Tracing the Ancestry of Galaxies (on the land of our ancestors)
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Local Group Galaxies in the Infrared

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Abstract. A survey has been conducted of Local Group galaxies with the Japanese/South African Infrared Survey Facility at SAAO, Sutherland. A number of Mira variables have been discovered in four dwarf spheroidals, which provides an opportunity to test the usefulness of these stars as distance indicators in galaxies beyond the Magellanic Clouds. These Miras are found to follow the same period-luminosity relation as in the LMC, provided bolometric magnitudes are used.

Keywords. galaxies: Local Group, distances stars: variables: Mira

1. Introduction

A survey of Local Group galaxies conducted with the IRSF at Sutherland has so far covered 4 dwarf spheroidals: Leo I, Fornax, Phoenix and Sculptor. The aim is to study the large amplitude red variables (Miras), which provide information on the intermediate-age population in a galaxy, and which are major contributors through mass loss to the enrichment of the interstellar medium. Such stars obey a period-luminosity relation in the LMC, and may act as independent distance indicators in the Local Group and in more distant galaxies.

The IRSF Japanese/South African 1.4m f/10 telescope at Sutherland is equipped with a simultaneous 3-channel JHK_S camera (SIRIUS). The field of view after un-dithering images is about 7.2 arcmin square with a scale of 0.45 arcsec/pixel. Typically, 10 dithered images are used to produce a final image. Limiting magnitudes are 19.2, 18.6 and 17.3 at J, H, K_S, respectively, for a total exposure time of 900 sec and S/N = 10.

2. Data

Leo I was found to have seven Mira variables and five semiregular variables amongst 26 asymptotic branch stars in a field of 19.7×19.2 arcmin squared centred on the galaxy (Menzies *et al.* 2010). The Miras show a large range of periods, $158 < P < 523$ days, suggesting a significant range of ages. One of the Miras is recovering from a dust ejection event, while several others show clear signs of circumstellar shells. Applying the Mira period-luminosity relation to these stars yields a distance modulus of 21.80 ± 0.12 mag. This agrees well with distances from RR Lyrae stars and from the tip of the red giant branch.

The Fornax dwarf galaxy is one of the most populous dwarf spheroidal companions to our Galaxy, with star formation over most of its lifetime. Its extended asymptotic giant branch has numerous carbon stars. In our survey of a 42 arcmin square field centred on the galaxy (Whitelock *et al.* 2009), we have found seven Mira variables, of which five are known carbon stars, and 10 periodic semiregular variables. The Mira pulsation periods range from 215 to 470 days, and three of these stars are very red, indicating very heavy mass loss. These stars give a distance modulus of 20.69 ± 0.08 mag, in good agreement with determinations from the tip of the red giant branch, from the red clump, from δ Sct stars, and from various methods involving the horizontal branch.

The Phoenix dwarf galaxy is the most distant of the Milky Way's satellite galaxies, which makes it a difficult object for us to study. Nevertheless, in a 7.2 arcmin square field centred on the galaxy we have discovered a single Mira variable with a period of 425 days (Menzies *et al.* 2008). The distance modulus for this star is 23.10 ± 0.18, which is consistent with other estimates.

In a study of Sculptor currently in progress we have found two Mira variables, both of which are carbon stars. This was unexpected since Sculptor is well know to have a predominantly old, metal-poor population. Fitting the LMC period-luminosity relation to these two stars leads to a distance modulus of 19.38, in reasonable agreement with moduli determined from RR Lyrae stars and from the tip of the red giant branch.

3. Period-Luminosity relations

Armed with mean K_S magnitudes and periods together with the distance moduli above, we can plot these parameters and compare the result with the LMC period-luminosity relation for carbon-rich Miras as in Fig. 1(a). The LMC relation, $M_K = -3.51(logP - 2.38) - 7.24$ of Whitelock *et al.* (2008), defines an upper envelope for the points. Presumably points falling well below the line do so because of circumstellar absorption. The energy absorbed by the dust shell will be re-radiated at longer wavelengths. To account for this extra flux, we can correct the mean K_S magnitudes by applying a bolometric correction. We adopt the procedure and result of Whitelock *et al.* (2006) and plot M_{bol} against log P in Fig. 1(b), with the LMC relation (assuming a distance modulus of 18.39 for the LMC), $M_{bol} = -4.271 - 3.31(logP - 2.5)$ from Whitelock *et al.* (2009).

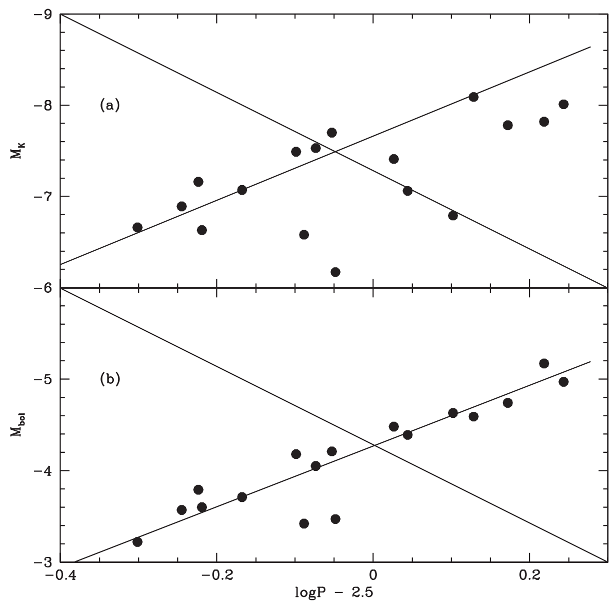

Figure 1. (a)M_K vs *logP* for the Miras showing a large scatter below the LMC relation due to circumstellar absorption. (b) M_{bol} vs *logP* for the Miras showing good agreement with the LMC relation, except for two stars where presumably the dust shell only partially obscures the star.

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The intrinsic scatter about the LMC relation is 0.12 mag. The slope of the relation fits the Local Group galaxy Miras extremely well. The two stars falling below the line are presumed to be undergoing dust obscuration events in which the dust cloud only partly obscures the star. The good agreement suggests that, provided there are several Miras in a particular galaxy, the LMC bolometric period-luminosity relation can be used with confidence to derive an independent measure of the distance modulus. This point is reinforced when we note that a Cepheid with a period of 50 days has about the same absolute K_S magnitude, $M_{K_S} = -7.9$, as a 380-day carbon-rich Mira variable. Miras should serve as well as Cepheids in distance determination for remote galaxies.

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