*Carnegie Observatories Astrophysics Series, Vol. 5:
RR Lyrae Stars, Metal-Poor Stars, and the Galaxy
ed. A. McWilliam (Pasadena: Carnegie Observatories)*

Metal Abundance Calibration of the Ca II Triplet Lines in RR Lyrae Stars

GEORGE WALLERSTEIN[1], THOMAS GOMEZ[1,2], AND WENJIN HUANG[1,3]

(1) Department of Astronomy, University of Washington, Seattle, WA 98195

Abstract

The GAIA satellite is likely to observe thousands of RR Lyrae stars within a small spectral window, between 8470 Å and 8750 Å, at a resolution of 11,500. In order to derive the metallicity of RR Lyrae stars from Gaia, we have obtained numerous spectra of RR Lyrae stars at a resolution of 35,000 with the Apache Point Observatory 3.5 m echelle spectrograph. We have correlated the Ca II triplet line strengths with metallicity as derived from Fe II abundances, analogous to Preston's (1959) use of the Ca II K line to estimate the metallicity of RR Lyrae stars. The Ca II line at 8498 Å is the least blended with neighboring Paschen lines and thus provides the best correlation.

1. Introduction: The GAIA Satellite

During the next decade, the study of galactic structure will be greatly enhanced thanks to two new instruments, the Large Synoptic Survey Telescope (LSST) and the GAIA satellite. The European Space Agency (ESA) is heading the GAIA satellite project, an enormous improvement over *Hipparcos*.

In addition to measuring parallaxes and proper motions, GAIA is expected to observe a small spectral window between 8470 Å and 8750 Å with a resolution of 11,500 to capture the Ca II triplet for radial velocity measurements. This spectral window also includes some of the hydrogen Paschen series. GAIA's mission plan is to measure each star multiple times in order to gather the necessary information, primarily for parallaxes and proper motions as well as for variability. The GAIA spectral window is shown in Figure 1 for several RR Lyrae stars (SW And, XZ Cyg, and X Ari). We

Electronic address: (1) wall@astro.washington.edu
(2) Present address: Department of Astronomy, University of Texas at Austin
(3) Present address: Brion, Inc.; wenjin.huang@brion.com

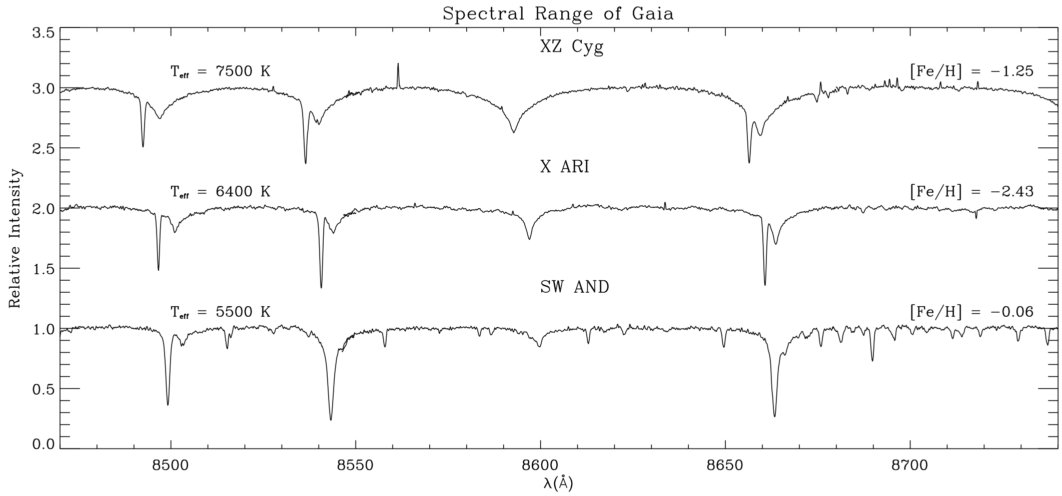

Figure 1.— The sample spectral range for the GAIA satellite showing a range of [Fe/H] and a range of temperatures. The orignal resolving power of 30,000 has been reduced to 11,000 to imitate the expected resolution of the GAIA spectrograph.

correlated [Fe/H] against the equivalent width (EW) of the Ca II triplet for RR Lyrae stars in the same manner as Cole et al. (2004) did for red giants. This is important because GAIA will map an estimated one billion stars, including many RR Lyrae variable stars, which are important for studying galactic structure and stellar populations. The calibration of the Ca II triplet allows us to infer one of the fundamental properties of RR Lyrae stars without additional measurements.

2. Observations and Data Analysis

We observed many RR Lyrae stars with the Apache Point Observatory (APO) echelle spectrograph, which has a resolution of 35,000 and covers a wavelength interval from 3800 Å to 10,400 Å. The signal to noise (S/N) of our observations ranged from 70 to 200 in the 8500 Å region. The RR Lyrae stars were observed at random phases in order to replicate GAIA observations. Exposure times were generally 10 minutes for the brighter stars and 20 minutes for the fainter ones. Data reduction was accomplished using programs in the IRAF package. Equivalent width measurements were obtained both at the full resolution of APO's echelle and at the expected reduced resolution of GAIA.

The measurement of equivalent widths was automated by an IDL program written by W. H. Table 1 gives the list of observed stars and their metallicities, as obtained from the literature, as well as the dates of our observations. Lines of the hydrogen Paschen and Balmer series, the Ca II triplet, and selected lines of Fe II, Fe I, and other elements were measured. The equivalent widths of Fe II were analyzed with a Kurucz model atmosphere to determine [Fe/H]. Further abundance analyses of other elements

TABLE 1
Lists of observed stars (sorted by constellation), their [Fe/H] and [Fe/H] reference. The observation date and time are included.

Star	[Fe/H]	UT of Observation	Star	[Fe/H]	UT of Observation
AT And	−1.18[a]	2010-11-21 04:22	RX Eri	−1.33[b]	2010-11-21 06:42
SW And	−0.38[a]	2009-12-27 05:01	SV Eri	−2.04[a]	2009-12-27 06:17
XX And	−1.94[b]	2010-11-21 05:14			2009-11-27 06:00
BR Aqr	−0.74[b]	2010-11-21 03:50	RR Gem	−0.35[a]	2009-12-27 06:45
BS Aqr		2008-12-16 00:53			2008-12-16 06:03
X Ari	−2.43[b]	2010-11-21 05:40	VX Her	−1.58[b]	2009-03-15 10:50
		2009-12-27 05:52	VZ Her	−1.03[a]	2010-03-25 10:38
		2009-11-27 05:35			2009-03-15 11:34
		2009-08-04 11:33	RR Leo	−1.57[a]	2009-03-15 08:21
RS Boo	−0.32[a]	2010-03-25 07:17	TT Lyn	−1.56[b]	2009-12-27 08:09
		2009-06-08 06:02	TT Lyn	−1.56[b]	2009-12-27 08:09
ST Boo	−1.86[a]	2009-03-15 09:25			2009-03-15 08:09
RR Cet	−1.52[a]	2009-11-27 03:45	KX Lyr	−0.46[a]	2010-03-25 11:13
		2009-08-04 10:30			2009-06-08 06:29
XZ Cet		2009-11-27 04:39	RR Lyr	−1.37[a]	2009-12-27 00:55
W CVn	−1.21[a]	2009-06-08 04:58			2009-08-04 09:41
		2009-03-15 09:05			2009-06-13 07:32
XZ Cyg	−1.52[a]	2009-08-04 09:57			2009-03-15 12:22
		2009-06-13 07:49	V445 Oph	-0.23[a]	2009-06-08 05:26
		2008-12-16 01:36			2009-03-15 11:11
SW Dra	−1.24[a]	2010-03-25 08:27	AV Peg	−0.14[a]	2009-06-13 08:58
		2009-05-09 08:26	BH Peg	−1.38[a]	2009-12-27 02:36
XZ Dra	−0.87[a]	2010-03-25 11:50	AR Per	−0.43[a]	2009-12-27 07:42
		2009-12-27 01:11	TU UMa	−1.44[b]	2009-03-15 10:12
		2009-06-13 08:06	UU Vir	−0.82[a]	2010-03-25 07:59
DX Del	−0.56[a]	2009-12-27 01:36			2009-03-15 09:50
		2009-11-27 01:46			
		2009-08-04 09:16			
		2009-06-13 08:33			
		2008-12-16 01:22			

[a] Layden (1994)
[b] Feast et al. (2008)

will be presented in the full publication.

The temperature of each star at the observed phase was determined from the hydrogen Balmer and Paschen lines using Kurucz models. Based on the known luminosity of RR Lyrae stars and an estimated mass of 0.7 $M_{\odot}$, we assume log $g = 2.5$ unless the star is hotter than 6750 K. Stars with $T_{\rm eff} \geq 6750$ K are assumed to have log $g = 3.5$. The appropriate Kurucz model was then used in MOOG to determine the abundances of other elements. Our Fe abundances compared to values from the literature are shown in Figure 2.

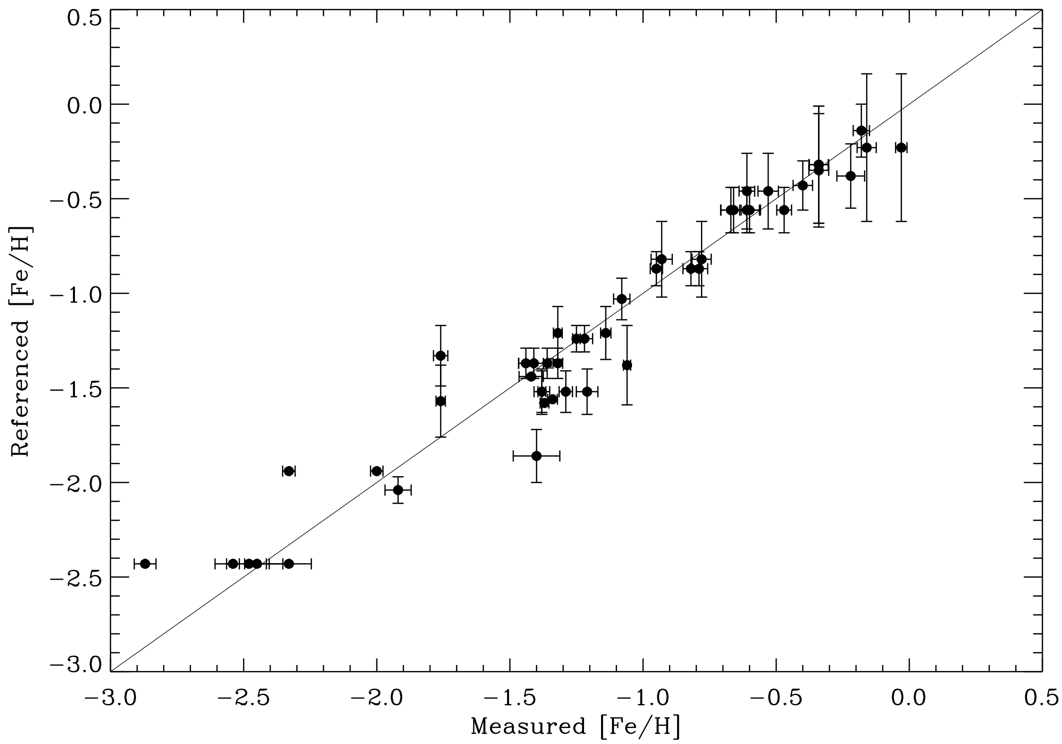

Figure 2.— The derived values of [Fe/H] compared to values from the literature, given in Table 1. We show measurements from multiple exposures of individual stars separately on this plot. For example, we have 5 X Ari measurements corresponding to the points at [Fe/H] = −2.5.

3. Metallicity Relation

Preston (1959) related [Fe/H] to ΔS, the difference between spectral types derived from the Ca II K line and the Balmer series. Clementini et al. (1991) derived a tighter correlation between [Fe/H] and the Ca II K equivalent width. The Ca II triplet will provide a comparable relationship due to the sharp profiles of these lines compared to H and K.

We have shown in Figure 1 several examples of the GAIA spectral window for RR Lyrae stars at different phases in their cycles. In the metal rich stars, the Paschen lines are clearly blended with their neighboring Ca II line. As expected, the Paschen series varies with temperature, but does not show any obvious distortion at phases in which Hα goes into emission.

To derive the Ca II-[Fe/H] relationship using the Ca II triplet, the line that can best be measured is the Ca II line at 8498 Å because it can be fitted with a Gaussian and is only minimally blended with the Paschen line at 8502 Å (see Fig 1). The small separation between the other members of the Ca II triplet and their neighboring Paschen lines makes measuring them more difficult, especially for metal rich stars.

