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ABUNDANCE RATIOS IN A COMMON PROPER MOTION PAIR: CHEMICAL EVIDENCE OF ACCRETED SUBSTRUCTURE IN THE HALO FIELD?

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ABSTRACT

Elemental abundances are presented for the metal-poor ($[\mathrm{Fe/H}] = -1.50$) common proper motion pair HD 134439 and HD 134440. The abundances for the two stars are in very good agreement, with the neutral species showing only a small difference (~ 0.05 dex) which is well within the statistical and T_{eff} uncertainties. The essentially identical abundances, kinematics, and parallaxes of the two stars indicate that they share a common history. This history, however, appears to be different than other metal-poor stars. Suggestions, based on kinematic evidence, that these two-stars are representative of a distinct accretion event are corroborated by our abundance ratios, which indicate [Mg/Fe], [Si/Fe], and [Ca/Fe] are consistently some ~ 0.3 dex lower than the vast majority of metal-poor field stars. Such underabundances have been predicted in environments like dwarf Spheroidals and the Magellanic Clouds. Moreover, our abundance ratio deficiencies are consistent with those recently observed in the the anomalously young globular clusters Rup 106 and Pal 12, which have been alleged to have been accreted from the Magellanic Clouds. The [Fe/H] and retrograde motion of the common proper motion pair are characteristic of the subset of Galactic globular clusters suggested by Rodgers & Paltoglou [ApJ, 283, L5 (1984)] to have been coalesced from satellite galaxies. We also call attention to the metal-poor subgiant BD+03 740 as another possible representative of an accreted or chaotically formed member of the halo field. If recent Fe analyses of this star are correct, then [Mg/Fe] and [O/Fe] are 0.5 dex lower than in other metal-poor field stars. This star also has a relatively low photometrically inferred age; relative youth has been noted as a possible characteristic of accreted field populations, and is qualitatively consistent with the young ages of the purportedly accreted globular clusters Rup 106, Pal 12, Ter 7, and Arp 2. Additionally, the revised [O/Fe] ratio for BD+03 740 would suggest a large spread, perhaps 0.7 dex, in [O/Fe] of field stars of very low [Fe/H]; this itself might provide strong evidence of some degree of chaotic halo formation in independent fragments. If, on the other hand, earlier Fe analyses of this star are correct, [Mg/Fe] and [O/Fe] for this star are unremarkable; however, the low gravity estimates from earlier studies would then suggest that BD+03 740 is a $\lesssim 3$ Gyr field star with $[\mathrm{Fe/H}] \sim -3$. Further spectroscopic study of this interesting object is needed to determine if it may be similar to the metal-poor ($[\mathrm{Fe/H}] = -3.1$) high velocity star CS 22873-139, which Preston [AJ 108, 2267 (1994)] has argued is $\lesssim 8$ Gyr in age. Finally, our abundance ratios for HD 134439 and HD 134440 suggest that low [α/Fe] may be a characteristic of accreted halo systems including the anomalously young globulars. However, as has been noted by others, the low α-element abundances apparently cannot explain differences between photometric and Ca II-based metallicity estimates for these clusters, nor the variation in these differences between Rup 106 and Pal 12.

1. INTRODUCTION

Over the past decade or so, large samples of kinematically selected field stars have been compiled and utilized to study the formation and structure of the Galaxy (e.g., Carney *et al.* 1994; Ryan & Norris 1991; and Sandage & Fouts 1987). Two well-known previous investigations which influenced these vigorous efforts were those of Eggen, *et al.* (1962) and Searle & Zinn (1978). The former study used field star kinematic and abundance data to conclude that the Galactic halo was formed from an early monolithic rapid collapse. Based on the morphology of globular cluster horizontal branch morphologies, the latter study concluded that the halo displays a significant age spread and suggested halo formation occurred via accretion of discrete fragments.

These two contrasting pictures are not mutually exclusive, however. Indeed, scrutiny of large field star samples reveals evidence for distinct halo populations formed via both processes (Norris 1994; Carney *et al.* 1996). The degree to which each process might contribute to the halo field population is probably uncertain, however. Comparing theoretical isochrones with kinematically selected metal-poor stars in the $(B-V)$–[Fe/H] plane, Unavane *et al.* (1996) suggest only a few percent of the halo field could have originated

TABLE 1. HD 134439 and HD 134440 vital statistics.

Star	[Fe/H][a]	μ[b] ″/yr	θ[b] °	RV[b] km/s	d[c] pc	d[d] pc	U[b] km/s	V[b] km/s	W[b] km/s	$R_{\rm apo}$[b] kpc
HD 134439	−1.47	3.681	196	+310.6	28	29	−310	−467	−44	41.8
HD 134440	−1.53	3.680	196	+311.5	28	29	−311	−473	−48	43.8

[a] This work.
[b] Table 6 of Carney *et al.* (1994).
[c] Mean of *UBV* and *VRI* photometric estimates from Table 4 of Ryan (1992).
[d] Trigonometric value from Table 4 of Ryan (1992).

from accreted dwarf Spheroidal systems over the past ~10 Gyr. Preston *et al.* (1994) find a number of spectroscopically selected metal-poor dwarfs which are bluer (i.e., younger) than the halo turn-off. They suggest that 4%–10% of the halo field may be the result of accretion of dwarf Spheroidal systems. These values may be lower limits if observational bias is important. Specifically, dwarf Spheroidals having ages comparable or older than the mean of the Galactic halo field may have contributed to this halo field population, but might not be observed in the present day epoch if they have been preferentially accreted or disrupted.

Regardless of the precise fraction of the Galactic halo formed in different scenarios, there does exist observational evidence of accretion in the halo. The Sagittarius dwarf galaxy (Ibata *et al.* 1994) appears to have been caught in the act of dissolving into the Galactic field. The globular clusters Ter 7 and Arp 2 are thought to have been accreted from the Sagittarius dwarf galaxy (Fusi Pecci *et al.* 1995). Interestingly, these two clusters are believed to be significantly younger than the majority of Galactic globulars, and to possibly have a different chemical evolutionary history (e.g., Sarajedini & Layden 1997, and references therein). Additional pieces of evidence for accreted substructure in the halo field are the kinematic stellar stream or group noted by Majewski *et al.* (1994), the loose groupings of field horizontal branch (FHB) stars noted by Doinidis & Beers (1989, and references therein), and the spatial gradient in the color and color dispersion of FHB stars found by Preston *et al.* (1991) and interpreted by them as an age and age dispersion gradient.

