Structure of the Periphery of the Large Magellanic Cloud Further Revealed by 2MASS

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Abstract

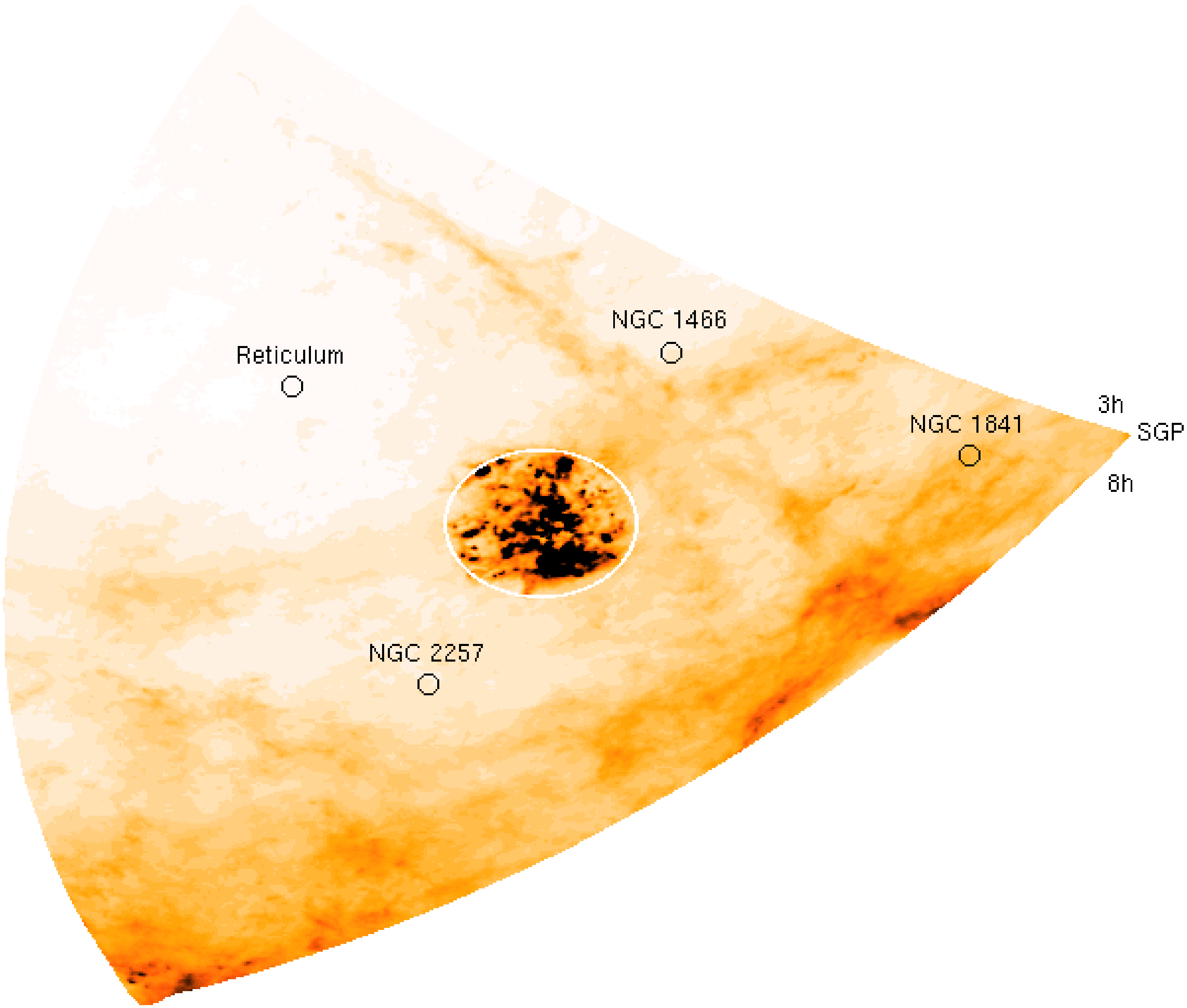
In order to better understand the nature of equilibrium structures like the flared outer disk and hot stellar halo of the Large Magellanic Cloud (LMC), I have reexamined the content of the 2MASS database on lines of sight toward the periphery of the LMC. I find evidence for a metallicity gradient as a function of projected radius based on the dereddened colors of the LMC's red giant branch (RGB) stars. I also find that the projected center of the number density contours depends systematically on the selected color (metallicity) of the RGB stars. Implications for microlensing are discussed.

