MAGNETIC TOPOLOGY AND THE HEATING OF EXTENDED CHROMOSPHERES

Robert E. Stencel
Joint Institute for Laboratory Astrophysics, University of Colorado and National Bureau of Standards, Boulder, CO 80309

ABSTRACT

New data indicate that red giants are surrounded by geometrically thick chromospheres of several stellar radii extent. Such chromospheres occur among stars which apparently lack coronae. Maintenance of this extended warm region may require non-compressional wave heating of a magnetic character, and this may provide a crucial clue to the mechanism of rapid mass loss from red giant stars.

INTRODUCTION

Red giant and supergiant stars are known from their optical spectra to possess cool circumstellar (CS) envelopes and winds. At issue is the nature of the interface between the warm photosphere and the cool CS shell. New spectroscopic evidence from optical and non-optical regimes, as well as direct imagery, is providing new insights into this question.

SPECTROSCOPIC EVIDENCE

Ultraviolet observations with the IUE satellite have made possible the exploitation of the mid-UV lines of C II near 2325 Å and 1335 Å as density and temperature diagnostics (Stencel et al. 1981). Combined with estimates for the ionization equilibrium and abundances, one can deduce column densities and lower limits to the physical thickness of the emitting region. For Arcturus, we deduced the existence of a 5000-10,000 K chromosphere of at least one stellar radii extent. The same technique yields geometrically thick chromospheres (5-10 stellar radii) for other non-coronal red giants, but thin chromospheres (few percent or less of a stellar radius) for G giants and the Sun (Stencel and Carpenter 1982).

The He I 10830 Å line is variably in emission and absorption in the spectra of non-coronal red giants (Zirin 1982). In contrast, the coronal-type, yellow giants show non-variable 10830 Å absorption, as is the case in the solar spectrum. However, the low upper limits on soft X-ray emission from red giants call into question any solar-like line formation mechanism of recombination following ionization of He by

J. O. Stenflo (ed.), Solar and Magnetic Fields: Origins and Coronal Effects, 445–448.

https://doi.org/10.1017/S0074180900030114 Published online by Cambridge University Press

X-rays. Alternatively, line formation in shocks over extended regions may explain the variable 10830 Å emission of the red giant stars.

Chromospheric velocity fields can, in principle, be derived from the profiles of the emission cores of the resonance doublets of Ca II, Mg II and similar features. Statistics on the asymmetries of these doubly reversed emission cores argue for a boundary in the H-R diagram between solar-like asymmetries (among yellow giants) and outflow asymmetries, among red giants (Stencel 1978; Stencel and Mullan 1981). These boundaries correlate with X-ray and transition region line statistics (Simon et al. 1982) and CS features (Reimers 1977). However, stars like Arcturus, which lie near these boundaries show a strong outflow asymmetry in Mg II, but a solar-like (and slightly variable) asymmetry in Ca II. These "discrepant asymmetry" stars may provide the crucial clue to the evolution of atmospheres between coronal and non-coronal states (Mullan and Stencel 1982). Extended chromospheres can help in the interpretation of this phenomenon.

Wischnewski and Wendker (1981) and Newell and Hjellming (1982) have discussed the implications of the recently established two component radio emission of the M supergiant Betelgeuse, in terms of its atmospheric structure. They demonstrate that the star probably possesses an extended chromosphere in substantial agreement with the C II results. Comprehensive models such as that by Jura and Morris (1981) should be re-explored with this new information.

Additional spectroscopic evidence which suggests the existence of extended chromospheres includes: (a) atmospheric eclipsing binaries (Stencel et al. 1982); (b) cool star ionization equilibria (Ramsey 1981); and (c) fluorescent emission in the mid-UV (Carpenter et al. 1982) and near Ca II H and K (Stencel 1977). For details concerning these factors, see Stencel (1982).

DIRECT EVIDENCE

Goldberg et al. (1982) have discovered that the apparent diameter of the M supergiant Betelgeuse increases by a factor of 5 when viewed in narrow band H-alpha speckle interferometry, compared to broadband continuum diameters of 0.05 arcseconds. Goldberg and colleagues also report changes in the intensity distribution over a three-month timescale which are correlated with changes in polarization measurements independently obtained by Hayes (1980). Further results are likely to be fundamentally important.

Similar efforts involving narrow band occultation observations have also indicated extended chromospheric emission among red giants and supergiants: White et al. (1981) found a two stellar radii chromosphere around the M supergiant 119 Tau; Radick and Africano (1981) reported the suggestion of an increased angular diameter of Aldebaran (K5 III) in intermediate band occultation studies.

CHROMOSPHERIC HEATING

Dimensional arguments suggest that extended chromospheres are orders of magnitude larger than their isothermal pressure scale heights. The average chromospheric densities implied by the C II diagnostics for Arcturus and Betelgeuse are 10^8 and 10^7 cm^{-3}, respectively, and the isothermal pressure scale heights in 10^4 K chromospheres are 10^{10} and 10^{12} cm, respectively. These are 200-500 times smaller than the dimensions implied by five stellar radii chromospheres for these stars. It appears that hydrostatic pressure alone is incapable of supporting these extended chromospheres.