Carney *et al.* (1996) have searched their extensive field star sample for the existence of moving groups. They were unable to confirm the existence of the metal-poor Kapteyn, Gmb 1830, or HD 74000 moving groups which Eggen has called attention to (e.g., Eggen 1978). However, these authors did point out possible stellar "groups" at large apocentric distances and very low V velocity, and suggested that they might represent "discrete accretion events." In particular, they noted that the large $R_{\rm apo}$ and low V stars HD 134439, HD 134440, G 25-1, and G 90-36 also have very similar W velocities and [M/H] values. Ryan (1992) included HD 134439 and HD 134440 in his study of halo common proper motion pairs. These stars are designated as a "physical" pair given their virtually identical radial velocity (confirmed by the spectra utilized here). Given their nearly identical photometric and trigonometric parallaxes, this implies essentially identical Galactic UVW kinematics. These similarities, summarized in Table 1, suggest that the two metal-poor field stars share a common history in terms of age, kinematics, and chemical evolution.

Here, we examine whether the detailed elemental abundances in this common proper motion pair might support the suggestion of Carney *et al.* (1996) that these stars are the products of a discrete accretion event. What are the abundance signatures that one might expect of an accreted fragment origin of our physical proper motion pair? In an independent fragment (primordial or not) which may have conceived our two stars, the SFR, IMF, onset of star formation, and chemical evolution may have been quite different from the nascent environs of other objects in the halo field. In particular, the majority of halo field stars studied spectroscopically clearly demonstrate the abundance signatures expected from elemental synthesis in Type II supernovae (e.g., Timmes *et al.* 1995); most notable are the observed overenhancements with respect to Fe for the elements O, Mg, Si, and Ca (e.g., Wheeler *et al.* 1989). Due to the number of variables, a variety of distinct abundance signatures may result from chemical evolution in differing independent environments (e.g., Smecker-Hane & Wyse 1992; Wyse & Gilmore 1992); additionally, conspiracy of different variables may result in similar stellar abundance patterns in differing independent fragments.

In terms of the present work, however, the chemical abundance patterns predicted by Unavane *et al.* (1996) of halo stars formed in dwarf Spheroidal systems are of particular interest. Citing evidence for self-enrichment and low SFRs in dwarf Spheroidals, these authors suggest that stars formed after a star formation hiatus in such systems will demonstrate abundances (namely, Fe) dominated by Type Ia supernovae production rather than Type II supernovae production. This idea may be consistent with the low [α/Fe] ratios inferred for the abnormally young (and possibly accreted) globular clusters Ruprecht 106 and Pal 12 by Brown *et al.* (1997). Here, we suggest that the common proper motion pair HD 134439 and 134440 exhibits similar abundance patterns consistent with the kinematic evidence of a discrete accretion event.

2. OBSERVATIONAL DATA

The data are those previously described by King (1997) in his study of the Li abundances of HD 134439 and HD 134440. The abundance results from the present study were used there to provide inputs to the spectrum synthesis of the λ6707 Li I region, to facilitate comparison of the Li abundances with theoretical models, and to check for significant differences in the abundances of the two proper motion pair components. Our spectra, which have an inverse resolution of $R\sim60{,}000$, were obtained with the 2D-coude spectrograph (Tull *et al.* 1995) of the McDonald Observatory 2.7-m telescope. Standard reductions (bias subtraction, flat-fielding, order tracing and extraction, scattered light correction, dispersion correction) were carried out with routines in the IRAF echelle package and with FIGARO routines imported into the IRAF environment. The S/N in the orders of the spectra utilized here ranges from 60–250 and 50–220 for HD 134439 and 134440. The vast majority of our spectral features, however, have S/N comparable to the Li I data; i.e., the typical S/N is ~230 and ~200 for HD 134439 and 134440.

3. ABUNDANCE ANALYSIS OF HD 134439 AND HD 134440

3.1 Stellar Parameters

The fundamental parameters for HD 134439 and HD 134440 are based upon those derived for HD 103095 in the spectroscopic analysis of Balachandran & Carney (1996, BC96); this procedure was utilized because the King (1997) Li I investigation included this star as well. BC96 determined $T_{\rm eff}$=5050 K, $\xi\sim1.5$ km s^{-1}, and [Fe/H]$=-1.22$ from an Fe I analysis with log $g=4.5$. Alonso *et al.* (1996) derived $T_{\rm eff}$ estimates from the infrared flux method for HD 103095, 134439, and 134440. The relative $T_{\rm eff}$ differences of HD 134439 and HD 134440 with respect to HD 103095 are -55 and -283 K. These are in good agreement with the photometric offsets, -49 and -249 K, of Carney *et al.* (1994). Based on BC96's value of 5050 K for HD 103095, we have thus employed $T_{\rm eff}$ values of 5000 K for HD 134439 and 4785 K for 134440. As we shall see, the abundance ratios—which are the focus of the present study—are fairly insensitive to $T_{\rm eff}$ uncertainties. We have utilized a microturbulent velocity of 1.5 km s^{-1}, the BC96 value for HD 103095; again, the abundance ratios are insensitive to plausible variations in this value.

A gravity of log $g=4.5$ was used in the abundance calculations. This value provided a conservative measure in the previous Li I analysis and was consistent with the BC96 HD 103095 Fe I analysis, which also adopted log $g=4.5$. Comparison of Chieffi & Straniero (1989) isochrones having a variety of ages and abundances suggests that the gravity difference between HD 103095, HD 134439, and HD 134449 is small (Δ log $g\lesssim0.05$). Therefore, log $g=4.5$ was also assumed for the latter two stars. However, BC estimate log $g=4.7$ from a reanalysis of Fe II lines. This difference is again unimportant for our abundance ratios except those for Ba and Y, which are derived from ionized lines; appropriate corrections will be discussed when these elements are later considered.

3.2 Equivalent Widths and Atomic Data

The ions, wavelengths, and atomic data used in the analysis are given in the first four columns of Table 2. The gf values come from Cunha *et al.* (1995; Fe); BC96 (Fe); Thevenin (1990; Fe, Si, Ni); Edvardsson *et al.* (1993; Si, Ba, Ca); Ryan *et al.* (1991; Si and Mg); Fuhrmann *et al.* (1995; Mg); Gratton & Sneden (1988; Na); and Hannaford (1982; Y). It is emphasized that the heterogeneity and absolute and relative accuracy of these oscillator strengths is not a concern here. For almost all lines, a consistently derived solar abundance was determined from the same feature using the same gf value; in the few cases where one was not, the feature is not used in estimating [X/H] or [X/Fe] values. In these cases, the analysis provides only a check on the relative abundances of HD 134439 and HD 134440.

