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Attention: Michele Jacintho
Contract Administrator

Subject: Quarterly Reports

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In Reply Refer To: 97-REP-0092

Dear Ms. Jacintho:

In accordance with above subject article, Raytheon STX Corporation ("RSTX"), formerly known as Hughes STX Corporation, encloses herewith the necessary copies of the subject report. These reports have been distributed as instructed in referenced contract Article C.2. Should additional information be required, please contact the undersigned at (301) 794-5496

Sincerely,

RAYTHEON STX CORPORATION

Ralph E. Powe III
Jr. Contract Administrator

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The Winds of B Supergiants (STX Task 3400-001)

During the first quarter of this contract, work concentrated primarily on data acquisition and reduction.

As outlined in the proposal, the first step in this project was the analysis of the 1996 time series of 2 B supergiants and an O star (the "MEGA 2" data). To obtain optimal results, it was necessary to perform customized extractions of the echellograms with the STARLINK IUEDR software. This step is now complete.

Rotational Modulation of B Supergiant Winds

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Abstract. We present a 30 day *IUE* time series of the B0 Ia HD 91969, a member of the Carina open cluster NGC 3293. We show that wind lines which probe more deeply into the wind vary more regularly and that the lowest stages of ionization and the Si III λλ1300 triplets have a dominant period of $\sim$ 7.9 days. The photospheric lines (primarily Fe IV) also vary regularly, except with a period of 3.95 – half the dominant wind line period. Further, the photospheric lines *do not* vary at 7.9 days. While these results show a clear relationship between the wind and photospheric variability, the physical nature of the connection remains elusive.

1 Introduction

The link between the incidence and strength of wind activity and apparent stellar rotational velocity, $v \sin i$, has been known for some time (Prinja 1988). This link was demonstrated to be causal by the *IUE* MEGA campaign (Massa et al. 1995) in which the rapidly rotating B supergiant HD 64760 was observed for 15 consecutive days (Prinja et al. 1995). At about the same time, Kaufer et al. (1996) published their study of luminous late B and early A supergiants which also display rotational modulation at Hα.

One problem with the MEGA campaign results is that they apply to rapidly rotating stars, leaving open the question of whether the observed rotational modulation is typical of all B supergiants or only rapidly rotating stars. To test this question, we observed a B0 Ia with a typical $v_{eq} \sin i$ during the final episode of *IUE*.

2 The program star

We observed the B0 Ia HD 91969 in the Carina open cluster NGC 3293. This star is a bit more luminous than optimal for wind studies, but it was our only option given the severe operating constraints during the final months of *IUE*. Because of its cluster membership, its M_v is known from main sequence fitting of the cluster B stars. Curiously, even though the star is classified B0 Ia by Walborn (1976), its absolute magnitude is closer to a B0 Iab. Table 1 lists the properties of HD 91969, along with references. A range for the derived quantities, $\log L/L_\odot$, $R/R_\odot$ and P_{max}, is given. The uncertainty results from adopting either the Humphreys & McElroy (1984) or the de Jager & Nieuwenhuijzen

(1987) temperature calibration. Because HD 91969 has a typical $v_{eq} \sin i$, its $\sin i$ and, hence, its actual rotation period are poorly constrained. The maximum period is between 14.0 and 18.4 days, and if we assume that the star would be spectroscopically peculiar if it had a v_{eq} much greater than 200 km s^{-1}, a minimum period of 4.6 – 7.9 days results.

Table 1

Sp Ty	B0 Ia	Walborn 1976
$v_{eq} \sin i$	83 km s^{-1}	Howarth et al. 1996
M_v	-6.3 mag	Turner et al. 1980, Feinstien &
Distance	2.6 kpc	Maraco 1980, Shobbrook 1983
$\log L/L_\odot$	5.5 dex	Humphreys & McElroy 1984,
$R/R_\odot$	22.9–31.6	de Jager & Nieuwenhuijzen,
P_{max}	14.0-18.4 d	1987

3 Results

We obtained 82 spectra over 29.6 days in May-June 1996 with a mean sampling of 8.6 hours and no major gaps in the time series. This time series spans at least 2 stellar rotation cycles. The spectra were reduced using the IUEDR package described by Giddings & Rees (1989). Figure 1 shows selected lines from the series as dynamic spectra normalized by the mean profile for the series.

Several aspects of the time series shown in Figure 1 are immediately apparent. First, variability extends to $v \sim -1800$ km s^{-1} in the strongest wind lines; second, there is activity to $v = 0$ km s^{-1} in Al III and the Si III triplets, and; third, as is often the case, two distinct, simultaneous forms of variability are present – strong, long period ($\sim$ 20 days) variability at high v in the high ions and regular variations at low v in the low ions.

In addition to the wind variability, we also noted activity in the strongest Fe IV photospheric lines. This was analyzed by cross-correlating the individual spectra with a template of 201 strong Fe IV lines lying between 1415 and 1845Å (omitting the wind line regions). The result is shown as a dynamic spectrum of the dispersions about the normalized mean profile in Figure 2. Notice that the mean profile has the expected position and width, but that the variability is primarily on the red portion of the line, centered at $v \sim +30$ km s^{-1}. Furthermore, some features can be seen to move from blue-to-red, as expected for surface features.

