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A New Globular Cluster Metallicity Scale Based on the Abundance of Fe II

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Abstract

When using Fe as a surrogate for "metallicity", the metallicity is best represented by the dominant species of Fe. Accordingly, we have derived a new globular cluster metallicity scale based on the equivalent widths of Fe II lines measured from high resolution spectra of giant stars. The scale is primarily based on the results of analyses by the Lick-Texas group of 149 stars in 11 clusters, supplemented by other high resolution studies in five additional clusters. We also derive *ab initio* the true distance moduli for M3, M5, M13, M15, and M92 as a means of setting stellar surface gravities. We find that $[\mathrm{Fe/H}]_{\mathrm{II}}$ is correlated linearly with W', the reduced strength of the near-infrared Ca II triplet defined by Rutledge et al (1997), although the correlation coefficients depend on the stellar atmosphere model employed. In addition to the 66 globular cluster metallicity estimates presented in a recent PASP review, we present here an additional 39 globular cluster metallicity estimates based on transformations from Q39, the photometric index defined by Zinn (1980).

1.1 Background

Because globular cluster stars are faint, they are difficult to study at high spectral resolution. Thus, metallicity-sensitive indices have been devised from photometric and low- to medium-resolution data in order to study large samples of clusters. Zinn & West (1984; "ZW84") provided the first truly extensive data set based on metallicity-sensitive photometric indices of integrated cluster light. Most recently, Rutledge et al (1997a,b), employed infra-red ("IR") Ca II triplet features in low-resolution spectra of individual cluster giant stars. Regardless of the method employed, both indices require calibration to high-resolution abundance analyses of [Fe/H]. Metallicity estimates for other clusters are then derived by interpolating the correlation of the observed values of the indices and [Fe/H] determinations. The resulting metallicity scale therefore depends upon the reliability of the [Fe/H] determinations of nearby key clusters.

At the present time, two competing calibrations based on high resolution spectroscopic analyses exist. ZW84 employed the high resolution studies of Cohen (1978, 1979, 1980, 1981) and supplemented the results by Butler's (1975) measurements of ΔS determinations for RR Lyrae stars. Later, in a study by Carretta & Gratton (1997; "CG97"), CCD-based equivalent width ("EW") measurements were adjusted to a common system in order to define a new metallicity scale. CG97 employed a common set of Fe I *gf*-values, Kurucz (1992, 1993) model atmospheres with overshooting, and a uniform colour-effective temperature

("T_{eff}") relationship (Gratton et al 1996) for 160 stars in 24 globular clusters. The difference in the metallicity scales, in the sense of Δ[Fe/H] = *CG97 – ZW84*, is –0.1 dex for metal-rich clusters and $\sim$ +0.2 dex for metal-poor clusters.

1.2 Developments Since 1997

In the five years since the CG97 scale was established, there have been new developments that affect the abundance analysis of metal-poor giants, and thus the metallicity scale of globular clusters. First, new scales of colour versus T_{eff} have been devised, one by Alonso et al (1999) based on the IR Flux Method (Blackwell et al 1990), and another by Houdashelt et al (2000) who modelled broad-band colours as a function of T_{eff} and stellar surface gravity ("log *g*"). Second, consideration of the effects of non-local thermodynamic equalibrium ("non-LTE") suggests that the assumption of LTE ionization equilibrium between Fe I and Fe II may be invalid; iron may be overionized in the atmospheres of metal-poor giant stars (see e.g. Thévenin & Idiart 1999; "TI99"). Finally, new cluster distance moduli based on *Hipparcos* (ESA 1997) parallaxes for nearby subdwarfs has led to slightly increased globular cluster distances, which has slightly decreased the estimates of log *g* in globular cluster stars.

1.3 Why Fe II?

By "metallicity", we make the usual assumption that it is equivalent to [Fe/H] as derived from high resolution analyses. In the past, [Fe/H] has normally been based on the abundance derived from Fe I lines, or on the mean of the abundances derived from both Fe I and Fe II lines. However, in a detailed study of LTE models of metal-poor stellar atmospheres, TI99 concluded that abundance analyses of Fe I underestimate the abundance of iron. At any given optical depth, the populations of the atomic levels of Fe I are affected by the outward leakage of higher energy photons from inner layers; the local kinetic temperature is not in equilibrium with the radiation field. The result is that iron is overionized. But, in such atmospheres, Fe II is by far the dominant species and is essentially unaffected by departures from LTE. So, the effect of this lack of equilibrium, while serious for Fe I, is negligible for Fe II. Thus, metallicities for globular clusters can safely be based on LTE analysis of Fe II. This is supported by 3-dimensional atmosphere modelling by Asplund & Garcia Perez (2001) and Nissen et al (2002).

1.4 Basis of Re-Analysis

Although the analyses vary widely in cluster sample size, high resolution abundance analyses for giant stars in over 30 globular clusters can be found in the literature. Many giants are in common to multiple investigations. These stars provide information from which T_{eff} and log *g* transformations can be estimated. We focussed our attention on those clusters in which a reasonable number of Fe II lines (N >4) were measured in each giant star analyzed and to those clusters in which at least three giants were studied. The clusters studied by the Lick-Texas group (see Kraft & Ivans 2003 for all of the references employed; "KI-03") usually proved to include results for more stars in a given cluster than those included by other groups. In addition, the Fe linelists and *gf*-values chosen varied considerably from group to group. Thus, we focussed our attention on 16 clusters, uniformly analyzed for Fe II abundances mostly by the Lick-Texas group, ranging in metallicity –2.5 $\leq$ $[Fe/H]_{II}$ $\leq$ –0.7. The present results are based on more than 150 stars.

Table 1.1. *True Distance Moduli of Five Key Clusters*

Cluster (1)	$[Fe/H]_{II}$ (2)	$(m–M)_0$ (3)	$(m–M)_0$ from Previous Studies (4)
M15	–2.42	15.25	15.26 (1) 15.25 (2a) 15.31 (2b)
M92	–2.38	14.75	14.49 (1) 14.93 (2) 14.71 (3)
M13	–1.60	14.42	14.08 (1c) 14.26 (1d) 14.48 (2) 14.40 (3)
M3	–1.50	15.02	14.79 (1)
M5	–1.26	14.42	14.03 (1e) 14.40 (1f) 14.45 (2) 14.59 (3)

References:
(1) Lick-Texas group (all relevant citations can be found in in KI-03)
(2) Reid 1997
(3) Carretta et al 2000
Additional Notes:
(a) Reid $E(B–V)$ = 0.07
(b) Reid $E(B–V)$ = 0.11
(c) Kraft et al 1997
(d) Pilachowski et al 1996
(e) Sneden et al 1992
(f) Ivans et al 2001

In order to put the clusters on the same metallicity scale, we needed to make adjustments to the input parameters. The following considerations were incorporated: (i) the adopted solar Fe abundance; (ii) the derivation of *gf*-values for Fe I and Fe II; (iii) estimates of interstellar reddening; (iv) the assignment of T_{eff}; (v) estimates of cluster moduli and stellar masses; and (vi) the determination of log g. The Lick-Texas group studies, which made up the bulk of our sample, are based on analyses employing MARCS models (Gustafsson et al 1975). Thus, we also derived transformations to Kurucz models, both with and without overshooting. We adopted the colour-T_{eff} relationship of Alonso et al but also derived the offsets that need to be applied if one employs the Houdashelt et al calibration instead. Details of the strategy we devised are found in KI-03 (their §3 and Table 5).

In column (3) of Table 1.1, we display the true distance moduli we derived for five key clusters on the basis of *Hipparcos*-based distances to low-metallicity subdwarfs. Column (2) shows the metallicity we derived. Details regarding the method of the analysis, including the adoption of T_{eff}, log g, *gf*-values, the solar model, and log $\epsilon(Fe)_\odot$, are presented in KI-03.

1.5 Revised Cluster Abundances Based on Fe II

The clusters in our sample were divided into three groups. Group 1 clusters are those with T_{eff} and log g based on colours and absolute magnitudes. They all possess $E(B–V) \leq 0.10$ and Lick-Texas group analyses of at least six giants per cluster. Group 2 clusters are those with larger, less certain reddenings. Group 3 clusters include those from non-Lick-Texas studies with the results transformed to those on the Lick-Texas group system. Table 1.2 presents the reddening and distance moduli values we adopted in our study, as well as the revised cluster abundances based on Fe II. For each cluster, three metallicity estimate

Table 1.2. *Revised Globular Cluster Abundances Based on Individual Stellar Abundances of Fe* II*, Segregated By Model for 16 Key Clusters*

