EVIDENCE FOR PRIMORDIAL INHOMOGENEITIES FROM ABUNDANCE OF GIANTS IN M5, M13, AND M22

Ruth C. Peterson
Lockheed Palo Alto Research Laboratory

There is spectroscopic evidence for initial abundance inhomogeneities from star to star within M13 and M22. Among three stars in M13, there is an order-of-magnitude range in the sodium-to-iron ratio, which lies well beyond all known random and systematic errors; details will be given in a paper in preparation. In M22, the spread discussed below in logarithmic iron-to-hydrogen ratios, [Fe/H], is 0.6 dex, which is far larger than that found here for any other globular cluster.

The abundance analyses on which these results rest are based on Kitt Peak 4-m echelle spectra of a total of ten globular-cluster giants, half of which were generously loaned by George Wallerstein and Caty Pilachowski of the University of Washington. All spectra were reduced at Lockheed and analyzed at Kitt Peak using the program WIDTH of Kurucz (1970) and the metal-poor K-giant models of Gustafsson *et al.* (1975); details will be published separately. To determine model effective temperatures, Fe I excitation was used rather than *V-K* color.

The results for each star in each cluster are as follows:

STAR	Teff	[Fe/H]	STAR	Teff	[Fe/H]	STAR	Teff	[Fe/H]
M5 IV-81	4000	-1.47	M13 II-67	4000	-1.70	M22 V-8	4200	-2.18
M5 I-68	4150	-1.27	M13 III-63	4100	-1.73	M22 III-26	4000	-1.81
M5 IV-59	4250	-1.41	M13 II-76	4250	-1.71	M22 III-3	4000	-1.62
						M22 IV-97	3750	-2.15

Average [Fe/H] values and the standard deviation of an individual value from the average for each cluster are -1.38 and ±0.10 for M5, -1.71 and ±0.02 for M13, and -1.94 and ±0.27 for M22.

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The estimate of sources and sizes of random [Fe/H] errors in the adjacent table leads to ±0.16 as the expected uncertainty in [Fe/H]. It depends below 4000 K on the uncertain estimate of error in V_{turb}. However, the standard deviation in M22 [Fe/H] value is larger than ±0.16 and substantially larger than the mean of ±0.06 found for the other two clusters. It is

	Random Errors		(One-Sigma)
	Size	Effect	Notes
V_{turb}	±1.0	±0.12	
Teff	±100	±0.08	Smaller for T<4000 K
Log g	±0.3	±0.05	Larger for T<4000 K
Eq. Wid.	±20%	±0.05	30 Fe I lines used.

suggestive of an intrinsic spread in [Fe/H] from star to star within the cluster. Note that all four M22 stars are confirmed to be radial-velocity members: from telluric O_2 lines, all stars were found to have a radial velocity within 2km s^{-1} of that of the cluster.

Star V-8 lies well above the giant branch of M22, and is a long-period variable. Line widths and microturbulent velocity were measured to be marginally larger, but otherwise the analysis shows no peculiarities indicative of abundance errors. Also, in support of the identification of star III-3 as relatively metal-rich is the observation by J. Frogel (1979) that it has extremely strong CO absorption relative to that of the other cluster members.

This suggestion of an intrinsic spread in [Fe/H] within M22 adds support to the arguments presented by Hesser and Harris (1979) for an analogy between M22 and ω Centauri: the exceptional characteristics of the latter cluster appear to be mirrored to a lesser degree in the former.

REFERENCES

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DISCUSSION

CARNEY: Just for our edification, what did you get for M5?

PETERSON: For M5 Caty Pilachowski and I agree very nicely; [Fe/H] $\sim$ -1.3.

CAYREL: Have you also the NaD lines for the two stars?

PETERSON: Unfortunately I do not.

CAYREL: Please do them. The NaD lines are radiation damped and are *very* sensitive to the temperature. They're one of our temperature criteria in our analyses. They are extremely important to do.

FROGEL: I'd like to ask a couple of questions about the M22 data. First, the last star you had listed as 5-8 and I think that's V-8.

PETERSON: It probably is - it's a very luminous star.

FROGEL: O.K. And the comment I'd like to make about that star is that it's one of a class of cluster variables that lie far above the giant branch and I guess one theory of them, or one interpretation of them, is that they've already completed their asymptotic giant branch evolution and are, in fact, evolving to the blue. So it may be a little bit dicey to analyze a star like that.

PETERSON: Well, it's true in fact that these all tend to lie above the giant branch, as do most of the stars that echelle spectroscopy is done on this . . .

COHEN: No, no, no. Not above. I mean, they lie along - this star lies above.

PETERSON: Well, this top one lies on the tip. This one lies substantially above, so that you have a gradation of stars in terms of their relation with respect to the giant branch. But, again I've applied all the usual tests which I go through: excitation temperature, microturbulent velocity. I should say I'm slightly resolving the intrinsic line widths at this point. And it does agree with this. I mean, this does have slightly larger line widths than are expected, but I can see no other reason in terms of the analysis itself - no internal difficulties with the analysis.

FROGEL: Some more comments on M22. You're right in saying that there is a large spread in CO abundance among the giants that I've looked at; however, the giant branch itself in a bolometric magnitude-effective temperature plot shows essentially no width that could not be understood in terms of errors in the reddening. I'd like to ask some question about the sodium lines in M13. Faber, in measuring sodium in the integrated light of M31, claims that the only way which she can explain the strong sodium in the integrated light of the galaxy is by requiring a large dwarf population. Do you think the sodium lines have

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any bearing on the problem of understanding the stellar synthesis models of the galaxy?

PETERSON: I absolutely do. I'm working on extensive series of determinations of dwarfs. I do think that that's a very important aspect.

HARRIS, G.: As you mentioned, Jim Hesser and I have been trying to get spectra of the giants in M22 - definitely trying to find out about the CN variations. A couple of comments. We have spectra of the variable V8 and we find more heavy element absorption, whether it's molecular or line features is pretty hard to tell, because our spectra are so underexposed relative to the other stars we have in M22. So there's clearly a lot more absorption of something in that star - what it is I can't comment. We have tried to get spectra along the giant branch. We have not been able to go significantly below the horizontal branch due to bum weather for our 4-m time, but in the last run in this July we got about 25 spectra on the 1-m and approximately one third of those, I would say, show significant absorption in the CN features. Particularly the ultraviolet 3883 Å feature, which is much more sensitive to small variations than the 4215 Å feature. Relative proportions may be similar to what Judy Cohen was showing with her CO analysis, separating branches. However, I would urge people who are getting spectra of the giant stars looking for these things to try very hard to get the 3883 Å band, because it may be able to show us intermediate variations in the CN strengths if they do exist.

CANNON: I just want to be a little bit nasty, or else I've misunderstood something slightly, but you've kindly given us a good discussion of your errors there. As far as I can see, the four values of [Fe/H] that you give in M22 are nicely contained between -2 ± 0.3 which is $\pm2\sigma$ which is exactly what you would expect for no intrinsic scatter if your errors are well estimated.

PETERSON: You can make that argument. However, this scatter is much larger than anything that is seen in any of the other clusters by, I gather, several people working in this field.

CANNON: O.K. That's a much more convincing argument. (Laughter).

PETERSON: O.K. We'll leave it at that.