LONG AND SHORT TIMESCALE VARIABILITY OF MAGNETIC ACTIVITY
ON THE BY DRA STAR BD +26° 730

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ABSTRACT

BD +26° 730 is a very active K5V flare star with a 60 year starspot cycle. Since it is also nearly pole–on, it presents an unusual opportunity to study purely temporal evolution of magnetic activity. We report new, contemporaneous IUE, magnetic flux, polarimetric, and Hα observations of the star taken over several rotational periods in 1988. When combined with older photometry, optical and IUE archive spectra, the data show a suprising lack of any activity variability on either short (few days) or long (years) timescales. We suggest the lack of variability may be due to a nearly saturated level of magnetic activity on the star, as indicated by its large magnetic filling factor.

Keywords: stellar activity, magnetic fields, flare stars, stellar atmospheres, variable stars

1. INTRODUCTION

BD +26° 730 (= Gliese 171.2A; K5Ve) has several unusual characteristics which make it an important laboratory for the study of stellar magnetic activity:

- It is one of the most active K dwarfs known, as evidenced by its strong chromospheric and transition region emission (Ref. 1). Unusually energetic optical flares (for a K dwarf) have been observed (∆V = 0.9 magnitudes; Ref. 2).
- BD +26° 730 has a asymmetric magnetic starspot cycle of ≈ 60 years (Ref. 3; Fig. 1). It is the most active dwarf star with a known cycle period, and one of the youngest (a Hyades supercluster member, age ≈ 7x10⁶ yr; Ref. 4).
- We view BD +26° 730 nearly pole–on. The v sin i of 7.4 km s⁻¹ (Ref. 5) combined with

\[ P_{\text{rot}} = 1.85 \text{ days (Ref. 6)} \] and a K5 dwarf radius of R/R₅ ≈ 0.8 imply that i ≈ 20°. Thus, the vast majority of the activity variation seen on BD +26° 730 can only be attributed to time evolution of magnetic features and/or flares.

- Because v sin i is low, rotational broadening of stellar line profiles is small, and the magnetic parameters, f (filling factor of brighter magnetic regions analogous to solar plage and network) and B (mean field strength in these regions), can be measured from high resolution, high S/N unpolarized spectra. It is one of the fastest rotators for which such a measurement is possible.

![Graph](image)

Figure 1. Long-term photometric variability of BD +26° 730 showing a 60 year starspot cycle (from Ref. 3). The error bars indicate the ±σ variation from the yearly mean points. Recent observations (x; from Ref. 7) confirm the downward trend since the last maximum in ≈ 1977.

Since the star is viewed nearly pole–on, almost all variability results from the evolution of activity in time, rather than rotational modulation. BD +26° 730 thus presents a unique opportunity for observing long–term, purely temporal variability due to a magnetic cycle on an extremely active star.
2. OBSERVATIONS AND ANALYSIS

We observed BD +26° 730 in a multiwavelength campaign in the fall of 1988. As part of IUE program FSKSS, we obtained six SWP and eight LWP low dispersion spectra with FES photometry on 27, 28, 29, 31 October and 2 November. Ten high resolution ($\lambda/\Delta\lambda \approx 90,000$) optical spectra of magnetically sensitive and insensitive line profiles were taken between 24 October and 9 November using the NSO McMath echelle spectrograph and a TI CCD. Hα spectra (NOAO Coude feed) and Hα filter photometry (Van Vleck Obs.; Ref. 8) were obtained on 13 nights between 7 October and 4 November. Occasional spectra of the Li I region and the Ca II infrared triplet were also obtained. Broadband linear polarization measurements of the star were made on 5, 10, and 12 September using the multichannel double image chopping polarimeter of the Univ. of Helsinki (Crimean Astr. Obs.; Ref. 9).

We reduced the IUE data and measured line fluxes using standard software at the CU-RDAF. Two IUE archive spectra of BD +26° 730 were also analyzed. Results for the C IV line are plotted versus photometric phase (see Ref. 3) in Figure 2.

