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The M-dwarf L726-B of *UV Ceti*

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1. Background

UV Ceti is a visual binary system of two red dwarfs discovered by W. J. Luyten in 1949 during a proper motion survey of over 520,000 stars. The two *UV Ceti* stars are identified as Luyten 726-A and Luyten 726-B, the latter being significantly dimmer than the former. At a distance of 2.695 ± 0.03 pc (Benz et al. 1998), this binary system is the sixth closest to the Sun. The binaries have a combined mass of $\sim 0.2 M_\odot$ but are considerably faint: $1.1 \times 10^{-4} L_\odot$. The orbit has a high ellipticity ($e = 0.62$) such that the stellar separation ranges between 2.2 and 8.8 AU, with an orbital period of 26.5 years (Benz et al. 1998). Luyten 726-B is known to be an extreme example of a flare star, and as it was one of the first of its kind discovered it is commonly known as "Luyten's Flare Star". In this paper, we will focus on the properties of this flare star, L726-B.

2. Basic Observational Properties of Luyten 726-B

The fainter member of the *UV Ceti* system, Luyten 726-B, is a main sequence red dwarf star with designated spectral class M6.0 V. It contains approximately half the mass of the binary system, with $0.11 M_\odot$ (Geyer et al. 1988) and has a photospheric radius of 1.0×10^{10} cm (Pettersen 1980). It displays a (quiescent) luminosity of $4 \times 10^{-5} L_\odot$, and during flare activity has been observed to reach a luminosity 75 times larger, i.e. $3 \times 10^{-3} L_\odot$ on a timescale of a few seconds to minutes. The large variation in observed luminosity is coupled with a similar variation in surface temperature estimates: these typically show $T_e \sim 2800$K but have reached $T_e \sim 16000$ K coincident with flaring (Stepanov et al. 1995). This variability is not unusual for M dwarfs due to their highly conductive stellar coronae (as will be discussed in the next section).

3. Predictions and Models for dM Stars

Due to the fact that the violent flaring activity of L726-B originates from the outer components of the star (i.e. the corona), we will assume it is reasonable to use general

stellar models to estimate the physical properties and processes of the M dwarf which take place nearer to the core. The basic models for stellar structure of a $0.10M_{\odot}$ main sequence star predict a luminosity of $9.5 \times 10^{-4} L_{\odot}$, an effective temperature of 3000 K, and a stellar radius of 8×10^{9} cm (Hansen & Kawaler, 1994). In comparison with the observed values for L726-B (during periods of quiescence), the models provide a fairly accurate estimate of the mass, radius and temperature of the star but over-predict the luminosity by a factor of ~ 5 . This is consistent with the observations that L726-B is a very dim star for its spectral class (to which the basic models apply).

The models also predict that for a $0.10M_{\odot}$ MS star the core temperature is $T_c \approx 4.5 \times 10^6$ K, the core density $\rho_c = 545 g/cm^3$, the core pressure is $P_c = 4.8 \times 10^{17}$, and that the entire depth of the star is convective (Hansen & Kawaler, 1994). It should be noted that detailed modeling of these dim, cool stars such as L726-B is extremely difficult as their equation of state has many complicated dependencies and the opacities in their outer layers are dominated by radiative transitions which have not been thoroughly studied yet. However, if we apply the basic polytrope model for pressure (with index $n = 3/2$) to the entire depth of the star, and assume the star consists of an ideal gas (with mean molecular weight $\mu = 0.6$) in hydrostatic equilibrium, the following scaling relations can be derived:

$$< \rho >= 475 R_{10}^{-3} (M/M_{\odot}) \tag{1}$$

$$T_c = 7.4 \times 10^6 (M/M_{\odot})(R/R_{\odot})^{-1} \tag{2}$$

which predicts a core temperature of only a few million degrees for stars such as L726-B (Hansen & Kawaler, 1994).

The above discussion focused on predictions which are primarily applicable to quiescent periods of L726-B. It should be noted that the violent flaring activity of UV Ceti stars has also invoked theoretical models which we will briefly discuss here. The coronae of rapidly rotating young stars emit significantly more radiation than the coronae of typical solar-type stars (Benz et al. 1998). This radiation is thought to be caused by both thermal and non-thermal radiation mechanisms. In the high frequency regime, thermal bremsstrahlung radiation in M dwarfs is observed as soft X-ray photons. At the other end of the spectrum, non-thermal synchrotron radiation is observed from these sources in the radio band. The non-thermal and thermal radiation from flaring M dwarfs such as L726-B have been shown to be causally connected, due to the observed lag time (~few seconds) between the optical and the X-ray and radio emission. As in the case of solar flares, this causality suggests that the corona is heated by energy from non-thermal particles (e.g. electrons or protons).

