Exchanging the Coronal Heating on the RS CVn Binary HR 1099

V.I. Airapetian and R.D. Robinson

Computer Sciences Corporation, Code 681/CSC, Goddard Space Flight Center, Greenbelt, MD, 20771

S.P. Maran and K.G. Carpenter

Laboratory for Astronomy and Solar Physics, Code 681, Goddard Space Flight Center, Greenbelt, MD 20771

HR 1099 is one of the most magnetically active of the RS CVn binary systems, showing spots, enhanced chromospheric, transition region and coronal emission as well as large flare events, normally observed at X-ray and radio wavelengths. Recently Wood et al. (1995) observed HR 1099 with the Goddard High Resolution Spectrograph aboard the Hubble Space Telescope and reported extremely broad transition region lines, with non-thermal broadening in excess of 100 km s$^{-1}$. These observations were confirmed by Robinson et al. (1995), who also report non-thermal broadening of 30 km s$^{-1}$ in weak chromospheric lines and $\leq$65 km s$^{-1}$ in the Fe XXI ($\lambda$1354) coronal line. It is expected that these line broadenings are closely associated with the physical process which is heating the stellar atmosphere.

Wood et al. (1995) suggest that the broadening is caused by the stellar analog to the ‘transition region explosive events’, which are observed on the Sun. These small scale transient events resemble flares and are characterized by line widths of $\sim$100 km s$^{-1}$. In this paper we examine a second possibility; that the broadening is caused by MHD turbulence initiated by non-linear Alfven waves. A schematic representation of the process is shown below.

---

As pointed out by Ionson (1984) and others, convective motions can resonate with magnetic flux tubes and produce torsional Alfven surface waves. The maximum efficiency for this production occurs when the convective turnover time equals the Alfven transit time for the loop. These waves have characteristic velocity fluctuations, $\delta V$, which are maximum at the surface of the flux tube.
and monotonically decrease towards the center. Conservation of energy flux for non-WKB waves implies that $\delta V$ will be proportional to $B^{-1/2}$ and will therefore increase as the waves travel from the photosphere, through the chromosphere and into the transition region. This is exactly what the observations appear to show. Eventually, if the velocity shear becomes sufficiently large, then a Kelvin-Helmholz instability will be initiated which rapidly converts wave energy into MHD turbulence having a size scale comparable to that of the original velocity shear. The details of this process are still unclear. However, recent 3D MHD simulations by Ofman et al. (1995), have shown that non-linear Alfven waves propagating in an inhomogeneous medium will quickly develop highly sheared velocities and form compact vortices (e.g. turbulence) in both the velocity and magnetic field. Once formed, the large scale turbulence will quickly cascade to smaller sizes, presumably forming a Kolmogorov spectrum. The small scale turbulence is then efficiently damped through viscous and ohmic dissipation processes and will heat the atmosphere.

A formal expression for the heating rate, $H$, from Alfven wave induced turbulence is given by Holweg and Yang (1988) as:

$$H = \frac{\pi}{4} \frac{M_H N_e}{\Delta y} < 2\delta V^2 >^{3/2}$$  \hspace{1cm} (1)

where $M_H$ and $N_e$ are the proton mass and electron density respectively and $\Delta y$ is the original size of the turbulent eddy, before the cascade. For the corona, the heating rate should approximately equal the radiative losses from an optically thin plasma of temperature $\sim 10^7$ K and electron density $\sim 10^{10}$ cm$^{-3}$ (Robinson et al. 1995), which is $\sim 7.5 \times 10^{-3}$ erg cm$^{-3}$ s$^{-1}$ (Klimchuk & Gary, 1995). Assuming that $\Delta y \sim 10^9$ cm$^{-3}$, which is comparable to the cross sectional radius of a typical flux tube, then a turbulent velocity of $60$ km s$^{-1}$ is required to account for the coronal heating on HR 1099. This is approximately the amount of turbulence deduced from the observations. We therefore conclude that energy dissipation by MHD turbulence is a viable atmospheric heating process in HR 1099.

**Acknowledgements.** Support for this work was provided by NASA through Guaranteed Time Observing funding to the GHRS science team. V.I.A. wishes to acknowledge many fruitful discussions with J. Davila during the course of this work.

**References**
Holweg, J.V. & Yang, J. 1988, JGR, 93, A6, 5426.