Continuum rectification was carried out in the 1D spectrum analysis package SPECTRE (Fitzpatrick & Sneden 1987) by fitting low order polynomials to assumed continuum windows in each spectral order. Equivalent widths of the features listed in Table 2 were measured via direct integration and profile fitting routines in SPECTRE. The values for HD 134439 and HD 134440 are listed in columns 7 and 9. Solar values were measured from daytime sky spectra obtained during the same run, and are given in column 5 of Table 2.

3.3 Abundance Determinations

Abundances were determined from the equivalent widths using an updated version of the LTE analysis package MOOG (Sneden 1973). We employed model atmospheres from the $l/H_p=1.25$ grids of Kurucz (1992). Van der Waals broadening was handled in the manner of Unsold (1955). An enhancement factor of 2.0 was utilized for all species except Ba II, for which a larger value (3.5) typical of other modern analyses was employed. Column 6 of Table 2 gives the absolute abundances [on the usual scale where the number abundance of hydrogen is log N(H)$=12$] we derive for the Sun. In a few cases, no abundances were derived due to severe blending or to large equivalent width values which lead to concerns about the effects of damping. Columns 8 and 10 give the normalized (to solar) abundances with respect to hydrogen for HD 134439 and HD 134440. For those few lines without a derived solar abundance, the inferred absolute abundance is given in parentheses.

4. RESULTS AND UNCERTAINTIES

The abundance results for both stars are tabulated in Table 3. The mean iron abundances we derive for HD 134439 and HD 134440 are [Fe/H]$=-1.47\pm0.07$ (s.d.) and -1.53 ± 0.09. The standard deviations are good indicators of the uncertainty in the relative abundance of any species considered here as derived from a single line. The expected error in the mean of the [Fe/H] difference between HD 134439 and HD 134440 is ~0.03 dex, which is a bit smaller than the observed 0.06 dex difference. However, small uncertainties such as those (±50 K) in the relative $T_{\rm eff}$ values can easily account for the 0.03 dex remainder. The small abundance difference does seem to be "real" in the sense that the Na, Mg, Si, and Ca abundance (both absolute and solar normalized) differences between HD 134439 and 134440 are also ~0.05 dex in the same sense as seen for Fe I. Nevertheless, given the small magnitude of this difference, we conclude that our derived Fe, Na, Mg, Si, and Ca abundances for HD 134439 and 134440 are in very good agreement, and any differences are well within the statistical and parameter uncertainties. The fourth column of Table 3 contains our mean

TABLE 2. Equivalent widths and abundances.

Ion	λ Å	EP eV	log *gf*	EW (mÅ) ⊙	ε(*X*)	EW 134439	[*X*/H]	EW 134440	[*X*/H]
Fe I	6151.62	2.18	−3.43	49.4	7.59	23.3	−1.36	26.5	−1.47
	6157.73	4.07	−1.28	64.0	7.57	20.6	−1.42	22.1	−1.49
	6165.36	4.14	−1.57	47.8	7.60	10.4	−1.43	12.0	−1.46
	6173.34	2.22	−3.06	66.9	7.63	36.1	−1.46	45.4	−1.50
	6322.69	2.59	−2.35	79.4	7.52	44.9	−1.51	50.4	−1.61
	6481.87	2.28	−2.96	68.1	7.58	32.9	−1.52	36.6	−1.64
	6498.94	0.96	−4.66	47.9	7.52	25.8	−1.43	31.6	−1.56
	6593.87	2.43	−2.36	89.6	7.55	56.2	−1.55	63.9	−1.63
	6663.45	2.42	−2.45	86.2	7.56	50.9	−1.57	59.6	−1.63
	6750.15	2.42	−2.64	77.4	7.57	45.5	−1.47	51.9	−1.56
	6843.66	4.55	−0.73	60.0	7.35	16.5	−1.36	18.6	−1.38
	6855.16	4.54	−0.51	77.6	7.42	22.8	−1.50	23.7	−1.57
	7443.03	4.19	−1.83	38.6	7.67	7.0	−1.42	9.7	−1.36
	7531.15	4.37	−0.59	96.1	7.60	35.8	−1.57	40.7	−1.59
Na I	5688.21	2.10	−0.37	127.8	6.14	18.2	−1.85	22.3	−1.90
Mg I	3986.75	4.35	−2.10	···	···	88.8	(6.98)	95.6	(6.90)
	4057.51	4.35	−0.89	···	···	111.4	(5.93)	120.2	(5.85)
	4167.27	4.35	−0.71	···	···	152.6	(6.01)	180.4	(6.00)
	4571.10	0.00	−5.40	108.5	7.40	92.9	−1.59	110.1	−1.69
	4730.03	4.33	−2.31	73.6	7.72	13.9	−1.50	15.2	−1.58
	5711.09	4.33	−1.67	···	···	61.8	(6.34)	69.0	(6.28)
Si I	4102.94	1.91	−3.14	···	···	131.6	(6.51)	157.7	(6.59)
	5948.55	5.08	−1.22	85.8	7.62	13.7	−1.50	9.1	−1.67
	6155.14	5.62	−0.77	88.9	7.59	9.6	−1.52	8.8	−1.52
	7415.96	5.61	−0.63	95.2	7.53	13.2	−1.49	11.9	−1.49
Ca I	6161.30	2.52	−1.27	68.5	6.45	29.9	−1.26	38.5	−1.31
	6166.44	2.52	−1.20	71.4	6.43	33.8	−1.25	44.3	−1.28
	6169.04	2.52	−0.82	95.5	6.44	60.7	−1.27	72.4	−1.34
Y II	4883.69	1.08	+0.07	58.4	2.19	15.9	−1.67	14.3	−1.77
	4900.11	1.03	−0.09	55.7	2.23	10.4	−1.82	10.7	−1.86
Ba II	5853.68	0.60	−0.97	64.8	2.27	17.4	−1.85	18.8	−1.89
	6141.73	0.70	−0.06	122.8	2.40	63.3	−1.94	70.5	−1.93

estimate for both stars, $[\mathrm{Fe/H}] = -1.50 \pm 0.02$, where the uncertainty is the statistical uncertainty in the mean. Since we are interested here in abundance ratios ([X/Fe]), whose values are not very sensitive to the adopted parameters, only internal uncertainties are listed in column 5. The final three columns list the external uncertainties due to variations in $T_{\rm eff}$, log g, and ξ.

Our derived Fe abundances are in satisfying accord with the values (−1.57 and −1.52) found in the classic study of Peterson (1981). On the other hand; they are discrepant with the spectroscopic measurement (−1.92) for HD 134439 by Ryan *et al.* (1991). The exact cause of this large difference is not clear to us. However, important factors may be (a) their simple adoption of a solar abundance instead of the consistent normalization employed here (b) possible instrumental effects on their line measurements (their Fig. 1), and (c) model atmosphere differences. Regardless, we have confidence in the presently derived value given the excellent agreement with other spectroscopic determinations such as $[\mathrm{Fe/H}] = -1.43$ for HD 134440 by Spiesman & Wallerstein (1991). An independent check was provided by a similar consistent analysis of the λ6767.8 Ni I (an Fe peak element) feature, which yielded $[\mathrm{Ni/Fe}] = -0.09$ and −0.13 for HD 134439 and 134440; this is an unremarkable result consistent with other metal-poor stars at this Fe abundance (e.g., Fig. 4 of Wheeler *et al.* 1989).

Our Na abundance is based on just the one λ5688.2 line; however, in both stars this feature is free of any cosmetic defects, and our measurements of this only moderate strength line are very secure. The [Na/Fe] values, −0.38 and

TABLE 3. Abundance summary and sensitivities.

Ratio	HD 134439	HD 134440	Mean	σ dex	$\Delta T_{\rm eff}$ ±100 K	Δ log g ±0.5 dex	$\Delta\xi$ ±0.5 km/s
[Fe/H]	−1.47	−1.53	−1.50	0.02	±0.07	±0.04	∓0.03
[Na/Fe]	−0.38	−0.37	−0.38	0.06	±0.00	∓0.05	±0.03
[Mg/Fe]	−0.08	−0.11	−0.09	0.04	±0.04	∓0.06	∓0.03
[Si/Fe]	−0.03	−0.03	−0.03	0.04	∓0.08	±0.07	±0.02
[Ca/Fe]	+0.21	+0.22	+0.22	0.04	±0.02	∓0.09	±0.01
[Y/Fe]	−0.22	−0.23	−0.22	0.04	∓0.05	±0.15	±0.02
[Ba/Fe]	−0.39	−0.34	−0.36	0.04	∓0.03	±0.11	∓0.04

-0.37, of HD 134439 and 134440 are in superb agreement. The internal uncertainty in the mean [Na/Fe] value listed in Table 3 is based on an uncertainty of 0.08 dex for the Na abundance and 0.03 dex for the Fe abundance of each star.

The [Mg/Fe] values summarized in Table 3 are based on only the two lines for which we have consistently derived a solar abundance. As for Na, the [Mg/Fe] values, -0.08 and -0.11, for HD 134439 and 134440 are in excellent agreement. The internal uncertainties were derived with an assumed uncertainty of 0.08 dex for the Mg abundance (again, based on the Fe I line scatter) and 0.03 dex for the Fe abundance for each of the four measurements (2 per star). This estimate, ±0.04 dex, is slightly larger than that inferred from the observed scatter in the [Mg/Fe] ratios.

The [Si/Fe] values in Table 3 are based on the three Si I lines having a self-consistent solar abundance. As for [Na/Fe] and [Mg/Fe], the [Si/Fe] ratios are in excellent agreement; we find $[\mathrm{Si/Fe}]=-0.03$ for both HD 134439 and HD 134440. The uncertainty of 0.04 dex listed in Table 3 is derived in the same manner as for [Na,Mg/Fe], and is slightly larger than would be inferred from the observed scatter.

We find [Ca/Fe] ratios of $+0.21$ and $+0.22$ for HD 134439 and 134440. As for the other elemental abundance ratios, the agreement is outstanding. Scatter in the six estimates (from three features for each star) suggests a 1σ internal uncertainty of only 0.02 dex, but ±0.04 dex as derived for the other ratios is listed in Table 3.

Finally, we consider the n-capture elements Y and Ba. The continuum rectification of the Y II lines is more uncertain than for the other features considered. Additionally, while not extremely weak, the profiles are not as clean as the other features. Thus, we believe that the Y II measurements in Table 2 are more uncertain than for other elemental features of similar strength. Nevertheless, the line-to-line and star-to-star agreement is quite reasonable; the scatter in [Y/H] appears only to be 0.08–0.09 dex. The Ba II-based abundances show even better agreement; the scatter in the four [Ba/H] measurements is only 0.04 dex. Before comparison of the [Ba,Y/Fe] ratios, we recall the comments above that the gravity of $\log g=4.5$ adopted in our analysis (for consistency with the King 1997 Li I analysis and the BC96 Fe I analysis of HD 103095) may well be 0.2 dex too low as inferred from both isochrones and the Fe II reanalysis of BC96. As can be deduced from the parameter uncertainty effects listed in Table 3, experimentation with different model atmospheres shows that the [Y/Fe] and [Ba/Fe] computed from Table 2 must be raised on average by 0.06 and 0.04 dex, respectively, for $\log g=4.7$. These small corrections have been applied to the Y and Ba abundance ratios in Table 3. For Y, the mean result is $[\mathrm{Y/Fe}]=-0.22$ with a difference of only 0.01 dex between HD 134439 and 134440. The tabulated uncertainty in this mean value is based upon a per line, per star uncertainty of 0.08 dex in the Y abundance and 0.03 dex in the mean Fe abundance for each star. For Ba, the mean result is $[\mathrm{Ba/Fe}]=-0.36$ with a difference of only 0.05 dex between HD 134439 and 134440. The internal uncertainty in Table 3 is calculated in the same manner as Y and is ~0.02 dex larger than that directly inferred from the observed scatter.

In sum, all the abundance ratios (i.e., [X/Fe]) we have investigated in HD 134439 and 134440 are in outstanding agreement- perhaps even slightly better than might be expected. A small offset (~0.06 dex) in the abundances with respect to H (i.e., [X/H]) may be present for our neutral species, but this is well within the relative statistical and stellar parameter uncertainties. The abundances thus strongly corroborate the kinematic evidence that our two stars share a similar origin and history. The final three columns of Table 3 list the changes in the abundance ratios that result for the stated changes in T_{eff}, $\log g$, and ξ. Inspection of these suggests that the total 1σ level uncertainties in our ratios are ~0.10 dex-though perhaps ~0.15 dex for [Si/Fe] which has larger sensitivities to both T_{eff} and $\log g$. We also note that our [Ca/Fe] ratio demonstrates some sensitivity to $\log g$; a more reasonable estimate for $\log g=4.7$ is $[\mathrm{Ca/Fe}]=+0.18$, though the difference with that in Table 3 is only 0.04 dex.

5. DISCUSSION

5.1 Abundance Ratio Comparisons

The mean abundance ratios of our common proper motion pair are notably different from the vast majority of other stars of similar Fe abundance. In particular, metal-poor stars contain a clear signature of Type II SN nucleosynthesis; their [Si, Mg, Ca/Fe] ratios are observed to be ~+0.4 (e.g., Wheeler *et al.* 1989). HD 134439 and 134440 are different in this regard. We argue here that our common proper motion pair exhibits abundance patterns which are not consistent with production in massive Type II progenitors. Instead, they seem to demonstrate the dominant products (notably Fe) of Type I SN production.

Fuhrmann *et al.* (1995, hereafter, FAG95) have determined [Mg/Fe] ratios for 56 little-evolved stars having a wide range in [Fe/H]. While they suggest that a real scatter is present, typically $[\mathrm{Mg/Fe}]\sim+0.2$ to $+0.3$ for $[\mathrm{Fe/H}]\lesssim-0.7$. Indeed, our result of $[\mathrm{Mg/Fe}]=-0.09$ is lower than all but one of their stars—even those having a near solar Fe abundance. We note that any needed slight increase in $\log g$ for our stars would only lower the [Mg/Fe] ratio further. The results of Peterson (1981) also suggest an overdeficiency in Mg for HD 134439. Her value of $[\mathrm{Mg/Fe}]=-0.07$ is in excellent agreement with our determination.

Observations of the evolution of [Si/Fe] with [Fe/H] are summarized in Fig. 21 of Timmes *et al.* (1995). These data indicate [Si/Fe] is ~+0.4 at $[\mathrm{Fe/H}]\sim-1.5$. Again, our abundance ratio from Table 3 is significantly lower than this. Indeed, as can be seen from Timmes *et al.* (1995), our [Si/Fe] ratio of -0.03 for HD 134439 and 134440 is even lower than the values for solar Fe abundance stars studied by Edvardsson *et al.* (1993). This deficiency was also seen by Peterson (1981), who determined $[\mathrm{Si/Fe}]=+0.02$ for HD 134440; again, the agreement with our estimate is excellent.

Figure 25 of Timmes *et al.* (1995) summarizes the evolution of [Ca/Fe] as a function of [Fe/H]. For $[\mathrm{Fe/H}]\sim-1.5$, [Ca/Fe] is ~+0.35. Again, our ratio of $+0.22$ (or $+0.18$ if $\log g=4.7$ is more appropriate for our stars) is lower than that seen for the vast majority of metal-poor stars. It is also lower than many of the Edvardsson *et al.* (1993) stars having [Fe/H] between -0.5 and -1.0. Our abundance ratio is again supported by the determination of Peterson (1981), who finds [Ca/Fe]$=+0.13$ for HD 134440. HD 134440 is notable there in that its [Ca/Fe] ratio is some 0.2–0.3 dex lower than the other stars having [Fe/H]$\lesssim-1.0$ in her analysis.

For [Fe/H]$=-1.5$, the field star results of Gratton & Sneden (1994) suggest [Y/Fe]~-0.18, which is entirely consistent with the value we determine. However, their results also indicate that [Ba/Fe]$=-0.08$ with a star-to-star scatter of 0.10 dex. Thus, the difference with our value of -0.38 appears to be of some significance. Independent determinations by others to verify this would be welcome, however.

While significant uncertainty and scatter exists in metal-poor field star Na abundances, the best current evidence is that [Na/Fe] is approximately 0.0 (Wheeler *et al.* 1989) or slightly less (perhaps~-0.2; Pilachowski *et al.* 1996) in less evolved metal-poor stars. Our value [Na/Fe]$=-0.38$ is somewhat less than these estimates, though precise comparison with the recent study of Pilachowski *et al.* (1996) may be complicated by issues such as their solar normalization and atomic data. Evidence for a low [Na/Fe] ratio in HD 134440 can also be seen in the study of Peterson (1981). Her [Na/Fe] value is ~0.6 dex less than that derived for other stars of grossly similar Fe abundance in her study.

5.2 *Chemical Evidence for Accreted Substructure?*

Taken together, the different abundance ratios for our two common proper motion stars point to anomalous abundance patterns compared to almost all other field stars of similarly low [Fe/H]. Indeed, the [Mg/Fe], [Si/Fe], and [Ca/Fe] ratios are some ~0.3 dex lower than the typical metal poor field star. [Na/Fe] also appears to be low, but the magnitude is uncertain given the observational and theoretical uncertainties discussed in Wheeler *et al.* (1989) and Timmes *et al.* (1995). Our best guess is that the inferred [Na/Fe] deficiency probably is real, but possibly less than that for the α-elements; the Na results are presented here largely for completeness as they were an important part of the Li I study. The primary production site of Mg, Ca, Si, and probably Na (which seems to require an additional source, likely not Type Ia SN, at metallicities of perhaps [Fe/H]$\gtrsim-1.0$ or so) is massive stars (Timmes *et al.* 1995). It thus appears that the nucleosynthetic contributions from such objects to our common proper motion pair was significantly and consistently different than for other metal-poor field stars in the solar neighborhood.

We also point out that the apparent Ba deficiency but unremarkable [Y/Fe] ratio might be understood in a similar fashion. While both of these elements are usually spoken of as ''*s*-process'' elements, it must be recalled that this terminology is a convenience based on the dominant fraction assigned to solar system material. In principle, these elements can be produced nearly exclusively in the *r*-process. Indeed, such exclusive *r*-process production at low metallicity has been suggested by Truran (1981). If the *r*-process were a more significant contributor to Ba than to Y in our stars, then the Ba deficiency might be understood if the dominant *r*-process site were the same massive stars also responsible for the anemic Mg, Ca, and Si production inferred for HD 134439 and 134440. Concerning these two contingent premises, we note that (a) the solar system *r*-process contribution to Ba is over twice as large as for Y (e.g., Table 1 of Gratton & Sneden 1994), and b) observational and theoretical evidence supports massive stars as the *r*-process production site (e.g., Secs. 2.4 and 5.2 of Wheeler *et al.* 1989).

The [Eu/Fe] ratio of HD 134439 and 134440 might clarify some of these issues, but no reliable Eu abundance (stellar or solar) could be readily derived from our data. There are only two Eu II features that we could identify with any confidence in our spectra. However, they are weak in our high gravity stars, and are severely blended as well. Ryan *et al.* (1991) find a surprisingly large [Eu/Fe] ratio of $=+0.55$ for HD 134439. Since the mean [Eu/Fe] for $-2\lesssim$[Fe/H]$\lesssim-1$ is $+0.29$ with a scatter of 0.11 dex (Gratton & Sneden 1994), the Ryan *et al.* value would be very difficult to understand given the deficiencies we see in other elements. However, it should be noted that their uncertainty in the strength of the λ4129 Eu II feature they employ is a substantial portion ($>50\%$) of the measured equivalent width itself. As described below, we also believe the feature to be significantly blended. To investigate the Eu abundance of HD 134439, a spectrum synthesis was conducted with MOOG using the Eu hyperfine components from McWilliam *et al.* (1995) and a linelist taken from the Kurucz CD-ROM. This analysis was consistent with Ryan *et al.* (1991) in using the same (summed) Eu II *gf* value and adopting (correctly or not) the same solar Eu abundance. Comparison of the solar and HD 134439 syntheses with the Kurucz *et al.* (1984) solar flux atlas data and our HD 134439 spectrum reveal a feature(s) of significant strength slightly (0.05–0.10 Å) blueward of the Eu II components' combined absorption maximum. No adjustments to the extant line list data were able to satisfactorily account for this blending. While this should not affect solar abundance determinations made at high resolution, it prevents accurate determination of the HD 134439 Eu abundance. We also note that, compared to the atlas data, the solar synthesis was slightly too strong in the red wing of the combined Eu features' absorption maximum; however, the synthesis is tremendously weak compared to the HD 134439 data, which indicates a blending feature(s) of strength exceeding that of the combined Eu features. This redward absorption, not predicted by extant atomic data, is an even more serious obstacle to determination of the Eu abundance in HD 134439. While a detailed linelist calibration and consistent solar determination beyond the scope of this work are needed to derive an accurate Eu abundance, even our incomplete syntheses indicate a conservative upper limit of [Eu/Fe]$<+0.3$ for HD 134439. Moreover, experimentation reveals that augmenting the linelist with contrived atomic features which can better reproduce the HD 134439 spectrum to the blue and red of the Eu II feature(s) can easily force [Eu/Fe]$\lesssim+0.0$. Thus, we believe that a close examination of the evidence reveals the Eu abundance of HD 134439 does not conflict with our conclusions.

In the introduction, we reviewed the kinematic evidence from Carney *et al.* (1996) that HD 134439 and 134440 are accreted substructure in the halo field. We now ask whether our abundance ratios can provide corroborating evidence for this suggestion. A general feature of accretion scenarios is that the chemical evolution may vary from fragment to fragment. In this picture, the contributions of ejecta from Type I and Type II—which have different progenitor masses and thus operate on different time scales—may be different from fragment to fragment. Underabundances of elements such as Mg, Si, and Ca (and O), which are mainly products of massive Type II SN, might arise due to a variety of specific differences in different ''fragments'' (whether they be globular clusters, dwarf spheroidals, or other pockets of star formation). First, if the IMF in a hypothetical fragment in which HD 134439 and 134440 originated was significantly deficient in massive stars, then underabundances might result. Second, if for some reason this fragment were unable to retain and recycle the products of Type II SN, then underabundances might result. Third, if the stars formed after a hiatus in star formation, they might also be expected to show Type I SN products (Fe) rather than Type II SN products like Mg, Si, and Ca (Unavane *et al.* 1996).

This third possibility is a particularly intriguing one since it would imply that the stars deficient in Type II SN products could be Fe-poor like Galactic halo field stars, but have a younger age. Carney *et al.* (1996) note evidence that their ''high halo'' field star sample may be younger than their ''low halo'' sample. It is thus interesting that they also suggest their ''high halo'' sample to be an accreted population based on its retrograde motion. A metal-poor but intermediate-age signature also characterizes the local dwarf spheroidal galaxies. As noted in the introduction, observational evidence for accretion of these systems by the Galaxy is in hand (Ibata *et al.* 1994; Preston *et al.* 1994). Furthermore, Fusi Pecci *et al.* (1995) have suggested that the globular clusters Ter 7 and Arp 2 have been accreted from the Sagittarius dwarf galaxy, and Lin & Richer (1992) suggest that the globular clusters Rup 106 and Pal 12 are former members of the Magellanic Clouds. It is perhaps no coincidence that these clusters are purported to be anomalously young (e.g., Sarajedini & Layden 1997). More significantly, the Type II SN product deficiencies seen here in HD 134439 and 134440 are also present in the Rup 106 and Pal 12 giants studied by Brown *et al.* (1997); additionally, a star formation history and environment resulting in low [O/Fe] ratios has been suggested for the Magellanic Clouds (e.g., Gilmore & Wyse 1991). We believe that our abundance determinations and the abundances of other systems provide corroborating evidence that is consistent with the kinematic-based suggestion of Carney *et al.* (1996) that the common proper motion pair HD 134439 and HD 134440 are examples of accreted substructure in the Galactic halo field.

We also note the similarities between the common proper motion pair and the intermediate-metallicity globular clusters in the work of Rodgers & Paltoglou (1984). These authors found that globular clusters in the range $-1.7 \lesssim [\mathrm{Fe/H}] \lesssim -1.3$ demonstrate moderate retrograde rotation of $V_{\mathrm{rot}} = -72 \pm 41$ km s^{-1}, in stark contrast to the moderate prograde rotation characteristic of their other metallicity bins. They suggest that these clusters, which have a mean [Fe/H] of -1.49 ± 0.11, are the result of coalescence of satellite galaxies. It is perhaps interesting that we find a mean [Fe/H] of -1.50 for HD 134439 and 134440, and that Table 1 indicates retrograde motion for these objects.

5.3 The Metal-Poor Star BD+03 740

Inspection of Fig. 5 from the Mg abundance study of FAG95 reveals one very striking data point. The value of $[\mathrm{Mg/Fe}] = -0.28$ for the metal poor star BD+03 740 is some $\sim 0.5 - 0.6$ dex lower than their other objects having $[\mathrm{Fe/H}] \lesssim -0.7$. Indeed, the Mg abundance ratio is lower than even those objects of solar Fe abundance. Might this extremely distinctive Mg abundance ratio signal an accretion origin for this star also? Interestingly, BD+03 740 is also the youngest of the FAG95 sample having ages from Schuster & Nissen (1989). This age, 12.2 Gyr, is in the low end of the range in ages determined by them for a large sample of metal-poor stars.

