The Astrophysical Journal, 387:L85–L88, 1992 March 10

DISCOVERY OF A FAST WIND FROM A FIELD POPULATION II GIANT STAR

A. K. Dupree[1] and Dimitar D. Sasselov[1]
Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138
and
John B. Lester[1]
University of Toronto, Department of Astronomy, Erindale College, Mississauga, ON, Canada L5L 1C6
Received 1991 December 9; accepted 1991 December 30

ABSTRACT

The He I λ10830 absorption in the metal-deficient field giant star HD 6833, extends to at least -90 km s^{-1}, a value that is comparable to, or exceeds the escape velocity from the photosphere of the star. This spectrum provides strong observational evidence for mass loss. Because this field giant is a surrogate for red giants in globular clusters, and a velocity of 90 km s^{-1} is larger than the central escape velocity from most globular clusters, this observation suggests that material lost from globular cluster stars may easily escape from the cluster, and thus resolve the dilemma of the missing interstellar medium in globular clusters.

Subject headings: globular clusters: general — stars: chromospheres — stars: giant — stars: individual (HD 6833) — stars: mass loss — stars: Population II

1. INTRODUCTION

To reproduce the observed color magnitude diagram of globular clusters with stellar evolution codes, it has been necessary to *assume* that substantial amounts of mass are lost from stars ascending the red giant branch for the first time. Currently however, there is no direct observational detection of the mass-loss process. The emission wings in the Hα line of metal-poor giants (Cohen 1976; Cacciari & Freeman 1983; Smith & Dupree 1988) were thought to indicate circumstellar material. But this conclusion no longer seems acceptable because the emission can exhibit short-term variability, and calculations demonstrate that Hα emission wings can arise naturally in a static stellar chromosphere (Dupree, Hartmann, & Avrett 1984).

A consequence of mass loss would be the presence of interstellar material within globular clusters. Because of the general belief that red giants have slow winds ($V \approx 10$–20 km s^{-1}), whose speeds are much less than the escape velocities from a cluster core (≤ 80 km s^{-1}, Webbink 1985), high-mass clusters would retain the material (Faulkner & Freeman 1977; VandenBerg & Faulkner 1977), although it might escape from clusters with low mass. In the more massive clusters, the material is expected to build up and remain in the cluster until it is removed by ram pressure when the cluster passes through the Galactic plane. However, in spite of deep searches for interstellar matter using X-ray, optical, and radio techniques (see summaries in Roberts 1988; Faulkner & Smith 1991), no material has been detected, and upper limits frequently lie several orders of magnitude below the value of 10^2 to 10^3 $M_\odot$ postulated by theory. To resolve this awkward puzzle, Roberts (1988) has suggested that efficient steady-state cleaning mechanisms must be present. And Smith et al. (1990) have conjectured that a rapid massive wind occurs *briefly*, perhaps during the single helium shell flash of a red giant, providing the necessary energy to move material out of a cluster. They note that spectroscopic signatures are not likely to be detected since these flashes happen infrequently.

Metal-deficient field giants are similar to the red giants in globular clusters. The spatial distribution of the metal-poor red giants within the Galaxy, as well as their dynamical properties and metal deficiencies mimic those of the globular clusters (Carney 1988; Zinn 1988) even though the precise form of the metallicity distribution may differ (Laird et al. 1988). Our target star, HD 6833 [$V = 6.75$; $(B-V)_0 = 1.00$] is classified as G9.5 III Fe-2 (Keenan & McNeil 1989), and represents one of the brightest members of the metal-deficient group (Bond 1980), making it accessible to high resolution study in the infrared, optical, and ultraviolet. The [Fe/H] ratio in HD 6833, has been variously evaluated as -0.75 (Luck 1991), -0.85 (Cayrel de Strobel 1966), -1.2 (Gratton & Ortolani 1984), and -1.6 (Bond 1980). The metallicity and high radial velocity (-245 km s^{-1}, Roman 1955) of HD 6833 confirm that it is an old star (>12 Gyr) that can be identified with the thick disk population (Luck 1991). Cayrel de Strobel (1966) explicitly remarked on its similarity to giants in M5. These characteristics suggest that HD 6833 makes a reasonable surrogate for red giants in globular clusters—in particular, thick-disk clusters of moderate metal deficiency such as 47 Tuc.