Cluster (1)	$E(B–V)$ (2)	$(m–M)_0$ (3)	$[Fe/H]_{MARCS}$ (4)	σ (5)	$[Fe/H]_{K-on}$ (6)	$[Fe/H]_{K-off}$ (7)
			Group 1			
M5	0.03	14.42	–1.26	0.06	–1.19	–1.19
N362	0.05	14.70	–1.34	0.07	–1.27	–1.27
N288	0.03	14.66	–1.41	0.04	–1.33	–1.35
M3	0.01	15.02	–1.50	0.03	–1.42	–1.43
M13	0.02	14.42	–1.60	0.08	–1.52	–1.53
M92	0.02	14.75	–2.38	0.07	–2.32	–2.38
M15	0.10	15.25	–2.42	0.07	–2.36	–2.42
			Group 2			
M71	0.32	12.83	–0.81	0.07	–0.74	–0.74
M4(a)	0.33	11.61	–1.15	0.08	–1.08	–1.08
M10	0.24	13.41	–1.51	0.09	–1.43	–1.44
			Group 3			
47 Tuc	0.04	13.32	–0.70	0.09	–0.63	–0.63
N7006	0.10	18.00	–1.48	0.04	–1.40	–1.41
N3201(a)	0.25	13.61	–1.56	0.10	–1.48	–1.49
N6752	0.04	13.07	–1.57	0.10	–1.49	–1.50
N2298	0.16	15.17	–1.97	0.09	–1.91	–1.97
N6397	0.24	11.62	–2.02	0.07	–1.96	–2.02

Model Atmosphere References:
MARCS ≡ Gustafsson et al 1975;
K-on ≡ Kurucz with overshooting;
K-off ≡ Kurucz without overshooting
Additional Note:
(a) Reddening value is uncertain and variable across face of cluster.

values are provided. The estimates in column (4) corresponds to those based on the Lick-Texas group analysis which employed MARCS stellar atmosphere models. Columns (6) and (7) correspond to those derived in the Lick-Texas system and transformed to systems based on Kurucz stellar atmosphere models, with ("K-on") and without ("K-off") overshooting (we refer the reader to KI-03, their §5, for a detailed discussion of the transformation). Owing to the method we employed, the σ reported in column (5) is the same for columns (4), (6), and (7). The Fe II metallicities in Table 1.2 were derived employing the Alonso et al colour-T_{eff} calibrations. The difference between the Alonso et al and Houdashelt et al T_{eff} scales induces a difference of $\sim$ –0.04 dex in $[Fe/H]_{II}$ (we refer the reader to KI-03, their §6 and appendix, for details).

1.6 The Rutledge et al W' versus $[Fe/H]_{II}$ Calibration

Having established revised distance moduli for five key clusters, and revised metallicities based on Fe II for sixteen clusters, we extended the metallicity scale to other clusters using the reduced EW of the IR Ca II triplet (W') as produced by Rutledge et al (1997a, their Table 1). We refer the reader to KI-03 for further details and discussion (their §8, Table 4, and Figures 2 and 4). The coefficients and standard errors (σ) for the regressions of $[Fe/H]_{II}$ on W' derived in KI-03 are as follows:

(1) $[Fe/H]_{II} = 0.531_{(\pm 0.025)} \times W' - 3.279_{(\pm 0.086)}$ (MARCS)
(2) $[Fe/H]_{II} = 0.537_{(\pm 0.024)} \times W' - 3.225_{(\pm 0.082)}$ (Kurucz-on: with conv. overshooting)
(3) $[Fe/H]_{II} = 0.562_{(\pm 0.023)} \times W' - 3.329_{(\pm 0.078)}$ (Kurucz-off: without conv. overshooting)

In Table 1.3 we present a compilation of cluster $[Fe/H]_{II}$ estimates for which $[Fe/H]_{II} \leq 0.65$. The table includes the metallicity estimates reported in Tables 4 and 7 of KI-03, along with estimates for an additional 39 clusters. Column (3) lists our best estimate of $[Fe/H]_{II}$, based on the new metallicity scale, for a given cluster using a MARCS stellar atmosphere model and column (4) identifies the method that we employed to derive that estimate. Columns (5 – 7) show the fit of W' from Rutledge et al (or $W'_{est.}$ as estimated below) to the preceding equations.

1.6.1 W' Extension to Clusters Not Included by Rutledge et al

For clusters not included in the Rutledge et al compilation (and thus not previously reported in KI-03), we estimated a value for W' on the Rutledge et al system. We first determined the best fit between the Rutledge et al W' measurement to the ZW84 integrated metallicity index <Q39> for clusters in common between the studies (where <Q39> was not available, we adopted the value of Q39 from Zinn 1980). We then employed this fit to interpolate the <Q39> (or Q39) value for an additional 37 clusters to estimate W' on the Rutledge et al system. This value appears in column (8). We then applied Equations (1) – (3) to derive the estimated $[Fe/H]_{II}$ values shown in columns (5 – 7). For these clusters, the average error in $[Fe/H]_{II}$ is $\sim$0.15 dex, slightly larger than the typical error of $\sim$ 0.10 dex quoted for the key clusters with values of W' from Rutledge et al.

Thus, the estimates in column (3) of Table 1.3 have been obtained by one of the following methods as identified in column (4):

LTG+ metallicity estimates are based on detailed investigation of the results of high resolution analyses of individual stars adopting MARCS stellar atmosphere models (see KI-03, their §6, Table 4, and appendix for details).

R-W' metallicity estimates are based on the extension of LTG+ by using W' (the reduced EW of the IR Ca II triplet from Rutledge et al) and Equation (1).

Q39' metallicity estimates are based on our estimate of W' (based on a best fit of the Rutledge et al values to <Q39> or Q39) and Equation (1).

Columns (5 – 7) display the estimated $[Fe/H]_{II}$ one would derive employing the linear correlation of $[Fe/H]_{II}$ and W' (or W'_{est}) for both MARCS (Equation 1) and Kurucz stellar atmosphere models, with and without overshooting (Equations 2 and 3, respectively). Where no LTG+ estimates have been made, the results employing Equation (1) are simply repeated in column (3).

1.7 Some Additional Results and Concerns

Metal-Rich Clusters ([Fe/H] > –0.65): Most of the globular clusters more metal-rich than those included in our estimations lie in or near the Galactic bulge, are obscured by

Table 1.3. *Compilation of Cluster [Fe/H]$_{\rm II}$ Estimates*

NGC (1)	Alt. Name (2)	[Fe/H]$_{\rm II}$ MARCS (3)	Method (4)	MARCS (Eq'n 1) (5)	K-on (Eq'n 2) (6)	K-off (Eq'n 3) (7)	$W'_{est.}$ (8)
104	47 Tuc	–0.70	LTG+	–0.88	–0.79	–0.78	
288		–1.41	LTG+	–1.34	–1.26	–1.27	
362		–1.34	LTG+	–1.27	–1.20	–1.21	
1261		–1.26	R-W'	–1.26	–1.19	–1.19	
	Eridanus	–1.42	R-W'	–1.42	–1.34	–1.35	
1851		–1.19	R-W'	–1.19	–1.11	–1.12	
1904	M79	–1.64	R-W'	–1.64	–1.57	–1.59	
2298		–1.97	LTG+	–2.07	–2.00	–2.04	
2808		–1.29	R-W'	–1.29	–1.22	–1.23	
	Pal 3	–1.66	R-W'	–1.66	–1.59	–1.61	
3201		–1.56	LTG+	–1.46	–1.39	–1.40	
	Pal 4	–1.43	R-W'	–1.43	–1.35	–1.37	
4147		–1.79	R-W'	–1.79	–1.72	–1.75	
4372		–2.29	R-W'	–2.29	–2.23	–2.28	
	Rup 106	–1.18	Q39'	–1.18	–1.10	–1.10	3.960
4590	M68	–2.43	R-W'	–2.43	–2.37	–2.43	
4833		–2.06	R-W'	–2.06	–2.00	–2.04	
5024	M53	–2.02	Q39'	–2.02	–1.95	–2.00	2.367
5053		–2.41	R-W'	–2.41	–2.35	–2.41	
5272	M3	–1.50	LTG+	···	···	···	
5286		–1.69	R-W'	–1.69	–1.62	–1.65	
5634		–1.92	Q39'	–1.92	–1.85	–1.89	2.559
5694		–2.10	R-W'	–2.10	–2.04	–2.08	
5824		–1.93	Q39'	–1.93	–1.86	–1.90	2.548
5897		–2.09	R-W'	–2.09	–2.02	–2.07	
5904	M5	–1.26	LTG+	–1.32	–1.24	–1.25	
5927		–0.67	R-W'	–0.67	···	···	
5946		–1.29	Q39'	–1.29	–1.22	–1.23	3.743
5986		–1.61	R-W'	–1.61	–1.54	–1.56	
	Pal 14	–1.61	R-W'	–1.61	–1.54	–1.56	
6093	M80	–1.76	R-W'	–1.76	–1.69	–1.72	
6101		–2.13	R-W'	–2.13	–2.07	–2.12	
6121	M4	–1.15	LTG+	–1.22	–1.15	–1.15	
6139		–1.61	Q39'	–1.61	–1.53	–1.56	3.149
6144		–2.10	R-W'	–2.10	–2.03	–2.08	
6145		–1.75	Q39'	–1.75	–1.68	–1.71	2.885
6171	M107	–1.10	R-W'	–1.10	–1.02	–1.02	
6205	M13	–1.60	LTG+	–1.58	–1.51	–1.53	
6218	M12	–1.34	R-W'	–1.34	–1.25	–1.26	
6229		–1.41	Q39'	–1.41	–1.33	–1.35	3.522

Cont'd ...

NGC	Alt. Name	$[Fe/H]_{II}$ MARCS	Method	MARCS (Eq'n 1)	K-on (Eq'n 2)	K-off (Eq'n 3)	$W'_{est.}$
6235		–1.39	R-W'	–1.39	–1.31	–1.32	
6254	M10	–1.51	LTG+	–1.48	–1.41	–1.43	
6266	M62	–1.19	R-W'	–1.19	–1.11	–1.12	
6273	M19	–1.84	R-W'	–1.84	–1.77	–1.79	
6284		–1.32	Q39'	–1.32	–1.24	–1.25	3.698
6287		–2.20	Q39'	–2.20	–2.13	–2.19	2.033
6293		–2.00	Q39'	–2.00	–1.93	–1.97	2.413
6304		–0.73	R-W'	–0.73	···	···	
6316		–0.81	Q39'	–0.81	–0.72	–0.72	4.656
6325		–1.36	Q39'	–1.36	–1.28	–1.29	3.620
6333	M9	–1.79	Q39'	–1.79	–1.72	–1.75	2.811
6341	M92	–2.38	LTG+	···	···	···	
6342		–0.86	Q39'	–0.86	–0.77	–0.76	4.563
6352		–0.78	R-W'	–0.78	–0.70	–0.69	
6355		–1.33	Q39'	–1.33	–1.25	–1.26	3.675
6362		–1.15	R-W'	–1.15	–1.07	–1.07	
6366		–0.82	R-W'	–0.82	–0.74	–0.73	
6388		–0.89	Q39'	–0.89	–0.81	–0.81	4.491
6397		–2.02	LTG+	–2.12	–2.06	–2.11	
6401		–1.09	Q39'	–1.09	–1.01	–1.01	4.119
6402	M14	–1.41	Q39'	–1.41	–1.34	–1.35	3.514
6426		–2.43	Q39'	–2.43	–2.36	–2.43	1.606
6440		–0.72	Q39'	–0.72	···	···	4.823
6441		–0.85	Q39'	–0.85	–0.76	–0.75	4.582
6453		–1.46	Q39'	–1.46	–1.38	–1.40	3.427
6496		–0.78	R-W'	–0.78	–0.70	–0.69	
6517		–1.26	Q39'	–1.26	–1.18	–1.19	3.808
6522		–1.42	R-W'	–1.42	–1.35	–1.36	
6535		–1.80	R-W'	–1.80	–1.74	–1.76	
6539		–0.87	Q39'	–0.87	–0.79	–0.78	4.536
6541		–1.83	R-W'	–1.83	–1.76	–1.78	
6544		–1.41	R-W'	–1.41	–1.34	–1.35	
6553		–0.67	Q39'	–0.67	···	···	4.909
6558		–1.36	Q39'	–1.36	–1.29	–1.30	3.612
6569		–0.94	Q39'	–0.94	–0.86	–0.85	4.405
6584		–1.47	Q39'	–1.47	–1.39	–1.41	3.410
6624		–0.78	R-W'	–0.78	–0.70	–0.69	
6626	M28	–1.19	R-W'	–1.19	–1.11	–1.12	
6637	M69	–0.89	R-W'	–0.89	–0.81	–0.80	
6638		–1.04	R-W'	–1.04	–0.96	–0.92	
6642		–1.21	Q39'	–1.21	–1.13	–1.14	3.890
6652		–0.96	Q39'	–0.96	–0.88	–0.87	4.372
6656	M22	–1.71	Q39'	–1.71	–1.64	–1.67	2.958
						Cont'd	...

NGC	Alt. Name	$[Fe/H]_{II}$ MARCS	Method	MARCS (Eq'n 1)	K-on (Eq'n 2)	K-off (Eq'n 3)	$W'_{est.}$
	Pal 8	–0.81	Q39'	–0.81	–0.73	–0.72	4.648
6681	M70	–1.60	R-W'	–1.60	–1.52	–1.54	
6712		–1.10	R-W'	–1.10	–1.02	–1.02	
6715	M54	–1.47	R-W'	–1.47	–1.40	–1.41	
6717	Pal 9	–1.27	R-W'	–1.27	–1.20	–1.21	
6723		–1.11	R-W'	–1.11	–1.03	–1.03	
6752		–1.57	LTG+	–1.46	–1.39	–1.41	
	Arp 2	–1.74	R-W'a	–1.74	–1.67	–1.70	
6760		–0.81	Q39'	–0.81	–0.73	–0.71	4.654
6779		–1.88	Q39'	–1.88	–1.81	–1.85	2.637
6809	M55	–1.85	R-W'	–1.85	–1.78	–1.82	
	Ter 8	–2.18	R-W'a	–2.18	–2.11	–2.17	
	Pal 11	–0.80	R-W'	–0.80	···	···	
6838	M71	–0.81	LTG+	–0.82	–0.74	–0.73	
6864	M75	–1.29	Q39'	–1.29	–1.22	–1.23	3.743
6934		–1.59	Q39'	–1.59	–1.52	–1.54	3.178
6981	M72	–1.42	R-W'	–1.42	–1.35	–1.36	
7006		–1.48	LTG+	···	···	···	
7078	M15	–2.42	LTG+	–2.45	–2.39	–2.46	
7089	M2	–1.56	R-W'	–1.56	–1.49	–1.51	
7099	M30	–2.33	R-W'	–2.33	–2.26	–2.32	
	Pal 12	–0.95	R-W'	–0.95	–0.87	–0.86	
7492		–1.69	R-W'	–1.69	–1.62	–1.64	

Method:

LTG+: Investigation of individual stellar abundances in key clusters, with new derivations of distance moduli (as shown in Table 1.2; taken from Table 4 of KI-03).

R-W': Application of KI-03 Equation (1) to Rutledge et al determination of W' (taken from Table 7 of KI-03).

R-W'a: Same as (R-W') but did not appear in Table 7 of KI-03.

Q39': Application of KI-03 Equation (1) to $W'_{est.}$.

interstellar dust, and have not been studied extensively at high resolution. Extrapolating the correlations given in §1.6 predicts values of $[Fe/H]_{II}$ 0.3 – 0.5 dex lower than the measured metallicities in the literature. We refer the reader to further discussion in KI-03 (their §9).

Determination of [X/Fe] Ratios: If Fe is a surrogate for "metallicity", then metallicity should be represented by the dominant species of Fe. In the case of giant stars in globular clusters, the dominant species, by far, is Fe II. Use of Fe I for this purpose is troublesome due to possible departures from LTE. Summarizing the discussion in KI-03 (their §10), we make the following recommendations in the determinations of [X/Fe] ratios for globular cluster giant stars:

- C, N, and O are all overwhelmingly in the neutral state. Their abundances should be derived from indicators of the abundance of the neutral species and should be normalized to the abundance of iron based on Fe II.

- Elements such as Ti, Sc, Ba, and Eu, derived from features due to the singly ionized state, should have their [X/Fe] values normalized to the iron abundance based on Fe II.
- Other neutral elements which may suffer from effects of over-ionization similar to that of iron, should be normalized to abundance of iron based on Fe I.

1.8 Conclusions

There exists no “definitive" set of cluster metallicities that are systematically reliable on the 0.05 dex level. Any discussion of cluster abundances (Galactic or extragalactic) must state clearly the underlying assumptions concerning the stellar atmosphere models used; the adopted T_{eff}-scale; what is meant by “metallicity" (eg. Fe I? Fe II? or a mean thereof?); what is the method used to derive log *g*; and the origin of *gf*-values.

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