As discussed below, the [Fe/H] value derived by Axer *et al.* (1994, AFG94) and used by FAG95 is significantly higher than previous determinations. If one uses their [Fe/H] abundance with the O abundance from King (1994), whose adopted T_{eff} and log g values are very close to those of AFG94 and FAG95, then one obtains $[\mathrm{O/Fe}] = +0.27$. This is some ~ 0.3 dex lower than the [O/Fe] values of little evolved metal-poor stars as derived from the λ7774 O I lines using a similar T_{eff} scale (King 1993). Thus, with the AFG94 Fe abundance, both of the major Type II SN products Mg and O are seen to be underabundant compared to the vast majority of metal-poor stars. Coupled with its young (relative) age, this might suggest that BD+03 740 is a more metal-poor example of the distinctive nucleosynthetic history exhibited by HD 134439, HD 134440, and the young globular clusters Rup 106 and Pal 12.

The [Fe/H] value and queer [Mg/Fe] ratio derived by AFG94 and FAG95 for BD+03 740 may also partially explain the curiosity Carney *et al.* (1996) noted—the clear discrepancy between their metallicity determination, $[\mathrm{m/H}] = -2.78$, and that, $[\mathrm{Fe/H}] = -1.74$, of Schuster & Nissen (1989). The Fe determination of AFG94 suggests that the truth may indeed reside somewhere in the middle. The [Mg/Fe] value of FAG95 also might explain part of the discrepancy. The Carney *et al.* (1996) metallicities are derived over the wavelength range 5150 to 5250 Å. The strong Mg I features at λ5167.3, λ5172.7, and λ5183.6 fall within this range. If, in metal-poor stars like BD+03 740, much of the statistical power in the χ^2 minimization method used by Carney *et al.* to derive [m/H] comes from the Mg I lines, then low values of [Fe/H] (which is implicitly equated with [m/H] by Carney *et al.* in their comparison with Schuster & Nissen) might result. It would seem this possible effect could not account for the entire difference with Schuster & Nissen, even with liberal random errors in both determinations; it is unclear if anomalous abundance ratios or relative youth might affect the photometric determination of Schuster & Nissen.

The low [O/Fe] and [Mg/Fe] ratios noted above are contingent upon the AFG94 value of [Fe/H]$=-2.36$ for BD+03 740. This result is substantially discrepant with the determinations of Magain (1989; -2.98), Zhao & Magain (1990; -3.00), and Tomkin *et al.* (1992; -2.90). AFG94 discuss discrepancies between their abundances and these other sources. They attribute the differences seen to a combination of factors: different T_{eff} scales, possible differences in equivalent widths, differences in assumed solar abundances, assumptions concerning microturbulent velocities, and possible NLTE effects on ionization balance analyses. It is unclear, however, if these factors can explain the dramatic differences for BD+03 740; this star obviously merits considerably more detailed study.

There may be, however, one indication in favor of the AFG94 Fe analysis. The gravity, $\log g=3.20$, determined in the Magain (1989) analysis and apparently adopted in the study of Zhao & Magain and Tomkin *et al.*, seems very low for the T_{eff} (whether the 6264 K value of AFG94 or the 6110 K value of the other studies). The gravity is also quite discrepant with that suggested by theoretical isochrones; for example, Revised Yale Isochrones (Green *et al.* 1987) of 10–16 Gyr suggest gravities of ~ 3.65–3.95. Furthermore, it is discrepant with that derived from ionization balance analyses of other metal-poor stars. A good comparison is provided by HD 140283, which is of grossly similar metallicity ([Fe/H]~ -2.5 or so) but is some 400–500 K cooler than BD+03 740; several ionization analyses of HD 140283 suggest $\log g$ values in the neighborhood of 3.3–3.5. Thus, an even lower value for a significantly hotter star (BD+03 740) of similar metallicity and grossly similar age is difficult to understand. The LTE gravity estimate of AFG94, $\log g=3.72$, is in much better accord with observational and theoretical expectations. On the other hand, if the earlier $\log g$ estimates near 3.2 are correct, then the Yale isochrones suggest a surprisingly young age of $\lesssim 3$ Gyr for BD+03 740. Such a young star with [Fe/H]~ -3.0 might also be striking evidence for chaotic formation of some of the halo field. Indeed, Preston (1994) calls attention to the blue metal-poor ([Fe/H]$=-3.1$) spectroscopic binary CS 22873-139 as evidence for accretion of some halo field stars from Galactic satellites. Based on a comparison of the spectroscopically inferred mass ratio, the observed colors, and line strengths, Preston infers an age of $\lesssim 8$ Gyr for this system. BD+03 740 may be another example of such a young, metal-poor field star.

If the AFG94 Fe abundance of BD+03 740 is correct, then the evidence of a scatter in [O/Fe] at low [Fe/H] presented by King (1994) is greatly enhanced. Indeed, a spread of ~ 0.7 dex in the [O/Fe] ratios of BD+03 740, HD 140283, and BD−13 3442 would be implied. Such scatter in [O/Fe] may itself be a signature of inhomogeneous chaotic halo collapse or accretion of independent fragments—though not necessarily to the exclusion of a rapid smooth formation. Other possibilities, some exotic, also exist (King 1994). Additional O abundances in very metal-poor stars would illuminate these issues, but have not been forthcoming.

5.4 Abundance Ratios and Young Globular Cluster Metallicities

Sarajedini & Layden (1997, SL97) note that photometric [Fe/H] estimates are discrepant with those based on spectroscopy of the IR Ca II triplet for the anomalously young globular clusters Ter 7, Arp 2, Rup 106, and Pal 12. Evidence that these systems are accreted objects has already been discussed. SL97 speculate that these measurement differences may be due to differences in [α/Fe] ratios between these clusters and globulars used to calibrate the photometric and Ca II techniques; our abundance ratios of HD 134439, HD 134440, and possibly BD+03 740 suggest that accreted objects may well have distinctly different [α/Fe]. SL97 also argue that the metallicity estimate differences are functions of metallicity itself; correspondingly, the [α/Fe] ratios in accreted systems could be functions of metallicity like they are in the general Galactic field.