4 Periodic behavior

Figure 3 displays the amplitudes of the cleaned Fourier transforms, FTs, of the wind lines (see, Fullerton et al. 1997). There is a strong peak at $\sim$ 7.9 days in Al III (also visible in the raw data in Figure 1), C II and the Si III triplets. The high ions do not repeat exactly, but all do have a peak in their power at $\sim$ 8 days. Because $\sin i$ is so poorly constrained and since P_{rot} is so poorly determined,

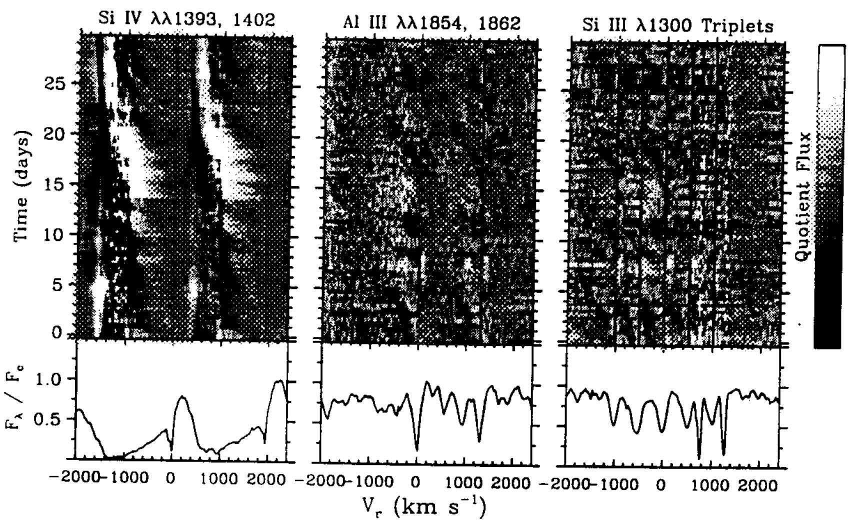

Fig. 1. Dynamic spectra of selected lines in HD 91969. Notice that periodicity is not obvious in the saturated Si IV doublet, but is progressively more apparent in the weak Al III resonance doublet and the Si III triplets.

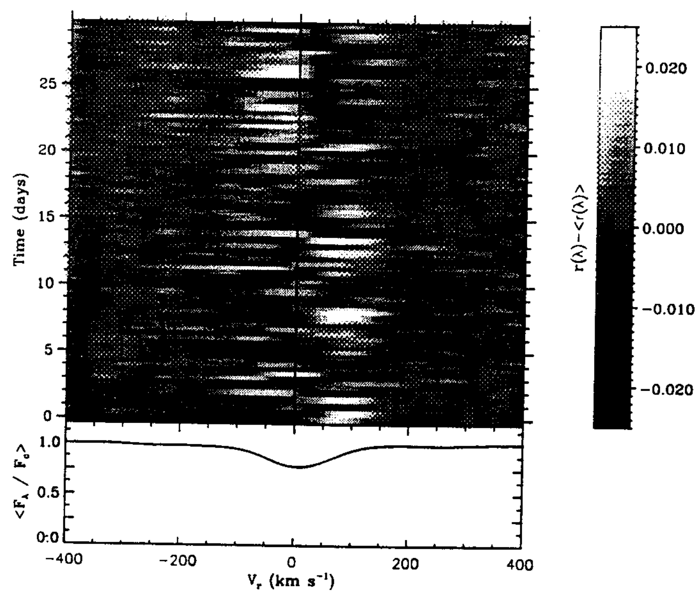

Fig. 2. Dynamic spectrum of the cross-correlation of the spectra and a template of Fe IV lines. The mean line is shown at the bottom.

it is difficult to decide whether the 8 day period in the wind corresponds to a disturbance which occurs once or twice per revolution.

Figure 4 shows the amplitudes of the cleaned FTs of the Fe IV data. In this case there is a distinctive peak at 3.95 days, but nothing near the 7.9 day period favored by the wind lines. Notice that the dominant peak occurs at roughly half of the period of the dominant peak in the wind lines.

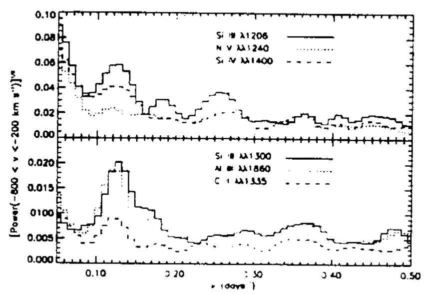

Fig. 3. Cleaned FT power in the wind lines.

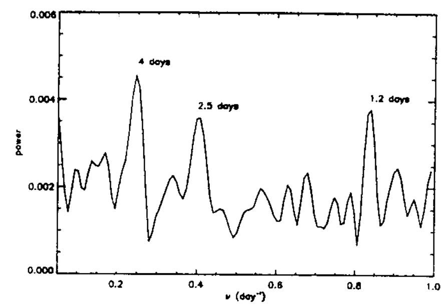

Fig. 4. Cleaned FT power in Fe IV.

5 Conclusions

A typical B0 Ia shows rotational modulation of its wind lines increasing in strength for lines formed deepest in the wind – implying that the coherency is introduced at or very near the surface and weakens as structures propagate outward. The cyclical period of the wind structures is $\sim$ 7.9 days which could represent either one or two fixed surface features or a traveling wave with several crests.

The Fe IV variability is photospheric because it is confined to $\pm v_{eq} \sin i$ and some features move from blue to red. However, the variability is not centered on the line. Its strongest period is *half* the dominant wind period. While this suggests a distinct connection between the two, the nature of this connection remains unclear.

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13. ABSTRACT *(Maximum 200 words)*
This quarterly report is comprised of a paper, "Rotational Modulation of B Supergiant Winds" presented at the ESO workshop "Cyclical Variability in Stellar Winds." Presented is a 30-day IUE time series of the B0 Ia HD 91969, a member of the Carina open cluster NGC 3293, which showed, among other things, that wind lines that probe more deeply into the wind vary more regularly.

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