It remains unclear how both thermalized and non-thermal particles can co-exist within the corona, but since the corona is highly conductive for stars of this spectral type, the radiating sources are expected to be shaped from the coronal magnetic field (Benz et al. 1998). The recent VLBA imaging of active regions on L726-B can therefore imply the shape and extent of the closed B-field lines in the stellar corona. Two spatial components have been resolved, the larger of which has an effective diameter which is $4.4 \pm 0.4 \times 10^{10}$ cm which is larger than the size of the stellar photosphere. In addition, the distance between the two components is approximately 4.5 stellar radii, and therefore demonstrates the extent of the closed magnetic field lines (Benz et al. 1998). Figure 1 shows the 3.6 cm radio emission from the two active components of L726-B.

Combined with simultaneous optical and X-ray observations of these flares, radio data of L726-B has enabled the models for flaring M-dwarfs to be improved and refined. For examples of this, Stepanov et al. (1995) and Schmidt et al. (1993) use multifrequency data (radio through X-ray) to constrain the plasma emission models for L726-B. The reader is referred to the these papers (and references therein) for a detailed discussion of the coronal emission mechanisms.

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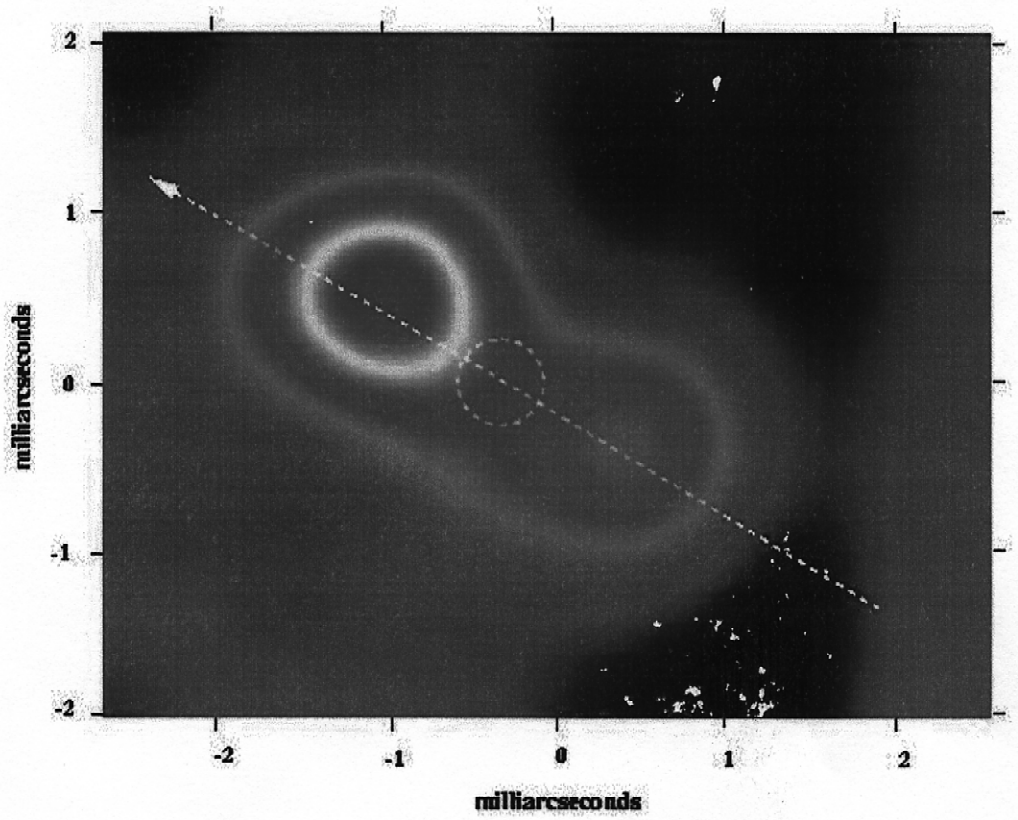

Fig. 1.— The flaring L726-B was resolved as at least two evolving spatial components that were separated by four to five stellar radii, in this VLBA/VLA radio image at 3.6 cm. The components changed in appearance over about six hours of observation but stayed aligned along the axis of the binary orbit, as shown by the arrow. (from Benz et al. 1998).