The chromospheric He I (λ10830; $2s\ ^3S \rightarrow 2p\ ^3P^o$) transition can indicate bulk mass motions in the atmospheres of luminous cool stars. Because it is formed higher in the atmosphere of a low gravity star than Hα, and Ca II and Mg II emission cores, its profile can reveal the dynamics of the upper atmosphere where the wind begins to accelerate. The transition has been surveyed in a number of cool stars (Zirin 1976, 1982; O'Brien & Lambert 1986; Lambert 1987) and Cepheids (Sasselov & Lester 1990; Sasselov 1990). Previous spectrographic observations at λ10830 were constrained only to bright stars due to technical reasons and include no Population II giants. This observation of HD 6833 is the only one we have obtained of a metal-poor giant.

2. OBSERVATIONS

The Fourier transform spectrometer (FTS) at the Canada-France-Hawaii Telescope (Maillard & Michel 1982) was used

[1] Visiting Astronomer, Canada-France-Hawaii Telescope, operated by the National Research Council of Canada, the Centre National de la Recherche Scientifique of France, and the University of Hawaii.

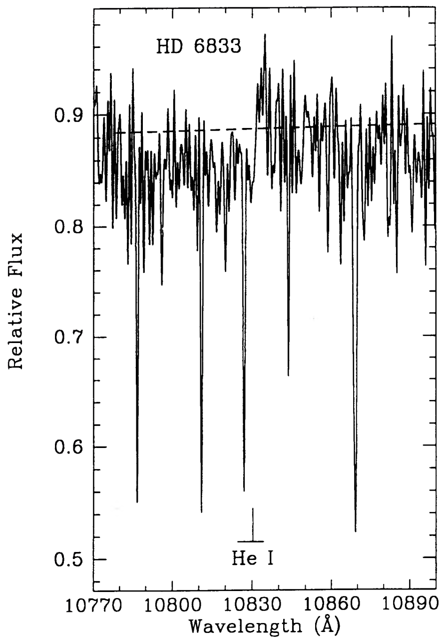

FIG. 1.—Spectrum of HD 6833 in the region of the He I λ10830 transition. The continuum was fit by least-squares techniques. The position and extent of the He I feature are indicated.

on the night of 1991 October 31 to obtain spectra of HD 6833. These spectra were centered near 1.1 μm and cover a band of 300 Å as defined by a custom-made filter. The spectral resolution ($\lambda/\Delta\lambda$) of 18,500 corresponds to 17 km s^{-1}. The spectrum of HD 6833 shown in Figure 1 is a co-addition of four FTS scans obtained over 20 minutes and has a signal-to-noise ratio of about 36. The He I feature is clearly visible near λ10830, and suggests that a P Cygni type profile is present. Spectra of α Bootis and α Aquarii shown in Figure 2 were obtained in 1990 July and 1991 June, respectively, using the same instrumental setup at higher resolution. Telluric contamination in the 10818 to 10840 Å spectral range is insignificant; the comprehensive list of Breckenridge & Hall (1973) was used for identification of telluric lines.

We find a profile of the He I line in HD 6833 which is similar to the profiles already known for α Boo and α Aqr (see also O'Brien & Lambert 1979, 1986). The spectra of the latter two stars (which have very high signal-to-noise ratios) show emission profiles of the He I line with extended short-wavelength absorption. This description characterizes the He I profile of HD 6833 as well. (The He I λ10830 transition is a triplet composed of two unresolvable components at λ10830.30, and an insignificant weak component at λ10829.08.)

The He I absorption is shallow, reaching about 10% of the continuum, but the short wavelength side of the line is extended at least to the narrow photospheric Si I absorption, and most likely to shorter wavelengths beyond.[2] To make a conservative estimate of the extent of the absorption wing, we take the velocity difference corresponding to the laboratory wavelength difference: $\lambda_{\rm He\,I} - \lambda_{\rm Si\,I} = -90$ km s^{-1}. Thus HD 6833 has bulk outward motions of the chromosphere amounting to 90 km s^{-1}.

[2] In fact, our study of this profile in many cool giants suggests that the He I line in HD 6833 may have a P Cygni profile with broad emission and a short wavelength extension to ≈200 km s^{-1}, but the minimum value of 90 km s^{-1} suffices for this discussion.