Another source of pressure in red giant atmospheres is due to turbulent and expansion velocities. The average pressure implied by the gravitational potential of material of 10^8 cm^{-3} density suspended at 5 stellar radii corresponds to approximately 50 km s^{-1} rms turbulent velocities. Although this velocity corresponds to transient CS absorption features seen in Arcturus (Reimers 1977), it appears too large for velocities normally associated with Betelgeuse (Bernat 1981), whether chromospheric turbulent or expansion. A plausible alternative to hypersonic velocities involves the support inherent in a modest magnetic field energy density. Assuming an r^2 divergence, a surface field of less than 10 gauss would suffice. Magnetic fields could provide forms of non-compressional wave heating which the extended emission distribution appears to require.

At present, two hypotheses appear capable of explaining several of the observed phenomena associated with extended chromospheres among non-coronal red giants and supergiants. Mullan (1982) has proposed a magnetic topology argument, with chromospheric heating and extent maintained by continually emerging, star-sized, discrete flux loops, which are unable to find stable, closed configurations (as they can in coronae). Hartmann and MacGregor (1980) have proposed an Alfvén wave heating theory which predicts extended chromospheres among red giants. Whereas the Alfvén wave theory predicts temperature and velocity distributions which could explain several observations, including perhaps the discrepant asymmetries, the unstable loop model matches the observed variability which is a major factor in the outer atmospheres of red giants.

CONCLUSIONS

Extended chromospheres may provide the missing link in the evolution of the outer atmospheres of cool stars between coronal and non-coronal states, as well as important clues to the nature of the mass loss process. Much work remains to be done to quantitatively improve the analysis of the spectroscopic clues listed above, including spectral synthesis work which includes spherical symmetry and velocity fields in chromospheres. Additional discussion of this point may be found in Stencel (1982). The enhanced spatial resolution offered by narrow band speckle interferometry ("speckle spectroscopy") ought to be pursued with vigor.

I am happy to acknowledge useful discussions with Reiner Hammer, and to thank NASA for support in this research, and the Symposium organizers for an invitation to participate in this meeting.

REFERENCES

Bernat, A.: 1981, Astrophys. J. 246, p. 184.
Carpenter, K., Wing, R., and Stencel, R.: 1982, Bull. A.A.S. 14, p. 614.
Goldberg, L., Hege, E., Hubbard, E., Strittmatter, P., and Cocke, J.: 1982, in "Second Cambridge Workshop on Cool Stars, Stellar Systems and the Sun," ed. M. S. Giampapa and L. Golub, S.A.O. Special Report 392, p. 131.
Hartmann, L. and MacGregor, K.: 1980, Astrophys. J. 242, p. 260.
Hayes, D.: 1980, Astrophys. J., 241, p. L165.
Jura, M. and Morris, M.: 1981, Astrophys. J. 251, p. 181.
Mullan, D.: 1982, Astron. & Astrophys. 108, p. 279.
Mullan, D. and Stencel, R.: 1982, in "Advances in Ultraviolet Astronomy: Four Years of IUE Research," eds. Y. Kondo, J. Mead and R. Chapman, NASA Conference Publ. No. 2238, p. 235.
Newell, R. and Hjellming, R.: 1982, Astrophys. J. (submitted).
Radick, R. and Africano, J.: 1981, Astron. J. (in press).
Ramsey, L.: 1981, Astrophys. J. 245, p. 984.
Reimers, D.: 1977, Astron. & Astrophys. 57, p. 395.
Simon, T., Linsky, J., and Stencel, R.: 1982, Astrophys. J. 257, p. 225.
Stencel, R.: 1977, Astrophys. J. 215, p. 176.
Stencel, R.: 1978, Astrophys. J. 223, p. L37.
Stencel, R.: 1982, in "Second Cambridge Workshop on Cool Stars, Stellar Systems and the Sun," ed. M. S. Giampapa and L. Golub, S.A.O. Special Report 392, p. 137.
Stencel, R. and Carpenter, K.: 1982, in "Advances in Ultraviolet Astronomy: Four Years of IUE Research," eds. Y. Kondo, J. Mead and R. Chapman, NASA Conference Publ. No. 2238, p. 243.
Stencel, R., Chapman, R., Kondo, Y., and Wing, R.: 1982, in "Advances in Ultraviolet Astronomy: Four Years of IUE Research," eds. Y. Kondo, J. Mead and R. Chapman, NASA Conference Publ. No. 2238, p. 492.
Stencel, R., Linsky, J., Jordan, C., Brown, A., Carpenter, K., Wing, R., and Czyzak, S.: 1981, Mon. Not. R. A. S. 196, p. 47p.
Stencel, R. and Mullan, D.: 1981, Astrophys. J. 240, p. 718.
White, N., Kriedel, T., and Goldberg, L.: 1981, Astrophys. J. 254, p. 670.
Wischnewski, E. and Wendker, H.: 1981, Astron. & Astrophys. 96, p. 102.
Zirin, H.: 1982, Astrophys. J. (submitted).