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FINAL REPORT

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"Wind Variabilty in Intermediate Luminosity B Supergiants"

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1. Introduction

The object of this study was to determine the ubiquity and nature of wind variability in intermediate luminosity B supergiants. These stars were selected for study because, unlike the more frequently studied O and WR stars, they contain spectral diagnostics which present distinct advantages for addressing many observational issues concerning wind physics. Some of these advantages are:

1. **BIs have well-developed, but unsaturated wind lines that span a wide range of ionization stages.** These can run from C II to C IV for B2-5 and from Si III to N V at B0-1, and often include adjacent stages of ionization for Si (Si III λ1206 and Si IV $\lambda\lambda$1400). Furthermore, many of these ions are much closer to the stages expected to be dominant in the wind. The fact that the lines are frequently unsaturated allows more reliable optical depths to be determined and the fact that they are closer to the dominant ionization stage allows more accurate estimates of mass loss, $\dot{M}$, to be made since smaller adjustments are required for the ionization fraction, q, of the observed ionic species.

2. **BIs frequently have more than one unsaturated wind line.** This situation occurs often and opens up the possibility of studying how the ionization ratios in the winds change with respect to the physical parameters of the star and with time, in the case of variable winds.

3. **After hydrogen, the strongest photospheric lines of BIs are the UV silicon lines.** The strong UV photospheric silicon lines provide sensitive temperature and surface gravity diagnostics. The strongest photospheric lines also show wind effects and serve as excellent probes of the wind–photosphere interface.

4. **Abundance anomalies can be quantitatively measured in BI winds.** Because the photospheric UV silicon spectra of BIs make it is possible to place their spectra onto a 2-dimensional silicon based grid unambiguously, one can study their wind lines independently. Typically, wind lines from carbon and nitrogen (when present) follow the trends indicated by the photospheric line strengths *and* the silicon wind lines. There are, however, distinct exceptions. The vast majority of these are related to abundance anomalies.

5. **BIs have longer wind flow times than O stars.** Because they have lower terminal speeds and larger radii than O stars, their wind flow times ($t_{flow} \propto R/v_\infty$ for a steady wind) are longer. This presents two distinct advantages. First, the spectroscopic signatures of their wind variability evolve more slowly. Thus, wind variations in BIs are easier to observe, especially at low velocities where the accelerations are largest. Second, the lower terminal velocities allow the two components of the important Si IV $\lambda\lambda$1400 doublet to become largely uncoupled.

2. Work Completed

The following work was completed under this contract:

1. A detailed analysis of wind variability in the B0.5 Ib star HD 64760 (Massa et al. 1995b, enclosure 1) which demonstrated:

   - The presence of massive ejections of material into the wind which involve the photosphere.
   - The first clear demonstration of the long sought after "photospheric connection" between wind and atmospheric lines.
   - The development of new analysis tools to examine the ionization in the wind and a new model fitting procedure.
   - A clear demonstration of whole scale shifts in the ionization of the normal stellar wind.

2. Organized and lead the large, international effort, dubbed the "*IUE* MEGA campaign" (Massa et al. 1995a, enclosure 2) which obtained unprecedented temporal coverage of wind variability in rapidly rotating, early-type stars. The results of this aspect of the study included

- The demonstration of recurring wind features which repeated with a period equal to an one fourth of the rotation period of a B supergiant. This result provided the first clear indication of wind enhancements whose origin is rooted in the stellar photosphere (Prinja, Massa & Fullerton 1995, enclosure 3).
- The periodic statistical behavior of wind enhancements in an O supergiant (Howarth et al. 1995, enclosure 4).

3. A detailed analysis of wind variability in the rapidly rotating B1 Ib, γ Ara (Prinja, Massa & Fullerton 1996, enclosure 5). This analysis demonstrated

   - The existence of a two component wind – with the denser, more slowly evolving component most probably associated with a wind compressed disk.
   - The discovered a stellar wind in a normal B supergiant which has distinctly different mean states from one epoch to the next.

4. Organized a follow on campaign to the MEGA project, designed to study slowly rotating O and B supergiants. This campaign was deemed a program of lasting value by the joint ESA/NASA review board, and will obtain 30 days of *IUE* observations of 4 OB stars. This program will be performed in May-June of 1996.

5. Performed a global survey of all the available *IUE* time series for B supergiants (Massa, Prinja, & Fullerton 1995, BAAS, 27, 1311, enclosure 6), and identified recurring spectroscopic signatures which were tentatively identified with different physical phenomena.

3. Work in Progress

The following work is still in progress.

- **Completion of item 5, the overall survey:** This final bit of work is still in progress, and will help to place the previous results into context. This work will be pursued this summer with Raman Prinja at University College, London. This work will be done in conjunction with a NATO visiting Scientist grant which will pay my living and travel expenses.

- **The follow on to the IUE MEGA campaign (item 4):** The observations from this project will be obtained this summer and will represent the longest time series ever obtained for stellar winds (a record which, unfortunately, will probably last for many years because *IUE* is scheduled to be decomissioned this fall) and it is extremely important to make these data available to the community. This will be one of my objectives during my stay in London this summer.

Publications resulting from this contract:

"Stellar Wind Variability: the Things B Supergiants Do", D. Massa, R.K. Prinja, & A. Fullerton 1995, BAAS, 27, 1311

"Wind Variability in B Supergiants: II. The Two Component Stellar Wind of γ Ara (B1 Ib)", R.K. Prinja, D. Massa, & A. Fullerton 1996, in press

"The *IUE* MEGA Campaign: Wind Variability and Rotation in Early-Type Stars" D. Massa, et. al. 1995 ApJ, 452, L53

"The *IUE* MEGA Campaign: Modulated Structure in the Wind of HD 64760 (B0.5 Ib)" R.K. Prinja, D. Massa, & A.W. Fullerton 1995 ApJ, 452, L61

"The *IUE* MEGA Campaign: The Rotationally Modulated Wind of ζ Puppis" I.D. Howarth, R.K. Prinja, & D. Massa 1995 ApJ, 452, L65

"Wind Variability in B Supergiants: I. The Rapid Rotator HD 64760 (B0.5 Ib)", D. Massa, A.Fullerton & R.K. Prinja 1995, ApJ, 452, 842.

Enclosure 1

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13. ABSTRACT *(Maximum 200 words)*

This study used the unique spectroscopic diagnostics of intermediate luminosity B supergiants to determine the ubiquity and nature of wind variability. Specifically, 1) A detailed analysis of HD 64760 demonstrated massive ejections into its wind, provided the first clear demonstration of a "photospheric connection" and ionization shifts in a stellar wind. 2) The international "IUE MEGA campaign" obtained unprecedented temporal coverage of wind variability in rapidly rotating stars and demonstrated regularly repeating wind features originating in the photosphere. 3) A detailed analysis of wind variability in the rapidly rotating B1 Ib, gamma Ara demonstrated a two component wind with distinctly different mean states at different epochs. 4) A follow-on campaign to the MEGA project to study slowly rotating stars was organized and deemed a key project by ESA/NASA, and will obtain 30 days of IUE observations in May-June 1996. 5) A global survey of archival IUE time series identified recurring spectroscopic signatures, identified with different physical phenomena.

Items 4 and 5 above are still in progress and will be completed this summer in collaboration with Raman Prinja at University College, London.

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