Introduction

Results from LMC microlensing surveys are not easily explained by empirical models of LMC structure or Galactic stellar populations (Alcock et al. 2000). The new cosmological paradigm favors nonbaryonic cold dark matter, and has focused attention on white dwarfs in the Galactic stellar halo rather than the dark halo to explain these microlensing observations (Salim et al. 2004).

Some microlensing is caused by stars in the LMC itself (Alcock et al. 2001), but models to explain all of it by invoking nonequilibrium structures like tidal debris have been ruled out (Zhao et al. 2003). However, other discoveries of equilibrium structures, like the flaring outer disk (Alves & Nelson 2000) and the hot stellar halo traced by metal-weak RR Lyrae variable stars (Minniti et al. 2003; Alves 2004), have changed our expectations for self-lensing. The discoveries of these persistent structures have increased the rate and modified the properties of expected self-lensing events, although not by enough to account for all of the observations. Incremental refinements to our understanding of the LMC's equilibrium structure may ultimately challenge the attribution of LMC microlensing to white dwarfs in the Galactic stellar halo. In this spirit, I have reexamined the content of the 2MASS database on lines of sight toward the periphery of the LMC in search of new clues relating to the microlensing puzzle.

Wide field photometry surveys like 2MASS and DENIS have rapidly advanced our understanding of LMC structure in the past few years. Of particular interest here is the mapping of the ratio of C type (carbon rich) to M type (oxygen rich) asymptotic giant branch (AGB) stars in the LMC by Cioni & Habing (2003). Using the DENIS near-infrared photometry database, these authors showed that the C/M ratio increases with projected radius, which they interpret as a gradient of decreasing metallicity. However, Nikolaev & Weinberg (2000) examined the 2MASS near-infrared colors of first-ascent red giant branch (RGB) stars in a field near the LMC center and in a comparison field several degrees to the northeast and found no indication of a metallicity gradient. (A bluer RGB star is more metal-weak.) Neither study corrected for interstellar reddening, or for contamination of their datasets by Galactic foreground M dwarfs, or probed the very extreme periphery of the LMC. These results and the limitations of the analyses set the stage for the present work.