![Figure 2](image_url)

Figure 2. Observed fluxes (ergs cm$^{-2}$ s$^{-1}$ Å$^{-1}$) in C IV vs. rotational phase for BD +26° 730 in January 1981 (●) and October 1988 (+). No variability is seen outside of the flare (●). The quiescent C IV surface flux is 70 times the solar value.

We modeled the magnetic line profiles using improved versions of the LTE codes described in Refs. 10 and 11. These models include disk-integration of the magnetic intensity profiles, and a detailed treatment of line blends (a significant problem in late K dwarfs). Lines of an inactive, slowly rotating star of nearly identical T$_{eff}$, HD 32147 (K5V, Pr = 46.8 days; Ref. 12) were used to determine the strength and position of weak line blends. This data was then used in the fits of BD +26° 730 line profiles. We first modeled lines of low magnetic sensitivity (Lande $g_{\text{eff}} < 1$; Fig. 3a) to obtain the velocity broadening parameters ($v \sin i$, macroturbulence). These values were then used as input to determine the magnetic parameters, f and B, using the model $F_{\text{obs}} = f F(B) + (1 - f) F(B=0)$, where $F_{\text{obs}}$ is an observed high $g_{\text{eff}}$ line and $F$ is the model spectrum for a field strength, B. A model for the magnetically sensitive $g_{\text{eff}} = 2.5$ Fe I 6173 Å line is shown in Figure 3b. We derive B $\approx$ 2600 G and $f \approx$ 0.50 from one of the better spectra (S/N $\approx$ 180).

![Figure 3](image_url)

Figure 3. Magnetic line models for BD +26° 730. Crosses are the data (S/N $\approx$ 180) for (a) the Fe I 6165 Å ($g_{\text{eff}} = 1.0$) and Ca I 6166Å ($g_{\text{eff}} = 0.5$) lines and (b) the Fe I 6173 Å ($g_{\text{eff}} = 2.5$). The solid curve represents the comparison star (HD 32147) broadened to $v \sin i = 7.4$ km s$^{-1}$; note the excellent agreement with BD +26° 730 everywhere but at the magnetically sensitive 6173 Å line. The dashed line (in b) shows a radiative transfer model of 6173 Å (plus blends) with B = 2600 G and $f = 0.50$. 

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3. DISCUSSION

Our 1988 IUE observations span \( \approx 3.5 \) stellar rotational cycles, and various optical activity diagnostics extend the coverage to \( \approx 18 \) cycles. Previous IUE observations were made in January 1981, near the maximum brightness (minimum spot coverage) of the star (in 1977). We can therefore search our data set for variability on both short (several stellar rotations) and long (magnetic cycle) timescales. Because of the asymmetric nature of the cycle (\( \approx 15 \) years decline, \( \approx 42 \) years rise; see Figure 1) the next minimum is predicted for \( \approx 1992 \) (Ref. 1). The average B magnitude was \( B \approx 9.45 \) during our observations in 1988 (Ref. 7; Fig. 1). Thus, the star was significantly fainter (more spotted) than in 1977, about halfway to its expected B magnitude at cycle minimum. Models of TiO bandhead observations made in March 1988 confirm the significant surface coverage by spots, indicating that \( \approx 20\% \) of the stellar surface was occupied by spots at \( T \approx 750 \) K cooler than the photosphere (Ref. 13).

The only notable variation in Figure 2 is the enhancement in the C IV flux at phase \( \phi \approx 0.1 \) to approximately twice the mean 1988 level. Other high temperature species (e.g., Si IV, C II, N V) show similar enhancements at this phase. We suspect that this observation encompassed a flare, however, since spectra taken 3 hours before (\( \phi \approx 0.05 \)) and two rotations later (\( \phi \approx 0.2 \)) show no deviation from the mean C IV flux. Excluding this one point, Figure 2 demonstrates that there was no significant variability in C IV during our 1988 observations. The other strong UV lines (O I, C II, He II, Si II, Mg II) also showed no change. Similarly, we found no variability in FES magnitudes (excepting one flare), in the magnetic line profile shapes, or in H\( \alpha \) equivalent widths (excepting one flare), the latter observed over \( \approx 18 \) rotational periods (Fig. 4).