SL97 also note that α-element deficiencies, like those seen here for HD 134439 and 134440, in the anomalously young clusters relative to calibrating clusters are consistent with the differences between both the Ca II-based and photometric "metallicity" determinations and the direct spectroscopic [Fe/H] determination of Brown *et al.* (1997). However, the α-element deficiencies, like those seen in our common proper motion pair and those seen in Rup 106 and Pal 12, apparently can not explain why the photometric metallicities are lower than the Ca II-based metallicities; SL97 note that the opposite effect would be expected. Additionally, the α deficiencies with respect to Fe are apparently much larger in Rup 106 than they are in Pal 12 (Brown *et al.* 1997), but the difference between the photometric and Ca II-based metallicities is larger for Pal 12 than Rup 106; thus [α/Fe] differences do not seem to provide a satisfactory explanation for this discrepancy either. While our abundance ratios in HD 134439 and 134440 and those measured by Brown *et al.* (1997) suggest that α-element deficiencies may be distinctive features of accreted halo systems, these variations do not yet provide a satisfactory explanation concerning anomalies in young globular cluster metallicities inferred photometrically and via Ca II-based spectroscopy.

6. SUMMARY

Abundances of several elements derived from high resolution and high S/N spectra have been presented for the common proper motion pair HD 134439 and HD 134440. We find a mean Fe abundance of [Fe/H]~ -1.50, with a small statistical error in the mean of 0.02–0.03 dex. This abundance is in very good agreement with the early results of Peterson (1981) and the analysis of Spiesman & Wallerstein (1991), but is ~ 0.4 dex larger than the abundance derived by Ryan *et al.* (1991). The abundances of elements derived from neutral line species exhibit a small ~ 0.05 dex difference between HD 134439 and 134440; however, this slight offset is well within the statistical and parameter uncertainties. The very good abundance agreement and outstanding abundance ratio agreement between HD 134439 and 134440 corroborate the kinematic and spatial evidence (summarized in Table 1) that these two halo field stars share a common history.

This history, however, seems to have been quite different from the majority of metal-poor field stars. The α-element abundance ratios [Mg/Fe], [Ca/Fe], and [Si/Fe] are some $\sim$0.3 dex lower than nearly all halo stars of similar [Fe/H]. A preliminary spectrum synthesis analysis indicates that [Eu/Fe] could be similarly low, but more detailed work beyond the scope of this paper is needed to derive a firm value. [Ba/Fe] appears to be low too. Coupled with the suggestion of Carney *et al.* (1996) that these stars' kinematics may point to an origin in a distinct accretion event, the abundance ratios derived here are consistent with an environment out of which our common proper motion pair formed that differed from that of most halo field objects.

Taken together, a variety of evidence provides a consistent picture in which anomalous [α/Fe] ratios may be characteristic of an accreted halo population- as has been suggested before (e.g., Gilmore & Wyse 1991; Unavane *et al.* 1996)—and that HD 134439 and HD 134440 have such an origin—as suggested by Carney *et al.* (1996). This trail of evidence proceeds as follows. Carney *et al.* (1996) note that their "high halo" field star sample exhibits retrograde rotation and no radial metallicity gradient; this is consistent with an accreted origin. These authors also find suggestive evidence that this sample is younger than their sample of stars showing prograde motion and a metallicity gradient consistent with a dissipative collapse. The globular clusters Rup 106, Pal 12, Arp 2, and Ter 7 apparently are anomalously young (SL97). It has also been suggested that these clusters have been accreted from the Magellanic Clouds and the Sagittarius dwarf (Lin & Richer 1992; Fusi Pecci *et al.* 1995). Furthermore, Rup 106, Pal 12, and the Magellanic Clouds demonstrate markedly low [α/Fe] and [O/Fe] ratios (Brown *et al.* 1997; Gilmore & Wyse 1991). These low ratios are also demonstrated by HD 134439 and 134440, whose kinematics suggest an origin in a discrete accretion event (Carney *et al.* 1996). We also note that the [Fe/H] and retrograde orbit of HD 134439 and 134440 are characteristic of the subset of globular clusters that Rodgers & Paltoglou (1984) suggest were accreted by the Galactic halo.

We also call attention to the metal-poor subgiant BD+03 740. If the recent Fe abundance derived in AFG94's analysis (which yields a gravity consistent with that expected from theoretical isochrones and similarly metal-poor stars) is correct, then both the [Mg/Fe] and [O/Fe] ratios are $\sim$0.5 dex lower than those exhibited by nearly all other metal-poor field stars. That this object might also represent an accreted metal-poor field star would seem to be supported by its relatively young age on the scale of Schuster & Nissen (1992). The AFG94 Fe abundance would also lead to an inferred spread of $\sim$0.7 dex in [O/Fe] at low [Fe/H]-even larger than suggested by King (1994); this itself might suggest at least some degree of chaotic halo formation in independent fragments. On the other hand, if the low gravity ($\log g \sim 3.2$) inferred in earlier studies (Magain 1989) is correct, theoretical isochrones suggest the presence of a $\lesssim$3 Gyr [Fe/H]~ -3 star in the field. BD+03 740, then, may be akin to the metal-poor ([Fe/H]$=-3.1$) high velocity field star CS 22873-139, which Preston argues is $\lesssim$8 Gyr old.

Finally, we recalled the problem of photometric and Ca II-based metallicity estimates in young globular clusters. Our results indeed suggest anomalous [α/Fe] ratios may be present in at least some accreted populations like Rup 106, Pal 12, Arp 2, and Ter 7. As SL97 note, such characteristic low ratios would explain the [Fe/H] estimate differences between photometric/Ca II and direct spectroscopic methods. However, low [α/Fe] ratios like those in HD 134439 and 134440 seem unable to explain the differences between the photometric and Ca II methods themselves, and they are unable to explain the variation in these differences between, e.g., Rup 106 and Pal 12.

Note added in proof: A minor typographical error in the λ6767 Ni I log *gf* value employed in the stellar data files has been discovered. The correct value lowers [Ni/Fe] by a small 0.05 dex to -0.14 and -0.18 for HD 134439 and 134440. Subsequent analysis by the author has revealed that these values are somewhat higher than those inferred from other Ni I features at 5099, 5102, 7414, and 7788 Å. Taken together, all the Ni I features yield [Ni/Fe]$=-0.26$ for both HD 134439 and HD 134440, and (consistent with the other neutral species) a slight 0.06 dex difference in [Ni/H] is again seen between the two stars. This [Ni/Fe] value resides near the lower envelope of extant data of similar [Fe/H] displayed in Fig. 4 of Wheeler *et al.* (1989). Thus, slightly anomalous ratios (perhaps like those inferred here for Ba and Na) may exist within the iron peak itself. The detailed solar and stellar Ni abundances, atomic data, and line strengths are available from the author upon request.

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