1984ApJ...284..774D

THE ASTROPHYSICAL JOURNAL, 284:774–783, 1984 September 15

THE ORIGIN OF LOW-VELOCITY ABSORPTION COMPONENTS IN THE Mg II RESONANCE LINES OF HYBRID-CHROMOSPHERE STARS

S. A. DRAKE,[1] A. BROWN,[1] AND J. L. LINSKY[1,2]
Joint Institute for Laboratory Astrophysics, University of Colorado, and National Bureau of Standards
Received 1984 January 19; accepted 1984 March 23

ABSTRACT

We argue that the low-velocity absorption features seen in the Mg II resonance lines of seven confirmed and three probable hybrid-chromosphere stars are interstellar rather than circumstellar in origin. From a comparison of radial velocities based on all available spectra in the *International Ultraviolet Explorer* (*IUE*) archives with estimates of the interstellar velocity along each line of sight, we find a good correlation between the *observed* position of the low-velocity component and the *predicted* interstellar feature. We also show that previous arguments in favor of the circumstellar origin of the low-velocity absorption features are either incorrect or implausible. Our conclusion may modify previously proposed models of hybrid star winds which have assumed *a priori* that both Mg II absorption components are circumstellar.

Subject headings: interstellar: matter — stars: chromospheres — stars: circumstellar shells — stars: late-type — stars: winds — ultraviolet: spectra

I. INTRODUCTION

Hartmann, Dupree, and Raymond (1980) introduced the term hybrid(-chromosphere) star to refer to those luminous, late-type stars that show spectroscopic evidence for *both* a cool ($T \sim 10^4$ K), high-velocity ($V \sim 100$ km s^{-1}) wind (as indicated by short-wavelength–shifted absorption in the Mg II *h* and *k* lines) *and* a solar-type transition region (as indicated by emission lines formed at $T \sim 10^5$ K, such as C IV). This apparent dual nature of the outer atmospheres of the hybrid stars is very interesting because these stars lie in a region of the H-R diagram separating stars with solar-like hot coronae (as implied by X-ray emission) from those with cool, massive winds (as evidenced by shortward-shifted "circumstellar" absorption components) (Linsky and Haisch 1979; Ayres *et al.* 1981; Stencel and Mullan 1980). Thus the hybrid stars could be in transition between these two types of atmospheric structure, perhaps as a result of evolution to the right in the H-R diagram. In a subsequent paper, Hartmann, Dupree, and Raymond (1981) proposed as an additional property of the hybrid stars that the low-velocity absorption components also seen in the Mg II lines in these stars are intrinsically *circumstellar*. These authors then applied the Alfvén-wave driven stellar wind theory of Hartmann and McGregor (1980) to model the Mg II lines and the strengths and widths of the Si III, C III, and C IV lines. Reimers (1982) proposed possible new hybrid stars purely on the basis of the two (high- and low-velocity) absorption features in either the Mg II or the Ca II resonance lines.

An alternative explanation for the low-velocity absorption features is that they are formed by interstellar material. All of the above papers have either ignored this possibility or argued that it is not the dominant cause of the low-velocity absorption features. Böhm-Vitense (1981), however, demonstrated that interstellar absorption features are prominent in the high-resolution Mg II *h* and *k* profiles of all stars. She concluded that, *even for the nearest stars*, the line-of-sight interstellar column density is sufficient to produce significant absorption in these lines. This conclusion is supported by high-resolution *Copernicus* observations of nearby hot and cool stars: e.g., Oegerle *et al.* (1982) measured in the *k* line of α Cen A (1.3 pc distant) an equivalent width for the interstellar absorption feature of 32 mÅ, and Kondo *et al.* (1978) measured equivalent widths of 70–170 mÅ for six hot stars lying between 3 and 22 pc from the Sun.

In this paper, we show that the evidence is overwhelmingly in favor of an interstellar origin of the low-velocity absorption components seen in the hybrid stars, contrary to the circumstellar explanation proposed in many previous studies. As a direct consequence, those stellar wind models that assume the low-velocity components to be circumstellar in origin may be invalid. In § II we discuss the previous measurements of the absorption component radial velocities in hybrid stars and present new values we have measured using the well-exposed spectra of these stars available in the *IUE* archives. In § III we discuss the kinematic properties of the local interstellar medium (LISM) and derive the expected interstellar velocity in directions toward the hybrid stars. In § IV we compare the *measured* radial velocities of the low-velocity absorption in the hybrids with the *predicted* line-of-sight LISM velocities and discuss implications concerning the origin of the low-velocity components. In § V we present our conclusions.

II. RADIAL VELOCITY MEASUREMENTS OF OBSERVED ABSORPTION FEATURES

Reimers (1982) summarized in his Table 2 the then-known information on the radial velocities of absorption components seen in Mg II and Ca II for six confirmed hybrids and seven "possible" members of this class identified solely on the basis of double absorption features. Since then, the bright giant γ Aql, one of the hybrid candidates, has been demonstrated to be a hybrid star (Hartmann *et al.* 1984), increasing the number of confirmed hybrids to seven. Of the other possible hybrids listed by Reimers, we exclude from further discussion 4 Dra (M3 IIIa) on the basis of its very late spectral type. We also do not consider further the two faintest hybrid candidates, HR 7762 and HR 9010, for which we have no new data. In our Table 1

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[1] Guest Observer, *International Ultraviolet Explorer Satellite*.

[2] Staff member, Quantum Physics Division, National Bureau of Standards.

TABLE 1

MEASURED RADIAL VELOCITIES OF ABSORPTION COMPONENTS IN HYBRID STARS[a]

STAR	DISTANCE[b] (pc)	HIGH-VELOCITY COMPONENT				LOW-VELOCITY COMPONENT			
		This Paper	Hartmann, Dupree, and Raymond (1980, 1981)	Reimers (1982)	Stencel *et al.* (1980)	This Paper	Hartmann, Dupree, and Raymond (1980, 1981)	Reimers (1982)	Stencel *et al.* (1980)
				Confirmed Hybrids					
α Aqr (G2 Ib)	360	−124 ± 5	−127	...	−135	−18 ± 2	−20	...	−51
β Aqr (G0 Ib)	310	−86 ± 4	−75	−80 (Ca)	−65 −137	−26 ± 2	−20	−24 (Ca)	−5
θ Her (K3 II)	150	−79 ± 8	...	−69 (Ca) −100	...	−0.3 ± 3	...	−13	...
δ TrA (G2 II)	100:	−81 ± 2	...	−88 (Ca) −90	...	−10 ± 2	...	−7 (Ca) −20	...
α TrA (K4 II)	40:	−93 ± 9	−84	−94 (Ca)	...	−20 ± 2	−15	−7 (Ca)	...
ι Aur (K3 II)	75	−77 ± 11	...	−75 (Ca) −95 (Ca)	...	−10 ± 3	...	−16 (Ca)	...
γ Aql (K3 II)	90	−71 ± 3	...	−66	...	−27 ± 2	...	−15	...
				Possible Hybrids					
9 Peg (G5 Ib)	410	−68 ± 3	...	...	−131	+6 ± 2	...	...	−7
12 Peg (K0 Ib)	700	−139 ± 6	...	−140 (Ca) −151 (Ca) −125 (Ca)	...	−5 ± 4	...	−7 (Ca) −20 (Ca)	...
ν^1 Sgr (K2 I)	700:	−70 ± 4	...	−94 (Ca)	...	−2 ± 4	...	−11 (Ca)	...

[a] All quoted velocities are in km s^{-1} and are in the stellar rest frame.

[b] All distances are based on spectroscopic parallaxes. Those values followed by colons are particularly uncertain.

TABLE 2

LINES USED TO DEFINE PHOTOSPHERIC REFERENCE FRAME

λ_{air} (Å)	Multiplet
Fe I	
2767.522	46
2772.074	45
2778.220	44
2788.104	44
2813.287	44
2828.808	45
2832.436	44
2845.594	43
2869.308	2
2874.172	2
Cr II	
2849.83	5
2855.67	5
2858.91	5
2860.92	5
2862.57	5
2865.10	5
2866.72	5
2867.65	5
2873.46	5

we include Reimers's data for the 10 remaining stars along with several additional radial velocities taken from Stencel *et al.* (1980) and Hartmann, Dupree, and Raymond (1980, 1981). Significant variations in the velocity of the high-velocity absorption features are clearly present (e.g., from -75 to -135 km s^{-1} for β Aqr), and smaller variations in the velocity of the low-velocity absorption are also evident (e.g., from -20 to -51 km s^{-1} for α Aqr).

It was uncertain, however, how much of this apparent variability is real and how much is due to the difficulty of measuring *absolute* radial velocities. We have therefore measured *relative* radial velocities in all of the well-exposed high-dispersion, large-aperture LWR spectra of these 10 stars that are available in the archives of the Colorado Regional Data Analysis Facility. We have used standard reduction procedures to measure the velocities of the Mg II absorption components and of nearby photospheric absorption lines. For the latter, we have used unblended absorption lines of Fe I and Cr II in the wavelength range 2760–2880 Å that were initially identified in an extensive line list of the K2 III star Arcturus (Carpenter, Wing, and Stencel 1983). Accurate laboratory wavelengths were obtained from the compilation of Kelly (1979), and the complete list of lines used to define the photospheric frame of reference is given in Table 2. Not all lines were of use in defining the photospheric velocity in any given star: typically we used the best 10 or so lines in a particular spectrum. We estimate that the measured relative radial velocities of the *h* and *k* absorption components *with respect to the photosphere* should be accurate to $\sim \pm 3$ km s^{-1} (± 1 standard deviation) on the basis of the repeatability of these values obtained from different spectra of the same star. This number is about the same as the accuracy with which a sharp feature's radial velocity can be measured in a single exposure, and corresponds to about half a pixel. For comparison, the instrumental profile has a FWHM of ~ 30 km s^{-1}. The results of our analysis are summarized in Tables 1 and 3. In the latter table, the errors in the photospheric radial velocities represent the standard deviation of the individual photospheric lines about the mean value used for that particular exposure. The errors quoted in Table 1 for the radial velocities of the Mg II absorption components relative to the photosphere are the empirical standard deviations of the measured values about the mean value obtained from the separate exposures. Mg II line profiles for all the exposures used in this analysis are shown in Figure 1.

The major inferences that can be drawn from our study of the Mg II lines in these 10 stars can be summarized as follows:

1. In each star the low-velocity absorption component is always narrower than the high-velocity component and is generally unresolved at the 30 km s^{-1} resolution of the LWR camera.

2. The low-velocity component for each exposure of a given star is *always* at the same radial velocity relative to the stellar photosphere. The values obtained from measurements of different exposures for the same star have a standard deviation of 2–4 km s^{-1} that is equal to our expected measurement error for a feature that is at constant radial velocity.

3. The high-velocity component is clearly variable in velocity in α TrA and probably also in ι Aur, and this component is variable in shape in many of the stars, confirming that it is circumstellar in origin.

Comparison of the newly obtained radial velocities presented here with the other radial velocities quoted in Table 1 leads to the following additional conclusions:

4. Many of the radial velocities obtained by Stencel *et al.* (1980) are not reliable. In the case of 9 Peg, where we measured a radial velocity of -67 km s^{-1} for the high-velocity absorption component relative to the photosphere in exposure LWR 4429, Stencel *et al.* (1980) give a value of -131 km s^{-1} using the *same* spectrum. Their value must reflect either a typographical or a measuring error. Their discrepant values for α and β Aqr may result from either of the above reasons or from their use of very short exposures.

5. Most of the discrepancies between our Mg II data and those from the quoted sources are probably due to the difficulty in establishing a photospheric reference frame against which to measure the absorption components. There is a clear need for new long-wavelength spectra taken simultaneously with wavelength calibration (WAVECAL) spectra of the onboard platinum light source. This procedure should provide absolute radial velocities accurate to ± 3 km s^{-1} (Thompson, Turnrose, and Bohlin 1982).

We believe that our radial velocities are probably reliable to the previously stated relative accuracy of ± 3 km s^{-1}, but we cannot exclude an additional zero-point error of ~ 5 km s^{-1}. Our radial velocity measurements should be superior to the previous published values, since they were obtained by using homogeneous methods and are average values obtained from the analysis of several of the best exposures for each star. We will therefore exclusively use *our* measurements in the remaining discussion. One could argue that Reimers's (1982) Ca II absorption radial velocities should be more accurate (to ± 1 km s^{-1}), since obtaining absolute radial velocities in the optical region is a standard, well-understood procedure. However, examination of the published Ca II line profiles (Reimers's Figs. 3–5) reveals one difficult problem intrinsic to the Ca II data: how does one separate the *intrinsic* self-reversal at the center of the Ca II emission from the effects of interstellar and/or circumstellar absorption? In any case, because of the well-known relative depletion of gaseous calcium in the interstellar medium, presumably due to incorporation into dust grains, we would not expect the Ca II lines to be as sensitive

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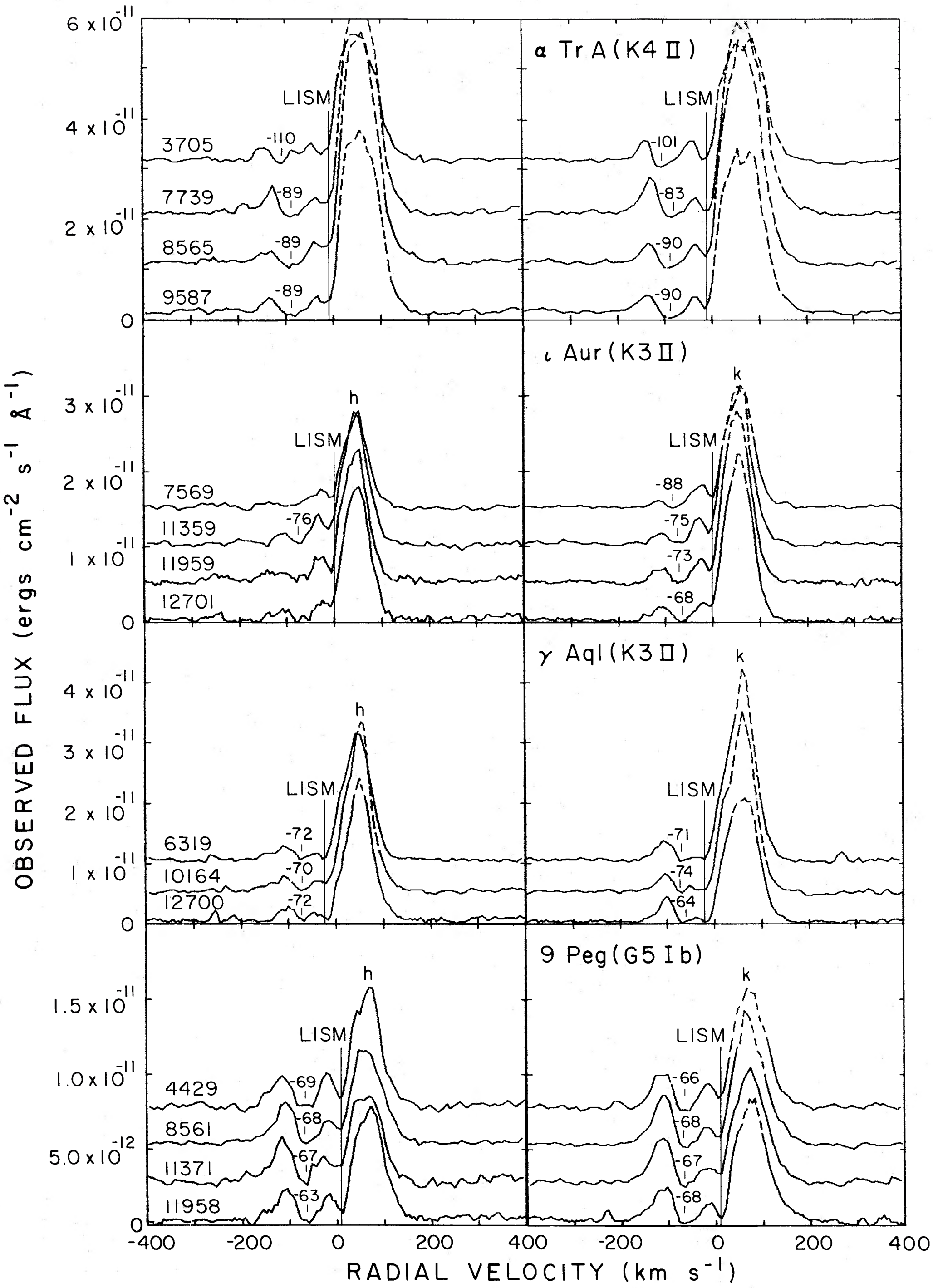

FIG. 1*a*

FIG. 1.—High-dispersion spectra of the Mg II *h* (2803Å) and *k* (2796Å) resonance lines obtained with the LWR camera of *IUE*. LWR camera image numbers for each (vertically displaced) spectrum are indicated at the far left. Saturated portions of the line profiles are indicated by dashed lines. The radial velocity scales in the reference frame of the stellar photosphere are determined from the measured central wavelengths of nearby absorption lines of Fe I and Cr II. The radial velocities of the high-velocity circumstellar absorption features are indicated for each spectrum. Also indicated are the radial velocities (relative to the photosphere) of the local interstellar medium (LISM) as estimated from the projection of the local interstellar flow vector onto the line of sight or in the cases of θ Her and γ Aql from the measured interstellar velocity toward a nearby hot star. Note the close agreement between the radial velocities of the low-velocity absorption features and the predicted LISM radial velocity.

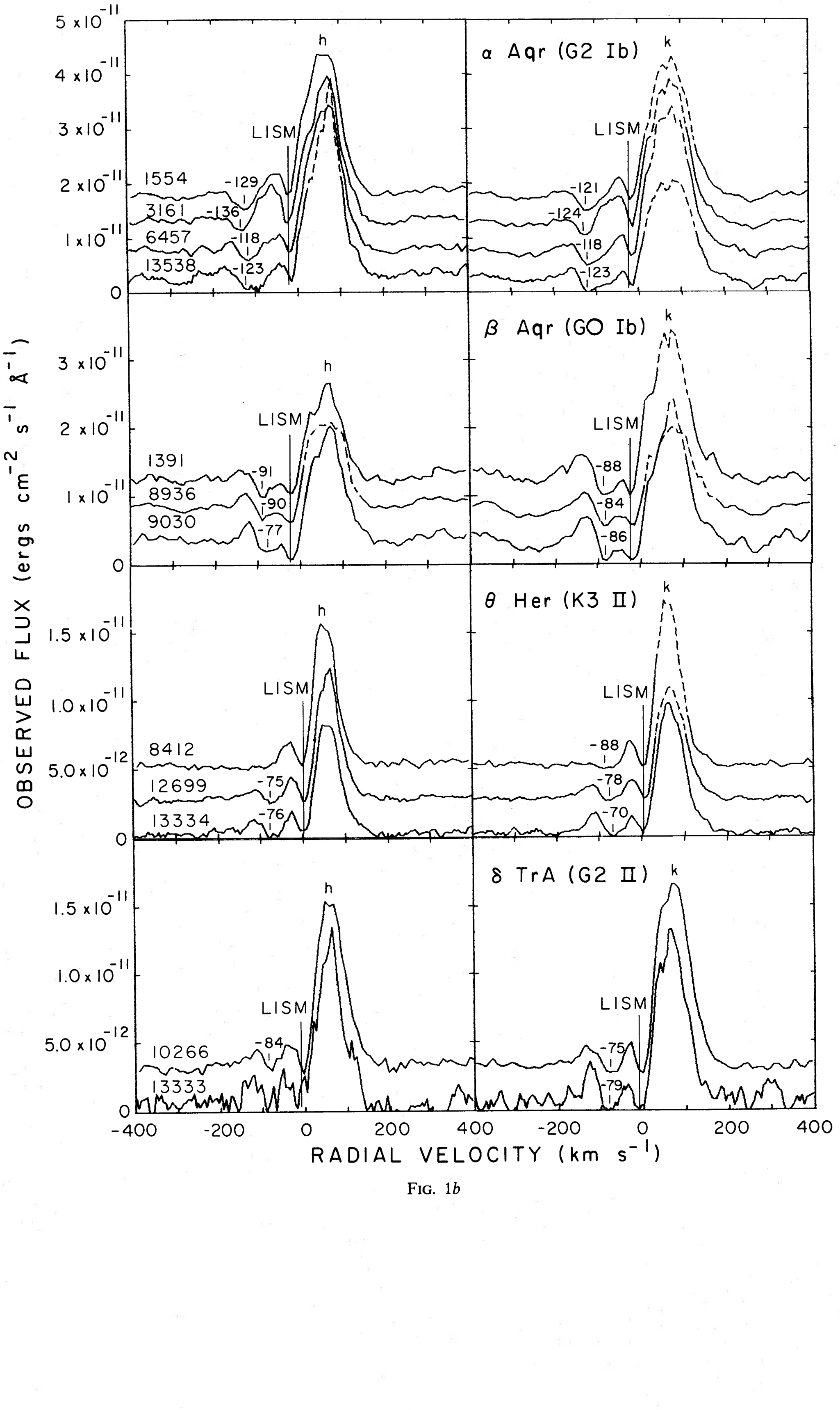
α Aqr (G2 Ib)
β Aqr (G0 Ib)
θ Her (K3 II)
δ TrA (G2 II)
h
k
LISM
1554
3161
6457
13538
-129
-136
-118
-123
-121
-124
-118
-123
1391
8936
9030
-91
-90
-77
-88
-84
-86
8412
12699
13334
-75
-76
-88
-78
-70
10266
13333
-84
-75
-79
5 x10^{-11}
4 x10^{-11}
3 x10^{-11}
2 x10^{-11}
1 x10^{-11}
0
1.5 x10^{-11}
1.0 x10^{-11}
5.0 x10^{-12}
OBSERVED FLUX (ergs cm^{-2} s^{-1} Å^{-1})
-400
-200
0
200
400
RADIAL VELOCITY (km s^{-1})

FIG. 1*b*

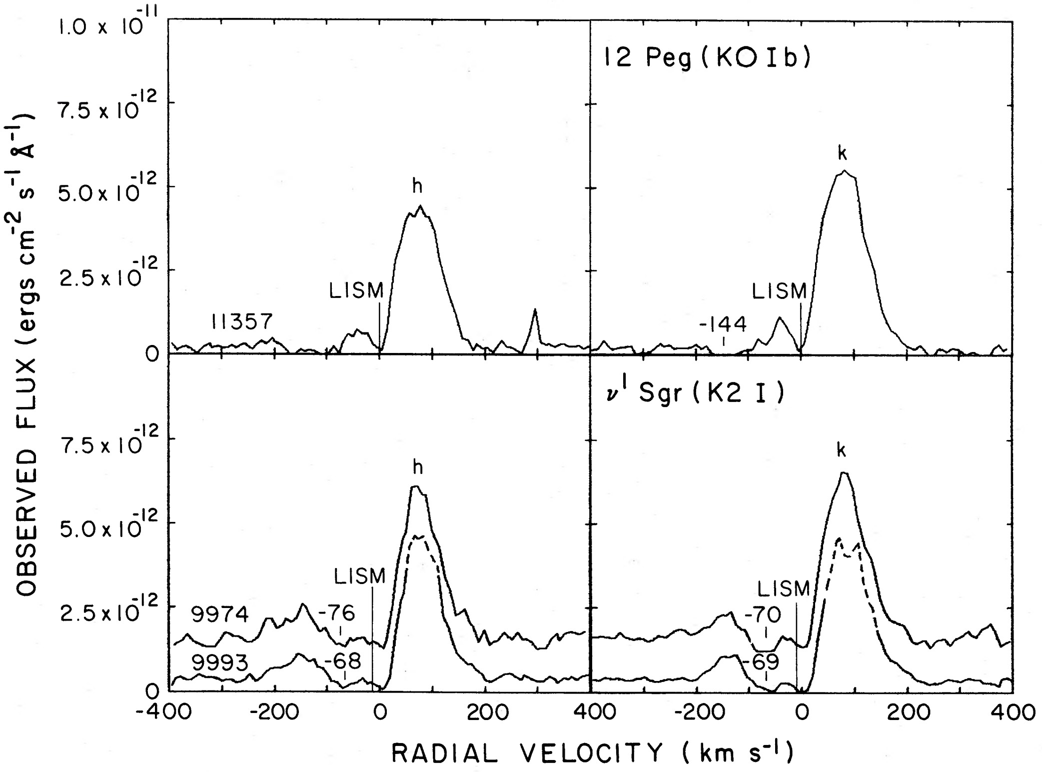

FIG. 1c

either to interstellar or to circumstellar absorption as the Mg II lines. An empirical relationship derived by Hobbs (1974) predicts an interstellar equivalent width in Ca II K of only ~ 10 mÅ for stars at 100 pc and ~ 50 mÅ for stars at 300 pc.

III. THE EFFECT OF ABSORPTION BY THE INTERSTELLAR MEDIUM

The interstellar medium within ~ 30–50 pc of the Sun, often called the Local Interstellar Medium (LISM), can be modeled to a fair degree of approximation as a discrete entity with a coherent velocity vector (V_l, α_0, δ_0) with respect to the Sun. Crutcher (1982) and Frisch (1981) have recently reviewed the evidence supporting this simple model and have determined values for this vector. Freeman *et al.* (1980) have modeled the resonant scattering of the solar He I $\lambda 584$ emission by material flowing through the solar system to obtain a *local* value for this vector that is in good agreement with the value obtained from observations of the interstellar absorption seen toward nearby hot stars (Kondo *et al.* 1978) and cool stars (McClintock *et al.* 1978; Böhm-Vitense 1981). In the Note to Table 4 we list six different estimates for the LISM vector derived from the various sources discussed above as well as the average value of this quantity. In Table 4 we use each of these estimates to calculate the heliocentric radial velocity of the LISM in the direction of the ten definite and possible hybrid stars discussed in this paper. As can be seen, there is a spread in the predicted values obtained from the different estimates that ranges, for a given direction, from 2 to 18 km s^{-1}. If the flow of the LISM were truly coherent, then this uncertainty would presumably be a consequence of measurement errors. Since we do not expect the radial velocities to be this imprecise, a more likely reason for the uncertainty in the LISM radial velocities is that the LISM flow is not as simple kinematically as our model assumes. Thus, if we use the "global" LISM assumption, we should not expect to predict the exact radial velocity in a given direction to better than ± 5–10 km s^{-1}.

When the LISM radial velocity has been measured by observations of a hot star close to the desired direction, this value should be much superior in accuracy to the "global" prediction. In fact, Kondo *et al.* (1978) have measured LISM radial velocities from *Copernicus VI* spectra of the Mg II lines of α Aql (A7 V, $d = 5.0$ pc), which is only $\sim 2°$ away from the hybrid star γ Aql, and α Lyr (A0 V, $d = 8.1$ pc), which is only 10° away from the hybrid star θ Her. The heliocentric LISM radial velocities, based on these nearby lines of sight, are -26 km s^{-1} toward γ Aql and -22 km s^{-1} toward θ Her, somewhat more shortward-shifted (by about 6 km s^{-1}) than the average values of the "global" LISM vector listed in Table 4.

IV. COMPARISON OF PREDICTED LISM RADIAL VELOCITIES WITH OBSERVED LOW-VELOCITY ABSORPTIONS

In Figure 2 we plot the *measured* radial velocities of the low-velocity components ($V_{\rm low}$) in the hybrid stars against the *predicted* LISM radial velocities (V_l) using the average values of the global LISM vector given in Table 4; in both axes the velocities were corrected to the stellar reference frames by subtracting the radial velocity ($V_{\rm rad}$) of the star. The same data are presented numerically in Table 5. We adopt a standard 1 σ measuring error of ± 3 km s^{-1} for the radial velocity of the low-velocity absorption, as discussed in § II; for the LISM velocity, we have used ± 6 km s^{-1} for the 1 σ error. The graph shows a reasonably good general correlation between the two quantities plotted, but several of the individual stars appear to be discrepant by about 2 σ, with θ Her the most discrepant. However, if we use the "locally" determined values of V_l for θ Her and γ Aql (indicated by circles in Fig. 2) rather than the

TABLE 3

DETAILED RADIAL VELOCITY MEASUREMENTS OF HYBRID STAR SPECTRA[a]

STAR	SPECTRUM No.[b]	EXPOSURE TIME (min)	RELATIVE TO *IUE* WAVELENGTH SCALE			RELATIVE TO PHOTOSPHERE	
			High-Velocity	Low-Velocity	Photosphere	High-Velocity	Low-Velocity
α Aqr	1554	40	−185	−78	−60 ± 4	−125	−19
	3161	30	−67	+44	+63 ± 5	−130	−19
	6457	30	−84	+14	+34 ± 5	−118	−19
	13538	30	−122	−15	+1 ± 8	−123	−16
β Aqr[c]	1391	30	+116	+117	+205 ± 8	−89	−28
	8936	90	−55	+8	+32 ± 4	−87	−24
	9030	26	−24	+32	+57 ± 3	−82	−25
θ Her	8412	60	−86:	−1	+2 ± 7	−88:	−2
	12699	80	−109	−30	−33 ± 6	−76	+3
	13334	50	−101	−30	−29 ± 6	−72	−1
δ TrA	10266	30	−92	−20	−12 ± 7	−80	−8
	13333	20	−84	−17	−5 ± 9	−79	−12
α TrA	3705	50	−94	−9	+11 ± 4	−106	−20
	7739	30	−93	−24	+7 ± 6	−87	−17
	8565	30	−60	+8	+29 ± 7	−90	−21
	9587	40	−80	−9	+10 ± 7	−90	−19
ι Aur	7569	45	−61	+21	+27 ± 6	−88	−6
	11359	35	−84	−22	−8 ± 4	−76	−14
	11959	25	−52	+13	+21 ± 7	−73	−8
	12701	25	−56	+2	+12 ± 8	−68	−11
γ Aql	6319	30	−50	−4	+22 ± 11	−72	−27
	10164	30	−98	−56	−26 ± 7	−72	−30
	12700	30	−80	−37	−12 ± 6	−68	−25
9 Peg	4429	83	−97	−25	−30 ± 9	−67	+5
	8561	90	−76	−5	−8 ± 4	−67	+3
	11371	60	−86	−13	−20 ± 5	−66	+7
	11958	60	−85	−12	−20 ± 6	−65	+8
12 Peg	11357	90	−154:	−14	−10 ± 6	−144:	−5
ν^1 Sgr	9974	90	−96	−28	−23 ± 8	−73	−5
	9993	180	−88	−18	−19 ± 9	−69	+1

[a] All quoted velocities are in km s^{-1}.

[b] Image numbers for the LWR camera. All spectra are high dispersion and were obtained through the large aperture.

[c] A third longward-shifted component at ∼ +25 km s^{-1} relative to the photosphere may be present in the Mg II lines of β Aqr.

"global" values, then the discrepancies for these stars are nearly removed. The most discrepant of the remaining stars are ι Aur and α TrA, which are about two standard deviations from the $V_{\rm low} = V_I$ line. If these deviations are real, which is uncertain, then the observed low-velocity absorptions may indicate that the LISM flow is not uniform. Another resolution of these small discrepancies would be the possibility that our measurements of $V_{\rm low}$ are systematically offset by ∼ +5 km s^{-1}. Shortward-shifting the line of equal radial velocities in Figure 2 by this amount vertically does produce a somewhat better correlation of the two plotted quantities. However, we believe that the most plausible reason for the observed scatter in Figure 2 is simply that introduced by approximating the LISM by a single "global" vector, and that when accurate "local" values are obtained for directions toward all of the hybrid stars, the scatter should be much reduced. We thus conclude that the *simplest* explanation for the origin of the low-velocity components in hybrid stars is that they are caused by *interstellar* absorption. Furthermore, all of the hybrid stars are sufficiently distant that interstellar absorption at the resolution of *IUE* must be present (Böhm-Vitense 1981).

TABLE 4

ESTIMATES OF HELIOCENTRIC RADIAL VELOCITY OF LOCAL INTERSTELLAR MEDIUM TOWARD HYBRID STARS USING "GLOBAL" VECTOR VALUES

STAR	RADIAL VELOCITY ESTIMATES							
	A	B	C	D	E	F	G	H
α Aqr	−16	−4	−12	−22	−18	−14	−14 ± 6	−15
β Aqr	−18	−7	−14	−24	−21	−18	−17 ± 6	−18
θ Her	−12	−12	−12	−11	−15	−22	−14 ± 4	−15
δ TrA	−12	−13	−12	−11	−13	−12	−12 ± 1	−13
α TrA	−11	−12	−11	−11	−12	−10	−11 ± 1	−12
ι Aur	+18	+19	+18	+16	+20	+23	+19 ± 2	+20
γ Aql	−20	−13	−17	−22	−22	−24	−20 ± 4	−20
12 Peg	−13	−3	−10	−18	−15	−14	−12 ± 5	−12
ν^1 Sgr	−22	−17	−20	−23	−25	−26	−22 ± 3	−23
9 Peg	−14	−4	−11	−19	−16	−15	−13 ± 6	−14

NOTE.—For estimates A–F, the LISM vector is followed by the reference. A: $(V_I, \alpha_0, \delta_0) = (22, 108°, +15°)$; McClintock *et al.* 1978. B: $(V_I, \alpha_0, \delta_0) = (20, 72°, +15°)$; Freeman *et al.* 1980. C: $(V_I, \alpha_0, \delta_0) = (20, 98°, +15°)$; Böhm-Vitense 1981. D: $(V_I, \alpha_0, \delta_0) = (25, 125°, +16°)$; Frisch 1981. E: $(V_I, \alpha_0, \delta_0) = (25, 108°, +14°)$; Crutcher 1982. F: $(V_I, \alpha_0, \delta_0) = (28, 90°, +2°)$; Crutcher 1982. G: $(V_I, \alpha_0, \delta_0) = (23 \pm 3, 100° \pm 18°, 13° \pm 5°)$; average of above values for vector. H: Value obtained by averaging radial velocities using estimates A–F.

Why, then, have most previous studies of hybrid stars assumed a circumstellar origin? Reimers (1982) has presented the most complete justification of this viewpoint. Reimers's arguments against an interstellar origin of the low-velocity absorption components may be summarized as follows: (1) In *all* stars with two absorption components, *both* are shortward-shifted. No case with one shortward-shifted and one longward-shifted component is now known. (2) The low-velocity absorption in 9 Peg, α Aqr, and β Aqr is the combined result of an interstellar absorption and an unresolved intrinsic self-reversal shortward-shifted by ∼40 km s^{-1}. (3) An interstellar origin can be ruled out in stars like θ Her that have sufficiently