3. DISCUSSION

The presence of He I in a red giant is not surprising; Zirin (1982) pointed out that G and K giants (through K3) exhibit He I. This feature indicates the atmosphere contains material at chromospheric temperatures (≈10,000 K), and other chromospheric indicators such as Mg II and Ca II have also been detected in HD 6833. Inspection of chromospheric line profiles from HD 6833 lends some supporting, but not definitive, evidence for the presence of a fast wind. Long exposures (≈8 hr) of the Mg II doublet with *IUE* show asymmetric profiles interpreted as expansion of the Mg II-forming region. An absorption feature might exist about 70 km s^{-1} shortward of the λ2795 transition (Dupree, Hartmann, & Smith 1990), but a subsequent 14 hr exposure is inconclusive. The Ca II *K*-line profile (Dupree & Whitney 1991) has a notch at -52 km s^{-1}, but it cannot be confidently distinguished from the noise in the Reticon detector. Two previous observations (Cayrel de Strobel 1966; Smith & Dupree 1988) of the Hα profile show symmetric absorption without emission wings. A spectrum of Hα obtained on 1991 November 16 at the Oak Ridge Observatory is similar to the earlier profiles. The unchanging Hα profile, spanning ≈25 years, suggests minimal global variability of the atmosphere. The lack of emission wings above the continuum and a symmetric core is consistent with other metal-poor giants of similar luminosity.

The escape velocity from HD 6833 is evaluated by taking the mass of the red giant as 0.8 $M_\odot$, and the radius as 30 to

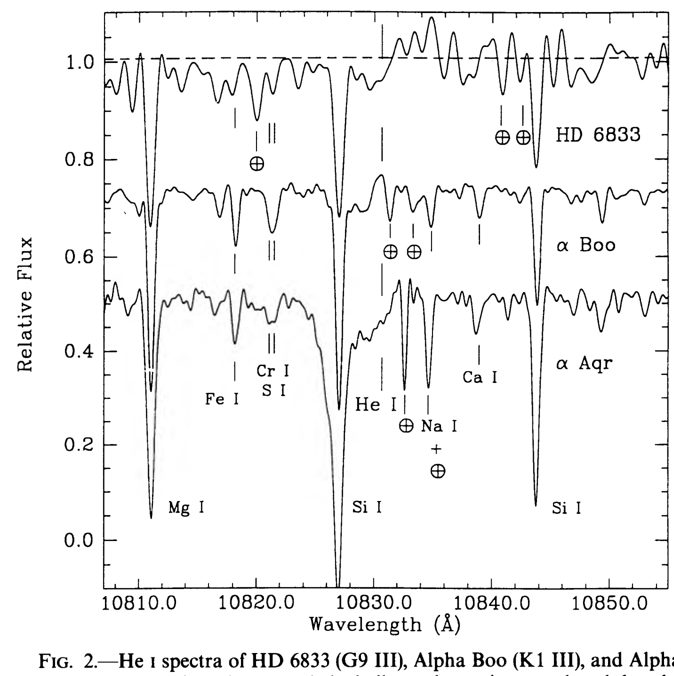

FIG. 2.—He I spectra of HD 6833 (G9 III), Alpha Boo (K1 III), and Alpha Aqr (G2 Ib) showing the extended shallow absorption produced by the λ10830.3 transition. The spectra have been coaligned on the photospheric Si I (Mult. 5) at (10827.09 Å) and placed on a laboratory wavelength scale. Because the radial velocities of the stars differ by ≈240 km s^{-1}, the terrestrial water vapor lines do not coincide. He I absorption in HD 6833 may extend to shorter wavelengths than the Si I photospheric line. The He absorption is stronger in HD 6833 than in α Boo; the weakness of the Si transition in HD 6833 is consistent with a lower metal abundance than in α Boo. Emission is clearly present in both α Boo and α Aqr. To avoid confusion, only a small number of the features that we have identified are labeled in the figure.

$45\ R_\odot$.[3] Then $v_{\rm esc} = 620(M/R)^{1/2} = 80$ to 100 km s^{-1}, at the surface. When the material is located above the photosphere, where the helium line is formed, the escape velocities should be decreased by $\approx 10\%$. At either value, the observed minimum extent of the He I line (90 km s^{-1}) is comparable to the escape velocity from the star, and exceeds the central escape velocity evaluated by Webbink (1985) for several hundred globular clusters. Thus, the fast wind provides a straightforward explanation for the lack of interstellar material in globular clusters.