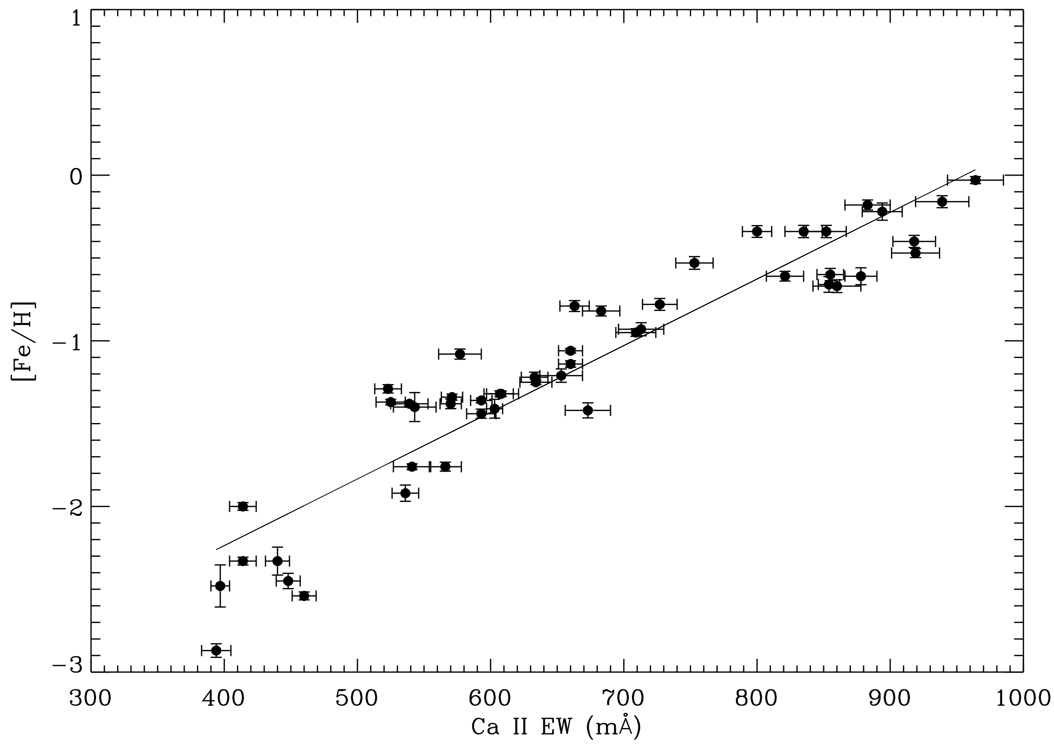

Figure 3.— The relationship between the equivalent width of the Ca II line at 8498Å and our derived [Fe/H]. The best least squares fit is described by equation 1. Here we again show individual measurements of [Fe/H] and of the Ca II EW separately.

Measurements are best made when the Paschen lines are at their weakest in order to determine the equivalent width with minimal errors. The final relationship between [Fe/H] and the equivalent width of the Ca II line at 8498 Å is shown in Figure 3.

In conclusion, we show that there is a relationship between [Fe/H] and the equivalent widths of the Ca II infrared triplet given by

$$[\mathrm{Fe/H}] \;=\; -3.846(\pm 0.155) + 0.004\ \mathrm{EW}, \tag{1}$$

where the equivalent width of the Ca II line at 8498 Å is given in mÅ. We note that this relationship has only been derived for RRab stars.

We are currently analyzing our data to evaluate how the line profiles of the Ca II triplet change throughout the cycle of variation of several stars. We are also examining abundance ratios for several elements and will present these findings elsewhere. Of particular importance is the ratio of Fe/Ca as derived from the neutral lines of each element.

We thank Ulisse Munari and Gisella Clementini for advice and assistance. This research was supported by the Kennilworth fund of the New York Community Trust.

We also thank the UW McNair program for their support of T. Gomez.

References

Clementini, G., Tosi, M., & Merighi, R. 1991, AJ, 101, 2168
Cole, A. A., Smecker-Hane, T. A., Tolstoy, E., Bosler, T. L., & Gallagher, J. S. 2004, MNRAS, 347, 367
Feast, M. W., Laney, C. D., Kinman, T. D., van Leeuwen, F., & Whitelock, P. A. 2008, MNRAS, 386, 2115
Layden, A. C. 1994, AJ, 108, 1016
Preston, G. W. 1959, ApJ, 130, 507