Finally, broadband polarization measurements were also relatively constant, except for a transient (\( \approx 2 \) hours) event, which we argue are the result of impact polarization due to particle beaming in a stellar flare (Ref. 14). Thus, outside of flare-related events, there was no evidence of variable magnetic activity on BD +26\(^\circ\) 730 during our observations. BD +26\(^\circ\) 730 appears to be non-variable over long timescales as well. The C IV flux from 1981 is identical, within the errors, to the mean of the non-flare 1988 observations.

Thus, two striking results have emerged:

- In 1988, there was no change in the UV emission of BD +26\(^\circ\) 730 (outside of one flare) over 3.25 rotational periods and no significant change in magnetic flux (observed over 9 rotational periods) or H\( \alpha \) emission (observed over 18 periods).

- While BD +26\(^\circ\) 730 was considerably fainter (i.e., more spotted) in 1988 than when first observed with IUE in 1981, the average fluxes in its UV emission lines were virtually identical.

![Figure 4. Emission equivalent width of H\( \alpha \) equivalent widths (in A) vs. rotational phase for BD +26\(^\circ\) 730 in 1981 (•) and 1988 (+). No significant variability is seen outside of one flare (•).](image)

Both results are intriguing. On the Sun, large spot groups generally decay in less than 3 rotations. Apparently, BD +26\(^\circ\) 730 either has much longer-lived magnetic structures, or, BD +26\(^\circ\) 730 has a sufficiently large magnetic filling factor that even rapid emergence and dissipation of the regions does not change the integrated flux to any great degree. There is evidence that spot regions are much longer lived on active stars (e.g., Ref. 15). Even more interesting is the implication that even though the star was more spotted in 1988, its magnetic activity level, as measured by UV and H\( \alpha \) emission, was unchanged. This result suggests a situation quite different from the Sun, where increased sunspot coverage parallels increases in other indicators of activity.

One possible explanation is that BD +26\(^\circ\) 730 is so active that it can only have increased spot area at the expense of a decrease in the area covered by the brighter magnetic regions (BMR) — the stellar analogs of plage and active network. An increase in the spot coverage might then lead to no change, or even a decrease in total activity. The spot filling factor of \( \approx 20\% \) (Ref. 13) and our derived plage fill-

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ing factor of $f \approx 50\%$ are certainly consistent with the idea that BD $+26^\circ$ 730 is near the saturation level of magnetic activity (e.g., Ref. 16; Ref. 17).

Another possibility arises from noting that solar activity is primarily centered, not in the spots themselves, but in the BMR. In this scenario, the reduced BMR area during spot maximum is compensated by an increase in the BMR radiative flux per unit area, so that $f \times F_{rad}$ is constant. Evidence that $F_{rad}$ increases with spot activity on the Sun (Ref. 18) would seem to support this idea. As we presently have only two time points during the the magnetic cycle of BD $+26^\circ$ 730, however, these ideas are still rather speculative. Note, however, that the breakdown of the correlation between spot area and activity on BD $+26^\circ$ 730 indicates a situation quite different from that traditionally assumed in rotational modulation studies of active stars. The lack of a strong correlation between photometric and activity variation seen in several of these campaigns (Refs. 19, 20) might then be explained if these stars are also at a nearly saturated level of activity and/or they have their activity dominated by BMR and not spots.

There are many outstanding questions: As BD $+26^\circ$ 730 continues to approach starspot maximum, will it become more active, or will it actually become less active, as the BMR fraction is reduced? Magnetic structures (i.e., spots) on BD $+26^\circ$ 730 are clearly variable on timescales of years, but on what timescales is the activity variable? Were the 1981 spectra (a single pair of SWP and LWP exposures) perhaps misleading, unusually enhanced due to a flare? Do active stars often remain at nearly constant activity levels throughout their magnetic cycles? Further observations and analysis of BD $+26^\circ$ 730 and similar stars should help answer these questions.

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References: