The Metallicity Gradient of the Old Galactic Bulge Population

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Abstract Understanding the structure, formation and evolution of the Galactic Bulge requires the proper determination of spatial metallicity gradients in both the radial and vertical directions. RR Lyrae pulsators, known to be excellent distance indicators, may hold the key to determining these gradients. Jurcsik & Kovacs (1996) has shown that RR Lyrae light curves and the phase difference of their Fourier decomposition, ϕ_{31}, can be used to estimate photometric metallicities. The existence of galactic bulge metallicity gradients is a currently debated topic that would help pinpoint the Galaxy's formation and evolution. A recent study of the OGLE-III Galactic Bulge RR Lyrae Population by Pietrukowicz et al. (2012) suggests that the spatial distribution is uniform. We investigate how small a gradient would be detectable within the current S/N levels of the present data set, given the random and systematic errors associated with the derivation of a photometric metallicity versus spatial position relationship.

1 Introduction

The eleventh part of the Optical Gravitational Lensing Experiment (OGLE-III) contains the most complete and up-to-date photometric data set of Galactic Bulge RR Lyrae pulsating stars currently available. The sample contains photometric light curves in the I and V bands for a total of 11,756 fundamental mode RR Lyrae (RRab) (Soszyński et al., 2011; Udalski et al., 2008). This extensive data set has proven useful in investigating the Galactic interstellar extinction, metallicity gradients, and 3-D spatial distributions (Pietrukowicz et al., 2012; Nataf et al., 2013;

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Smolec, 2005). The work presented here uses 10,456 RRab stars from the OGLE-III Galactic Bulge RR Lyrae catalog to investigate the detection limits of galactic bulge metallicity gradients.

2 Methodology

The present sample includes RRab stars with I magnitudes between $13+(V-I)$ and $16+(V-I)$, in order to exclude foreground and background stars. Background stars are likely to belong to the Sgr dSph Galaxy Soszyński et al. (2011); Pietrukowicz et al. (2012). From this sample, we create 1,000 population samples by assuming Gaussian distributions centered on the observed OGLE values and standard deviations equal to the respective errors for each star's Period, ϕ_{31}, I and V. For each of these population samples, the photometric metallicities are estimated using the P-ϕ_{31}-[Fe/H] relationship given in Smolec (2005):

$$[\mathrm{Fe/H}] = -3.142 - 4.903P + 0.824(\phi_{31} + \pi), \tag{1}$$

where a phase shift is necessary due to sine/cosine fitting differences in Smolec (2005) and Soszyński et al. (2011). The galactocentric distances for each sample are calculated following the methodology presented in (Pietrukowicz et al., 2012):

$$\log Z = [\mathrm{Fe/H}] - 1.765 \tag{2}$$

$$M_V = 2.288 + 0.882 \log Z + 0.108(\log Z)^2 \tag{3}$$

$$M_I = 0.471 - 1.132 \log P + 0.025 \log Z \tag{4}$$

$$R_I = A_I / E(V-I) \tag{5}$$

$$\log R = 1 + 0.2\,(I_0 - M_I) \tag{6}$$

$$R_{GCD} = \left[R_0^2 + R^2 - 2RR_0\cos(l)\right]^{0.5}. \tag{7}$$

We estimate the mean sample barycenter to be $R_0 = 8.48 \pm 0.01$ Kpc and a mean sample metallicity of -0.994 ± 0.327 for the OGLE-III Galactic Bulge RR Lyrae magnitude limited sample.

The effects that introducing a small synthetic gradient in the metallicity versus galactocentric distance plane would have on our observed variables are tested by introducing a Δ [Fe/H] to each stars metallicity based on its position. A backwards propagation of the Δ [Fe/H] perturbation is performed, under the assumptions that

- The distance to each star remains fixed,
- The ratio of total to selective extinction, R_I, remains unchanged,
- In cases of degeneracies, the induced perturbations are equally distributed between the fractional perturbations of all involved variables,

A synthetic data set is created for which new values of [Fe/H] and R_{GCD} and associated error distributions are calculated. In the case where Δ [Fe/H] values are introduced to create a synthetic gradient of -0.01 [dex/Kpc], our mean sample barycenter and mean sample metallicity become $R_0 = 8.47 \pm 0.01$ Kpc and [Fe/H]=-0.992 ± 0.329. Sampling through the defined [Fe/H] and R_{GCD} distributions of each star, 1,000 least-squares (LS) fits are performed. An F-test, to a confidence level of 0.05, is performed on each LS fit to determine the significance of derived trends. The mean fit coefficients and their standard deviations are obtained for both samples.

3 Preliminary Results

Re-deriving the OGLE-III Galactic Bulge RR Lyrae metallicities with the latest methodology, and fitting the R_{GCD} - [Fe/H] plane suggests that there exists a small but statistically significant galactic bulge metallicity gradient within the OGLE-III Galactic Bulge RR Lyrae database of strength -0.0239 ± 0.0006 [dex/Kpc]. In addition, using simulated data with an artificial trend of -0.01 [dex/Kpc] and realistic noise, a least squares fit results in an also statistically significant metallicity gradient of -0.012 ± 0.0006 [dex/Kpc]. In both cases the significance of the gradient is tested to a confidence level of 0.05. Therefore, we conclude that with the current methodology and data sample, a gradient as small as -0.01 [dex/Kpc] can be detected within the OGLE-III Galactic Bulge RR Lyrae.

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References

Jurcsik, J. & Kovacs, G. 1996, A&A , 312, 111
Nataf, D. M., Gould, A., Fouqué, P., et al. 2013, ApJ , 769, 88
Pietrukowicz, P., Udalski, A., Soszyński, I., et al. 2012, ApJ , 750, 169
Smolec, R. 2005, Acta Astron. , 55, 59
Soszyński, I., Dziembowski, W. A., Udalski, A., et al. 2011, Acta Astron. , 61, 1
Udalski, A., Szymanski, M. K., Soszynski, I., & Poleski, R. 2008, Acta Astron. , 58, 69