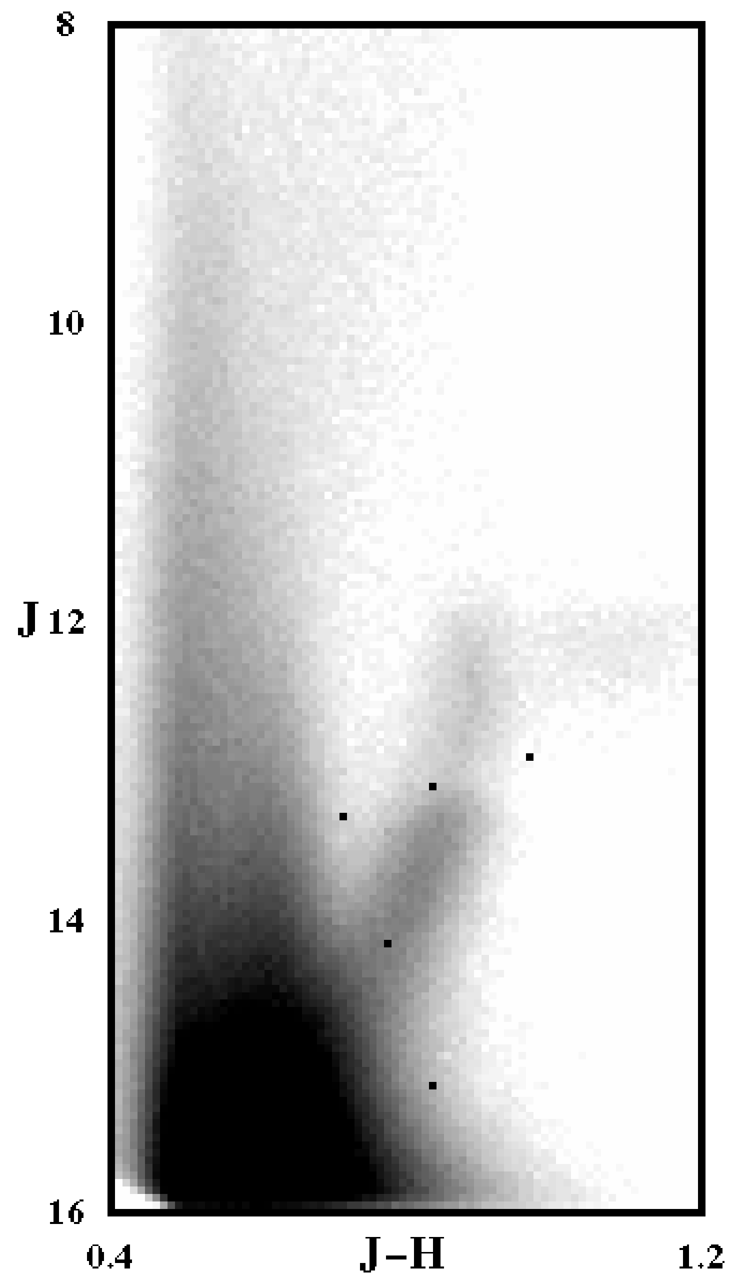


I. Reddening Map

Schlegel et al. (1998) polar projection reddening map derived from all-sky infrared survey data. This diagram shows RA from 3 to 8 hours and Dec $<$ -50. The pixel scale is approximately (2.37 arc min)^2. The units are E(B-V); dark areas indicate higher reddening. A saturated region in the center of the LMC is marked with an ellipse; it is excluded from all subsequent analyses. Four globular clusters in the LMC near its periphery are marked to indicate the full extent of the galaxy.