The He I λ10830 transition is especially suited as an indicator of mass motions in the atmospheres of cool stars with chromospheres for at least three independent reasons: (1) the He I line is a pure chromospheric feature, with no photospheric, circumstellar, or interstellar contamination; (2) it is formed higher than Hα, and Ca II and Mg II emission cores in the atmosphere of a low-gravity star; and (3) in such atmospheres, the source function of the λ10830 line couples weakly to local conditions, and absorption in the line is more efficient than emission from recombination, providing high sensitivity to bulk gas motions. Thus, the He I λ10830 transition represents a wind diagnostic in the chromosphere that is preferable to the Ca II and Mg II resonance lines which have collisionally dominated source functions. The latter emission profiles are more likely to be affected by dynamic transients (like shocks) and make the determination of the wind speed in the atmosphere more difficult and time dependent. Circumstellar absorption features in Mg II and Ca II can indicate the terminal velocity of a wind but these signatures occur away from the emission core, and so require exceptionally high-quality spectra to be detected against a weak continuum.

On the other hand, a single spectrum at He I λ10830 can give a reliable wind estimate. The formation of the helium spectrum in cool stars is complex and has been well understood only recently (Sasselov 1990; Avrett & Loeser 1992; Dupree, Whitney, & Avrett 1992). Most of the complexity however concerns the mechanisms for populating the He triplet levels, while the points discussed above are less model dependent. Figure 3 shows the results of non-LTE calculations for the atmosphere of HD 6833. The contribution function for He I, λ10830, peaks in a region of the atmosphere that is higher than the formation level of Hα, Ca II, and Mg II cores. Here we define (see Magain 1986) the contribution function, *CF*, to the specific intensity as

$$CF(\log_{10}\tau) = \frac{2.303}{\mu}\,\tau_0\,\frac{\kappa}{\kappa_0}\,S_\nu \exp\left(-\frac{\tau_\nu}{\mu}\right),$$

where τ_0 is the optical depth at a reference wavelength λ_0, κ is the absorption coefficient, S_ν is the source function at frequency ν, and $\mu = \cos\theta$. As appropriate, we use the CF to the line depression for which τ is defined in terms of $\kappa = \kappa_l + \kappa_c S_c/I_c$. The initial atmosphere model was Model 2 from Dupree et al. (1984) with abundances modified to correspond to those determined by Luck (1991) for this star. The model atom for helium has 15 levels and contains both stages of

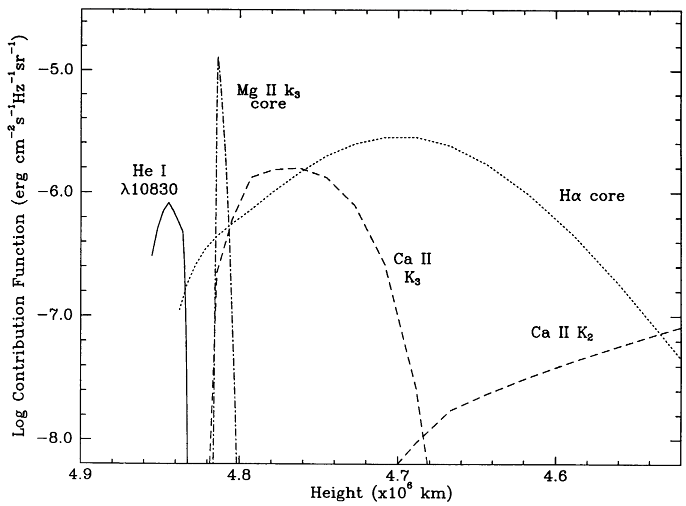

FIG. 3.—Contribution functions for He I (λ10830) and other chromospheric features computed with a semi-empirical plane parallel atmospheric model of HD 6833 with multilevel, non–LTE radiative transfer, and an expanding velocity field. The height is measured from the photosphere. Note that the He I line is formed at a level higher than the Mg II k-line core (k_2), the Ca II central reversal (K_3), the Hα core, and the Ca II emission (K_2). For a star of 40 $R_\odot$, the contribution functions are centered near 1.17 R_*.

ionization. The non–LTE solutions for H, Ca II, Mg II, and He are performed consecutively. To match the profiles of all lines, including the He I λ10830 transition, a rapid acceleration of the atmosphere is needed, at least to ≈ 100 km s^{-1}. The detailed model will be published elsewhere.