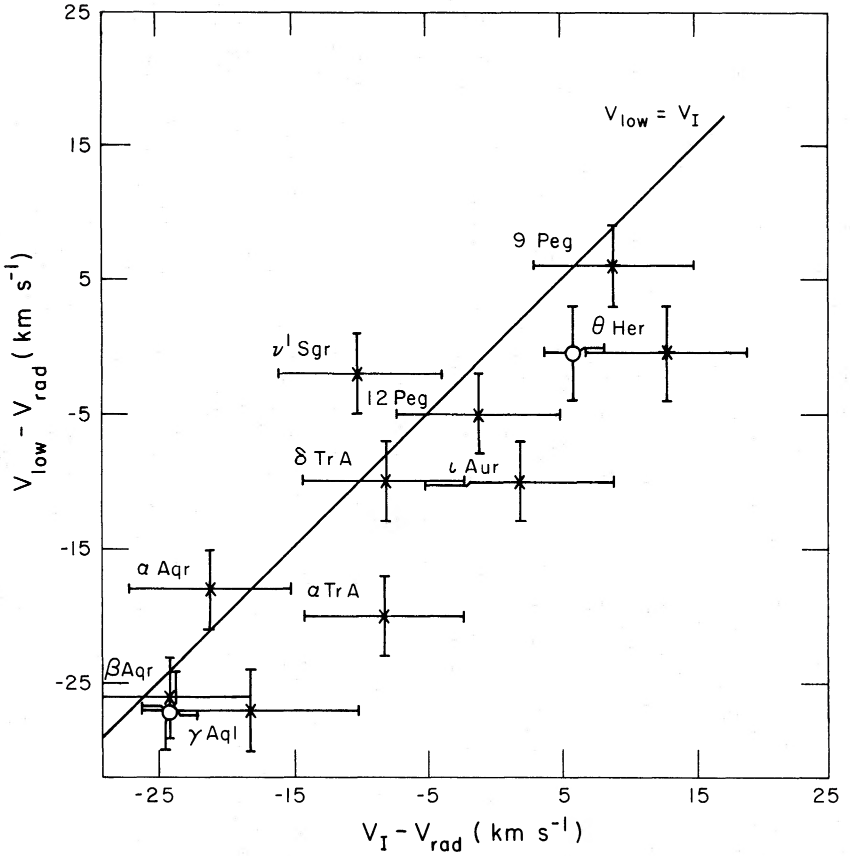

FIG. 2.—Comparison of the measured radial velocities of the low velocity components of the hybrid star Mg II lines ($V_{\rm low}$) with the predicted local interstellar medium (LISM) radial velocities (V_I), both corrected for the radial velocity of the stellar photosphere ($V_{\rm rad}$), using the average values of the global LISM vector (Table 4). The $V_{\rm low} = V_I$ line is indicated. For two stars, θ Her and γ Aql, the circles indicate that V_I was determined from the interstellar velocity toward a nearby hot star rather than from the mean global LISM vector, thereby improving the agreement with the $V_{\rm low} = V_I$ line, consistent with our conclusion that the low-velocity features are primarily interstellar in origin.

large negative radial velocities, and in stars like 12 Peg where the low-velocity Ca II component is variable. (4) All stars with two absorption components lie in the same region of the H-R diagram. We will address each of these statements in turn and show why, in our opinion, they are invalid.

First, we agree that, out of the seven proved hybrid stars, six have *both* absorption components shortward-shifted relative to the star. In the remaining star, θ Her, we measured the radial velocity of the low-velocity component to be essentially zero. In the three "possible" hybrids for which adequate *IUE* data exist, the situation is less dramatic: one star has an absorption at $+6$ km s^{-1} (9 Peg), one at -2 km s^{-1} (ν^1 Sgr), and one at -5 km s^{-1} (12 Peg). However, the predominance of negative low-velocity absorption components *cannot* be used as an argument against an interstellar origin, because in nine of the 10 stars the LISM is *predicted* to be at negative heliocentric radial velocities in the range of -10 to -25 km s^{-1}. We *are* also aware of stars in the same general region of the H-R diagram as the hybrids for which one shortward-shifted and one longward-shifted absorption component is observed: for example, ε Gem (G8 Ib) has two absorptions evident in both the Ca II resonance lines (Linsky *et al.* 1979*b*) and the Ca II infrared triplet (Linsky *et al.* 1979*a*) with radial velocities relative to the star of $+11$ km s^{-1} and -15 km s^{-1} (the predicted LISM radial velocity is $+10$ km s^{-1} in the stellar rest frame), and ζ Cep (K1 Ib) has two absorptions visible in the Ca II infrared triplet (Linsky *et al.* 1979*a*) at $+16$ km s^{-1} and -16 km s^{-1} (the predicted LISM radial velocity is $+16$ km s^{-1} relative to the star).

Second, we acknowledge that, particularly in the Ca II line-profile data, the low-velocity "absorption" may contain both an interstellar absorption component and an intrinsic "self-reversal." It should be noted, however, that the latter is not a true absorption in the classic sense but is due to the decrease in the line source function in the outer chromosphere where it decouples from the local Planck function. We dispute, however, the statement that the low-velocity feature is shortward-shifted by -0.4 Å from line center in some hybrids. This value was obtained from Böhm-Vitense's (1981) paper, which used the Stencel *et al.* (1980) radial velocities. As we have previously mentioned (and as Böhm-Vitense herself points out in the case of β Aqr), these latter numbers are wrong, as a result of either typographical or measurement errors; the low-velocity components in α and β Aqr are shortward-shifted by ~ -0.2 Å, while in 9 Peg the low-velocity component is *longward-shifted* by $\sim +0.05$ Å. Also, concerning the possibility of two different contributing mechanisms, the narrow width of the Mg II absorption components of these three stars suggests that only one mechanism, interstellar absorption, is needed to reproduce this part of the observed profile.

TABLE 5

COMPARISON OF RADIAL VELOCITIES OF LOCAL INTERSTELLAR MEDIUM AND OBSERVED LOW-VELOCITY ABSORPTION COMPONENT IN HYBRID STARS

Star	$V_{\rm rad}$[a]	V_I(H)[b]	V_I(meas)[c]	$V_I({\rm H}) - V_{\rm rad}$	$V_I({\rm meas}) - V_{\rm rad}$	$V_{\rm low} - V_{\rm rad}$[d]
α Aqr	+6.5 ± 1.5	−15	...	−21	...	−18 ± 2
β Aqr	+6 ± 2	−18	...	−24	...	−26 ± 2
θ Her	−28 ± 1	−15	−22	+13	+6	−0.3 ± 3
δ TrA	−4.5 ± 0.5	−13	...	−8	...	−10 ± 2
α TrA	−3.5 ± 0.5	−12	...	−8	...	−20 ± 2
ι Aur	+17.5 ± 3.5	+20	...	+2	...	−10 ± 3
γ Aql	−2 ± 6 v	−20	−26	−18	−24	−27 ± 2
12 Peg	−11.5 ± 0.5	−12	...	−1	...	−5 ± 4
ν^1 Sgr	−13 ± 1	−23	...	−10	...	−2 ± 4
9 Peg	−22.5 ± 0.5	−14	...	+9	...	+6 ± 2

[a] Stellar radial velocity (heliocentric) taken from Abt and Biggs 1972. In this one case, the ± does not mean a standard deviation but refers to the maximum range of values quoted in the above reference.

[b] Heliocentric LISM radial velocity using estimate H from Table 4.

[c] Heliocentric LISM radial velocity measured toward nearby hot star.

[d] Observed radial velocity of the low-velocity absorption component relative to the stellar photosphere, taken from Table 1.