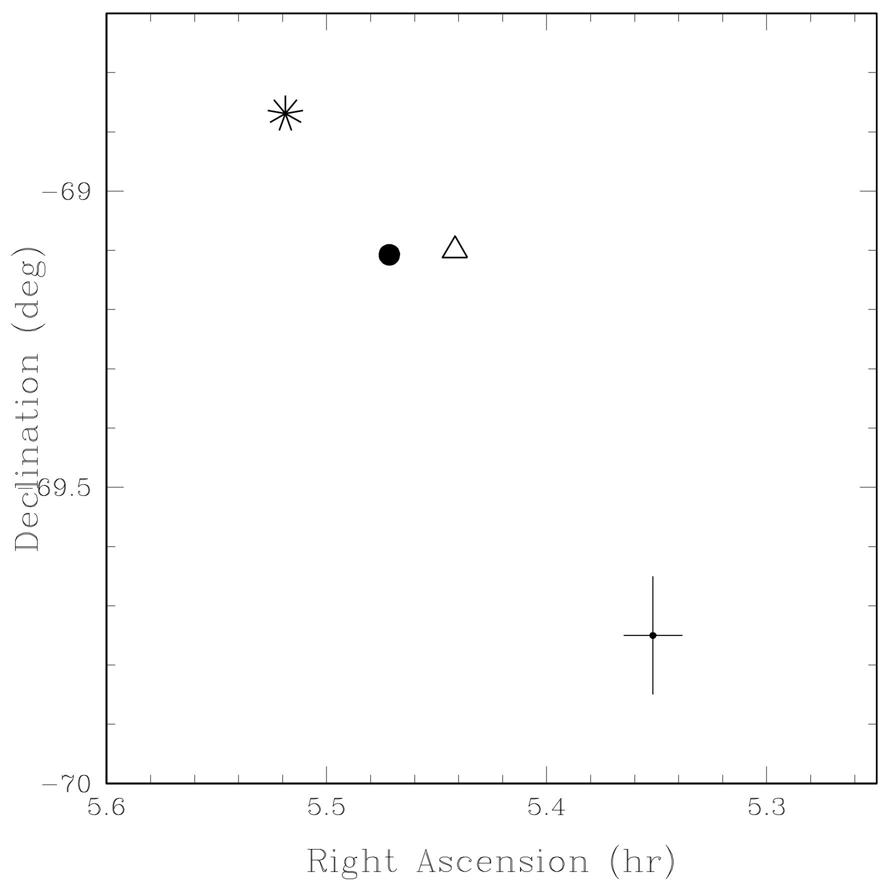
II. Hess Diagram

Approximately 1.9 million stars with (J-H) > 0.5, J < 16, 3 < RA < 8 hr, and Dec < -50 were extracted from the 2MASS online point-source database. Each star was assigned to its corresponding pixel in the Schlegel et al. (1998) reddening map. About 1.4 million stars lie outside of the excluded saturated zone. These dereddened (J-H), J data were binned into this Hess diagram, where darker regions correspond to higher densities of stars. Protruding to the right out of the foreground M dwarf sequence is the LMC's RGB. The 5 masked (dark) pixels outline a triangular region used to select 41613 RGB stars. Interloping foreground halo red giants, background quasars, and unresolved background galaxies are few in number and unimportant. The brightest 3 masked pixels are defined by the maximum absolute magnitude and corresponding color of RGB stars in the 2MASS photometry system (Ivanov & Borissova 2002), and an adopted distance of 50.1 kpc. The line connecting these points separates the AGB from the RGB. This range of color corresponds to a range of metallicity: from blue to red the 3 pixels indicate [Fe/H] = -1.7, -1.0, and -0.2 dex, respectively. The other (fainter) masked pixels define the adopted boundary between the M dwarfs and the RGB stars. The line connecting the two masked pixels that runs approximately through the middle of the RGB corresponds to [Fe/H] = -1.0 dex, and was used to distinguish between 8702 metal-weak RGB stars (in the sub-triangle in the blue corner), and 32911 metal-rich RGB stars (all of the rest).