Such a chromospheric velocity profle is also demanded by the He I lines in the G2 supergiant, α Aqr (Dupree 1991; Dupree et al. 1992) where ≈ 150 km s^{-1} is reached within 1.5 R_*. All of the detailed radiative transfer calculations show that the λ10830 absorption arises in the chromosphere, and that its extent gives a direct measure of the velocity profile in the atmosphere. This conclusion appears inescapable given the high densities found in the chromosphere as compared to regions more distant from the stellar surface. An emission feature in the He I line profile signals the presence of an extended atmosphere—not unexpected when low-gravity stars are considered.

We have no evidence for the behavior of the velocity beyond the region of formation of the He I line. There may be continued acceleration beyond the critical point, or modest deceleration could follow at large distances similar to our models for the hybrid supergiant α Aqr (Dupree et al. 1992). Line profiles of transition region lines (formed at $T \geq 50{,}000$ K) could give indications of the velocity field; and circumstellar features, indicative of the terminal velocity, would be apparent in a high-quality Mg II line profile and perhaps Ca II, provided that the wind is sufficiently cool.

Fast winds in luminous stars may be more common than generally believed. The He I λ10830 absorption extends to high velocities in a number of cool giants and supergiants (O'Brien & Lambert 1986, Lambert 1987, Sasselov 1990). Hybrid giants and supergiants that are well studied (Hartmann, Dupree, & Raymond 1981; Hartmann et al. 1985; Reimers 1982; Judge, Jordan, & Rowan-Robinson 1987) frequently show absorption troughs extending shortwards of the Mg II emission by several hundred km s^{-1}—velocities comparable to the escape velocity from the star. Models suggest this absorption arises from recombining ions several stellar radii distant. Many of these

[3] Infrared colors and luminosities (Frogel, Persson, & Cohen 1983) suggest that $T_{\rm eff} \approx 4400$ K for HD 6833 when compared with globular cluster giants of similar colors and comparable metallicities; this leads to $R_* = 30$ to 45 $R_\odot$. Most abundance analyses (Cayrel de Strobel 1966; Gratton & Ortolani 1984) yield spectroscopic gravities in agreement with the radii derived from infrared observations. These values are consistent with Luck's recent study (1991) which assumes upper and lower limits to the surface gravity ($\log g = 2.16$ or 0.88), and consequently radii between 12 and 75 $R_\odot$.

objects have wide, ultraviolet transition region lines that may be formed in an expanding atmosphere (Hartmann et al. 1981). The metal-deficient field giant HDE 232078 has variable Hα absorption, that once extended 60 km s^{-1} shortward of the line core (Smith & Dupree 1988).

This rapid mass outflow does not appear to be associated with a catastrophic event—such as a helium shell flash—or even an anomalous phase in the evolution of HD 6833, and we can only assume that such mass outflow is a fairly continuous process. The mass-loss rate needs to be evaluated through calculation of an atmosphere that is self-consistent with the set of observed line profiles. Because of the higher velocities that are detected here, the mass-loss rate could exceed the value of $\approx 2 \times 10^{-9}$ $M_\odot$ yr^{-1}, an upper limit derived (Dupree et al. 1984) from Hα profiles of other metal-poor giant stars. An order of magnitude estimate based on the Mg II asymmetry in HD 6833 led to 5×10^{-11} $M_\odot$ yr^{-1} (Dupree et al 1990). A much larger mass-loss rate, leading to ≈ 0.2 $M_\odot$ during the red giant phase, is required to match the amount required for horizontal branch morphology.

In summary, a fast wind has been detected in the metal-poor giant HD 6833 by studying the profile of the He I λ10830 transition which is formed higher in the atmosphere than the Hα core, and Ca II and Mg II emission cores. Because the speed of the outflow is comparable to the escape velocity from the photosphere of the star, this spectrum represents a true stellar wind, and not simply a flow of material. Red giants in globular clusters are similar to HD 6833; thus the stellar wind could provide the mass loss assumed for stellar evolution calculations but not observed previously. A wind with velocity ≈ 100 km s^{-1}, could escape the star, and also escape from a globular cluster; this finding provides a natural explanation for the lack of detected interstellar material within globular clusters.

We greatly appreciate the help of J.-P. Maillard in acquiring these spectra, R. Kurucz in calculating synthetic spectra for line identifications, and D. Zucker in preparing the figures. R. Stefanik and J. Zajac of the Oak Ridge Observatory kindly obtained the Hα spectrum on short notice. Observations at the CFHT were supported by a travel grant from the National Research Council of Canada. This research has made use of the Simbad data base, operated at CDS, Strasbourg, France.

