares on red dwarf stars. However, if the interpretation of the VLBI data given above is correct, this assumption may not be correct.

This is an indication of the kind of detailed new information which VLBI now may make available to stellar astronomers. More results from this powerful technique are eagerly awaited.

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D. J. Mullan.

MAGNETIC FIELDS IN LATE-TYPE STARS

Evidence of “solar-like” activity in late-type stars (dwarfs of spectral types K-M) has existed for about 35 years. This evidence includes photometric and spectroscopic observations of flares, periodic modulation of their light interpreted as the passage of giant spots across their faces, emission lines in their spectra which are indicative of hot chromospheres and, most recently, satellite detection of coronal X-rays. Further details will be found in D. J. Mullan’s review of IAU Colloquium No. 73 (Mullan 1982).

All of these diverse phenomena find a consistent interpretation by analogy with solar active regions. The latter are regions of concentration of magnetic field on the surface of the Sun. Within such areas are found sunspots, flares, plages, prominences, etc. Where the magnetic fields arch into the solar corona intense heating is seen to take place resulting in the emission of X-rays. Indeed, it is now believed that the million-degree corona of the Sun is heated via these X-ray hot-spots.

So the underlying cause of the late-type stars’ activity is the presence of large concentrations of magnetic field on and above their surfaces. That intense magnetic fields should occur on the late-type stars is consistent with our present theories of how such fields are ultimately generated. Dynamo theory predicts that more efficient magnetic field production should occur as we proceed down the main sequence. This is because the dynamo depends on convective motions for its functioning. Stellar material is substantially ionized and so, when it convects, it is easy to see in a qualitative way how one can get circulating currents, giving rise to magnetic-field generation.
The striking success of dynamo theory in explaining the general aspects of these kinds of stellar activity has been very satisfying. This contrasts sharply with the failure of attempts to measure the magnitude and extent of those fields. Early attempts using polarization methods (either of continuum or within lines via the Zeeman effect) failed totally to detect any signs of fields. The reasons for this are quite apparent if we refer again to the Sun. In general, the magnetic polarity of a region determines the sense of polarization of radiation emitted from that region; therefore, radiation from a region of mixed magnetic polarity will have polarizations which tend to cancel. In the solar case we overcome this problem by examining only small regions with a single polarity. In the case of an unresolved star this is, in general, not possible. So in examining integrated light from the stellar disk we are simultaneously receiving radiation from regions of opposite polarity and many differing field strengths.

The so-called “Robinson” method of recording magnetic fields on late-type stars also relies on the Zeeman effect but ignores the polarization produced (see Robinson, Worden and Harvey 1980). To understand the method let us briefly recall the Zeeman effect.

When an atomic species undergoes transition, which normally produces a single spectral line, in the presence of a magnetic field, the line will be split into a number of components. The precise pattern and number of these components depend on atomic factors. In the simplest case a triplet is produced with an undisplaced component and two symmetrically displaced components whose displacement $\Delta \lambda$ is given by

$$\Delta \lambda \propto g \lambda^2 B$$

where $B$ is the field strength, $\lambda$ is the undisplaced wavelength and $g$ is the Landé factor. These components will be variously polarized but the magnitude of the separation depends in this simple way on the line being observed (through $\lambda$ and $g$) and on the field strength.

When we observe the integrated light of a star we are recording line contributions from many active regions spread over the visible hemisphere, each with its own different field strength. Thus, even if we confine our attention to one line, the Zeeman pattern will be smeared out. It will however, result in an extra source of line broadening. If therefore we can find two or more lines with different Landé factors then those with higher $g$ should be broader.

Marcy (1984) has recently applied this technique to 29 G and K-type stars. He has successfully registered mean field strengths on 19 of them. They range from $\sim$600–3200 Gauss. The lines used were both iron lines arising from the same atomic level but having different Landé factors. Moreover, it was essential that the lines were unblended with other, nearby lines. This is a particularly important restriction in later-type stars where line densities are very high.

It is important to realize that the resulting field strengths are averages over the disk since the entire disk is observed at once. By assuming that the Zeeman pattern is of the simplest kind, i.e. a triplet as described above, an estimate is obtained of the fraction of the surface covered by the fields. This arises as follows. The ratio of the central intensity to those of the satellites is determined by the magnetic-field geometry
(inclination to the line-of-sight). Since we are measuring a mean field we can adopt some mean inclination (Marcy chose 34°). Then the central, undisplaced component of the line will contain contributions from the non-magnetic areas of the star plus that from the magnetic areas, now known from the above considerations. Simple arithmetic gives the area of the star covered by the mean field. The results range from 16%—89% coverage.

Gray (1984) has adopted a very similar approach in a study of 18 F, G and K stars, on 7 of which he recorded positive results. The fields are similar in magnitude to Marcy’s, ranging from 800—1900 Gauss and area coverage from 25—40%. His method differs slightly from Marcy’s in that he uses the Fourier transform of the line profile and also in that he works with more lines with a wider range of g-values. However, he is obliged to work with lines arising from different ionic species and even different elements. The difficulty with this approach is that, while accuracy should be improved by using more lines and a greater range of g, the different origins of the lines may result in different magnetic sensitivity.

It is encouraging that the results quoted above overlap with one another and with the range of magnetic field strengths observed in solar active regions. Thus it appears that at last direct evidence of magnetic fields on late-type stars has been found. Marcy showed in the discussion of his results that the area coverage of fields correlated well with total X-ray flux from the star normalized to $L_{bol}$. Surprisingly however, the total magnetic flux did not correlate well with X-ray flux as one might have expected.

These results open up new and exciting possibilities. For instance, if measurements such as these are made as a function of phase of a spotted variable (RS CVn or BY Dra) might it be possible to estimate the field strength in the spot? This would be a giant step forward in trying to model these phenomena.

References