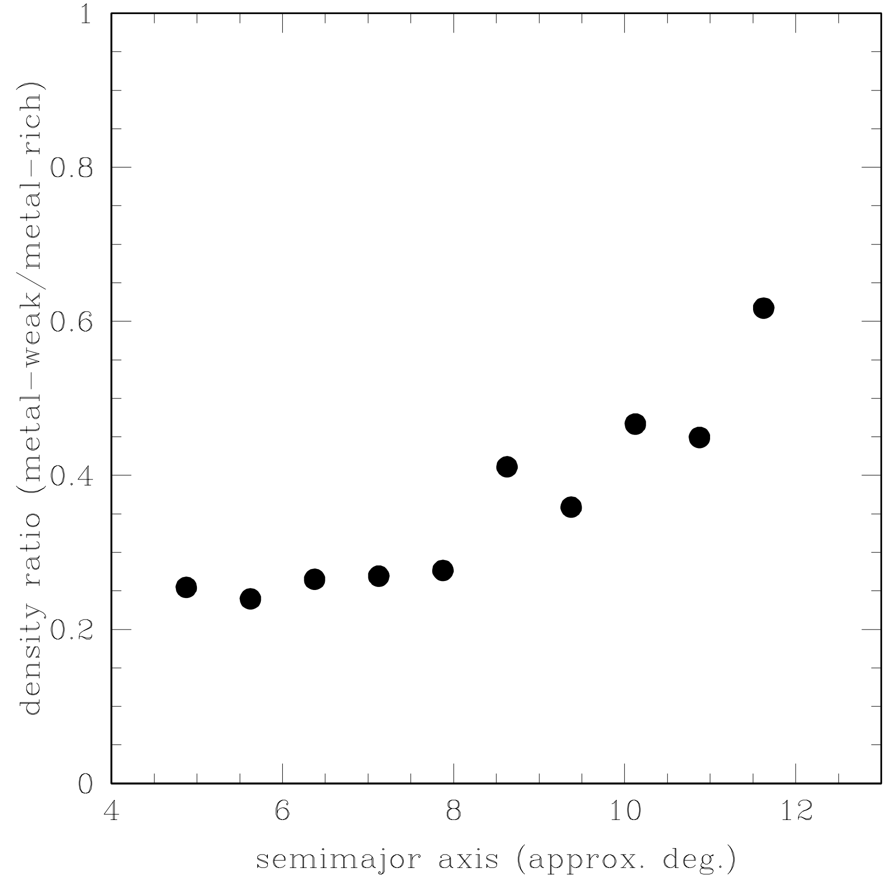
III. Star Count Maps

In an initial round of modeling the projected number density of metal-weak and metal-rich RGB stars, ellipse fitting yielded results similar to those of van der Marel (2001) for the ellipticity and position angle of the isodensity contours. Fixing these parameters, I then calculated the best-fit projected center for the metal-rich RGB shown here as a filled circle. The projected center of the metal-weak RGB is shown as an asterisk. For comparison, the position of the peak number density of RR Lyrae variable stars from Alves (2004) is plotted with error bars. This center is consistent with the peak-density center of all of the RGB and AGB stars in the 2MASS database as determined by van der Marel (2001). Last, the center of the outer-most contours of projected number density (AGB + RGB) from van der Marel (2001) is shown as a triangle. He explains that the drift from the peak-density center to the projected center of the outermost contours is due to a perspective effect on viewing an inclined disk. Since van der Marel's star counts are dominated by the metal-rich RGB in the 2MASS database, it is reassuring that my filled-circle and his triangle are approximately coincident. It is curious that the projected center of the metal-weak RGB lies farther from the peak-density center than that of the metal-rich RGB, and at the same position angle. However, I have no explanation for this result. Two conclusions follow. First, the metal-weak RGB stars are not distributed in a spherical halo otherwise their projected center and the RR Lyrae peak-density center would be coincident, which they are not. Second, this diagram provides a clue that the distributions of metal-weak and metal-rich RGB stars in the LMC are different.

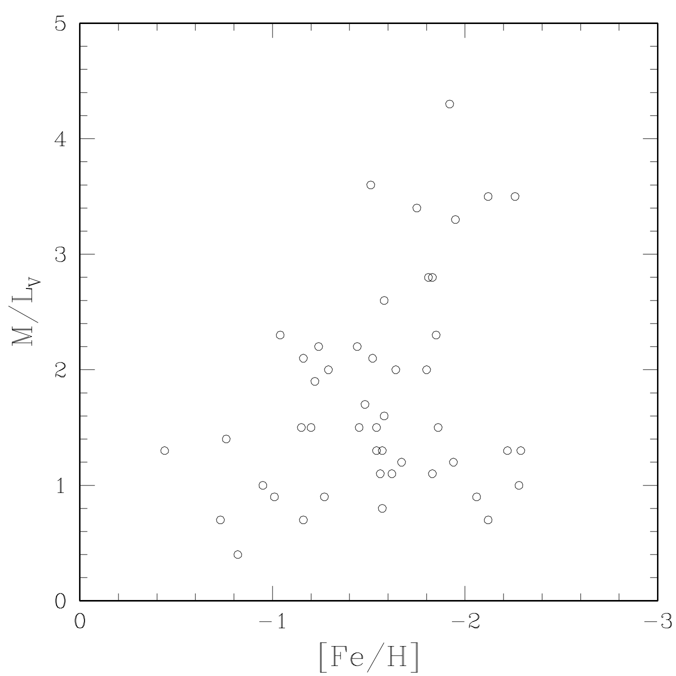


IV. Metallicity Gradient

Adopting the projected center of the metal-rich RGB, the diagram on the right shows the ratio in number-density of metal-weak to metal-rich RGB stars as a function of the semimajor axis of concentric elliptical annuli. The trend is to find more metal-weak RGB stars at larger projected radii. On average this is a trend of decreasing metallicity consistent with the result from Cioni & Habing (2003) based on the C/M ratio of AGB stars, but extending to greater projected radii.



If stars in Galactic globular clusters (GCs) are good analogs of those on the periphery of the LMC, then a gradient in metallicity may imply a gradient in the mass-to-light ratio in the sense that it increases with radius. The data for the GCs from www.physics.rutgers.edu/ andresj/gccat.html is plotted below.



V. Microlensing

Prior models of microlensing by the flared outer disk and stellar halo (Alves & Nelson 2000; Alves 2004) assumed a constant mass-to-light ratio. If the ratio increases with radius, then the rate of self-lensing has probably been underestimated. Additional modeling is now motivated.

References

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