Third, there *is* a good correspondence between the predicted LISM radial velocities and those of the observed low-velocity absorption in both the proved and the "possible" hybrid stars, as we have already shown. In the case of the star with the largest negative radial velocity (θ Her, $V_{\rm rad} = -28$ km s^{-1}), there *is* a 13 km s^{-1} discrepancy between the prediction from the "global" LISM vector of +13 km s^{-1} relative to the star and the measured low-velocity absorption (∼0 km s^{-1}, according to this paper). However, this discrepancy essentially vanishes when we replace the "global" LISM radial velocity value with the LISM value measured for the star α Lyr (∼10° away from θ Her): the LISM is then predicted to have a radial velocity of +5.6 km s^{-1} in the rest frame of θ Her, which is reasonably close to the observed radial velocity of the low-velocity component of −0.3 km s^{-1}.

As Reimers states, variability of the low-velocity absorption radial velocity *would* be evidence for a circumstellar rather than an interstellar origin, but we find *no* evidence in our study of well-exposed *IUE* spectra that this component in the Mg II lines varies in *any* of the stars (see Table 3). Reimers (1982) finds variations from −7 to −20 km s^{-1} in the position of the low-velocity component in the Ca II K line of the K0 Ib star 12 Peg. However, as we have discussed already, the Ca II lines have an intrinsic self-reversal that may dominate the LISM absorption, and they are, in general, more sensitive to variations of the inner chromosphere than are the resonance lines of Mg II, which are formed farther out in the chromosphere. Thus, fluctuations in the chromospheric structure in the region where Ca II K is formed may cause the center of gravity of the (probably) composite low-velocity "absorption" feature to vary. We believe that further monitoring of the Mg II and Ca II lines in all of the hybrid stars will shed more light on this whole question of whether or not the low-velocity absorption components are variable.

Fourth, all stars with two absorption components do *not* lie in the same region of the H-R diagram. We have already mentioned the cases of ϵ Gem (G8 Ib) and ζ Cep (K1 Ib). Other example of supergiants are ψ And (G5 Ib; Wilson 1976), ξ Cyg (K5 Ib) (see Fig. 1*m* in Stencel *et al.* 1980), α Ori (M2 Iab), and μ Cep (M2 Ia) studied by Bernat (1981). (In the M supergiants these absorption components are clearly due to the circumstellar envelopes, while in each of the three earlier supergiants one of the two absorptions for each star is at the predicted LISM radial velocity.) Other "double-absorption stars" are 4 Dra (M3 III), which is in fact one of the "possible" hybrids listed by Reimers (1982), 61 Leo (K5 III; Wilson 1976), and α Tuc (K3 IIIa; Stencel *et al.* 1980). In the case of the last giant star, because it has a large *positive* radial velocity of +42 km s^{-1}, the *expected* LISM velocity relative to the star is −52 km s^{-1}, which coincides with the *observed* velocity of the *high-velocity* absorption. Inspection of Figure 1 of Stencel *et al.* (1980) even reveals two subgiants—ϵ Sco (K1 III–IV) and β Hyi (G2 IV)—that appear to have multiple absorption components in Mg II. It seems to us, then, that stars in all parts of the cool luminous portion of the H-R diagram may be observed to have double absorption components and that, therefore, this is *not* a unique property of hybrid stars.

V. CONCLUSIONS

We have demonstrated that the most straightforward explanation for the *low-velocity* absorption components seen in the Mg II resonance lines of the ten hybrid and proposed hybrid stars is that they are due to absorption by the LISM rather than to circumstellar material. The major arguments in favor of this hypothesis are the correlation of the observed radial velocities with those predicted for the LISM in these directions, the observed narrow widths of these absorptions, and the absence of variation of the radial velocity relative to the stellar photosphere.

One may ask why all seven confirmed hybrid stars have two absorption components, since the presence of two absorption components in the Mg II lines of cool stars at the wavelength dispersion of *IUE* is somewhat uncommon, and since the low-velocity component is not an intrinsic property of the star. We believe that the presence of two absorption components is a *selection effect*: these stars all have stellar winds with outflow velocities in the range of −70 to −130 km s^{-1}, which are by far the highest observed speeds for stars in the cool, luminous region of the H-R diagram. As a result, the circumstellar absorption features produced by these high-velocity winds are well separated in radial velocity from the LISM absorption, and displacements of ≳30 km s^{-1} are required for *IUE* to resolve two distinct features.

Thus we suggest that hybrid stars be defined as cool, luminous stars with high-velocity winds, as evidenced by shortward-shifted, often variable, absorption components in the

Mg II and/or Ca II lines, *and* with detectable high-temperature lines such as C IV λ1550. We note that the detection of the high-temperature lines depends on the length of the SWP exposure and thus is somewhat ill defined in the sense that it may not be useful in discriminating against nonhybrid stars. The range of spectral class and luminosity for the known hybrid stars is fairly narrow, being confined to early G supergiants and G–K bright giants. It is important to know (1) whether there are more stars of these types that are hybrids, for example, whether all K3–4 II stars are hybrid; (2) whether the hybrid phenomenon occurs in a wider region of the H-R diagram, for example, in less luminous stars (luminosity class II–III or IIIa) or in cooler supergiants (like 9 Peg and 12 Peg); and (3) whether there are any hybrid stars with lower-velocity winds.

We have shown that interstellar absorption is a *sufficient* explanation for the low-velocity features in the ten stars studied here. We have not shown, however, that it is a *necessary* or a *complete* explanation, since we do not have detailed information on either the radial velocities of the LISM or the more distant interstellar medium (ISM) in the line of sight toward each star (except for γ Aql and θ Her) or the typical interstellar column density(ies) (as manifested by the characteristic equivalent widths). We are planning a study of hot stars located within 10° of the hybrids in order to obtain this specific information on the ISM flow velocities and column densities and thereby to eliminate the remaining uncertainties in the influence of the ISM on the Mg II profiles of the hybrids.

We are grateful for the assistance provided to us by the staff of the *IUE* Regional Data Analysis Facility at the University of Colorado, particularly the indefatigable Terry Armitage. This work was supported by grants NAG5-82 and NGL-06-003-057 from the National Aeronautics and Space Administration to the University of Colorado, which we gratefully acknowledge.

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A. BROWN, S. A. DRAKE, and J. L. LINSKY: Joint Institute for Laboratory Astrophysics, University of Colorado, Boulder, CO 80309