REFERENCES

Avrett, E. H., & Loeser, R. 1992, in 7th Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun, ed. M. Giampapa & J. Bookbinder (ASP Conf. Series), in press
Bond, H. E. 1980, ApJS, 44, 517
Breckenridge, J. B., & Hall, D. N. 1973, Solar Phys., 28, 15
Cacciari, C., & Freeman, K. C. 1983, ApJ, 268, 185
Carney, B. W. 1988, in IAU Symp. 126, Harlow Shapley Symposium on Globular Cluster Systems in Galaxies, ed. J. E. Grindlay & A. G. Davis Philip (Boston: Kluwer), 133
Cayrel de Strobel, G. 1966, Ann. d'Astrophys., 29, 413
Cohen, J. C. 1976, ApJ, 203, L127
Dupree, A. K. 1991, in Mechanisms of Chromospheric and Coronal Heating, ed. P. Ulmschneider, E. R. Priest, & R. Rosner (New York: Springer), 185
Dupree, A. K., Hartmann, L., & Avrett, E. H. 1984, ApJ, 281, L37
Dupree, A. K., Hartmann, L., & Smith, G. H. 1990, ApJ, 353, 623
Dupree, A. K., & Whitney, B. A. 1991, Nature, 354, 284
Dupree, A. K., Whitney, B. A., & Avrett, E. H. 1992, in 7th Cambridge Workshop on Cool Stars, Stellar Systems, and the Sun, ed. M. Giampapa & J. Bookbinder (ASP Conf. Series), in press
Faulkner, D. J., & Freeman, K. C. 1977, ApJ, 211, 77
Faulkner, D. J., & Smith, G. H. 1991, ApJ, 380, 441
Frogel, J. A., Persson, S. E., & Cohen, J. G. 1983, ApJS, 53, 713
Gratton, R. G., & Ortolani, S. 1984, A&A, 137, 6
Hartmann, L., Dupree, A. K., & Raymond, J. C. 1981, ApJ, 246, 193
Hartmann, L., Jordan, C., Brown, A., & Dupree, A. K. 1985, ApJ, 296, 576
Judge, P. G., Jordan, C., & Rowan-Robinson, M. 1987, MNRAS, 224, 93
Keenan, P. C., & McNeil, R. C. 1989, ApJS, 71, 245
Laird, J. B., Rupen, M. P., Carney, B. W., & Latham, D. W. 1988, AJ, 96, 1908
Lambert, D. L. 1987, ApJS, 65, 255
Luck, R. E. 1991, ApJS, 75, 579
Magain, P. 1986, A&A, 163, 135
Maillard, J.-P., & Michel, G. 1982, in IAU Colloq. 67, Instrumentation for Astronomy with Large Optical Telescopes, ed. C. M. Humphries (Dordrecht: Reidel), 213
O'Brien, G., & Lambert, D. 1979, ApJ, 229, L33
———. 1986, ApJS, 62, 899
Reimers, D. 1982, A&A, 107, 292
Roberts, M. S. 1988, in IAU Symp. 126, Harlow Shapley Symposium on Globular Cluster Systems in Galaxies, ed. J. E. Grindlay & A. G. Davis Philip (Boston: Kluwer), 411
Roman, N. G. 1955, ApJS, 2, 1955
Sasselov, D. 1990, Ph.D. thesis, Univ. Toronto
Sasselov, D., & Lester, J. B. 1990, ApJ, 362, 333
Smith, G. H., & Dupree, A. K. 1988, AJ, 95, 1547
Smith, G. H., Wood, P. R., Faulkner, D. J., & Wright, A. E. 1990, ApJ, 353, 168
VandenBerg, D. A., & Faulkner, D. J. 1977, ApJ, 218, 415
Webbink, R. F. 1985, in IAU Symp. 113, Dynamics of Star Clusters, ed. J. Goodman & P. Hut (Dordrecht: Reidel), 541
Zinn, R. 1988, in IAU Symp. 126, Harlow Shapley Symposium on Globular Cluster Systems in Galaxies, ed. J. E. Grindlay & A. G. Davis Philip (Boston: Kluwer), 37
Zirin, H. 1976, ApJ, 208, 414
———. 1982, ApJ, 260, 655