

Abstract

The NGC 3109 association is a nearly-linear group of dwarf galaxies located at the edge of the Local Group ($d \sim 1.4$ Mpc). The origin of this group is unclear: is it an infalling dark matter filament, a set of 'backsplash' galaxies which have passed through the Milky Way, or a group of tidal dwarfs formed in a past Milky Way/M31 encounter? Distinguishing among these possibilities requires a complete accounting of the galaxy members of the association followed by characterization of their star formation histories and kinematics. CFHT/MegaCam provides the ideal capabilities to begin a detailed search for additional galaxies. The results of such a search will test a recent prediction from simulations that the Local Volume should have at least a dozen more dwarf galaxies than are currently observed. The proposed MegaCam imaging will also serve an additional purpose: it can also be used to search for the tidal break and other low-surface-brightness features around the foreground (240 kpc) dwarf galaxy Leo I.

Science Justification

The large scale structure of our local universe is dominated by voids and filamentary structures of groups and clusters of galaxies (e.g., Courtois et al. 2013). Half of the Local Volume galaxies reside in loose groups and associations, such as the Sculptor filament and the Canes Venatici Cloud (Karachentsev 2005). The nearest such structure is the NGC 3109 association (see Figure 1), an association of 5 dwarf galaxies in Leo, Sextans, and Antlia (van den Bergh 1999; Tully et al. 2006). This galaxy association, with a linear extent of 1.2 Mpc across the sky (Bellazzini et al. 2013), lies just at the edge of the Local Group at a distance of 1.3–1.7 Mpc. Pawlowski & McGaugh (2014) identified several possibilities for the origin of the NGC 3109 association: an infalling dark matter filament, a pre-existing group tidally stretched by an encounter with the MW, or galaxies formed as tidal dwarfs from a past Milky Way/M31 encounter. Constraining the number and properties of additional group members can help to discriminate between these possibilities. The search for additional group members also has implications for predictions from Local Volume simulations that at least a dozen more dwarf galaxies outside the virial radii of M31 and the Milky Way remain to be discovered (Garrison-Kimmel et al. 2014).

Recent discoveries of the newest member of the NGC 3109 association, Leo P (Giovanelli et al. 2013), and tidal substructure near the Antlia dwarf suggestive of an interaction with NGC 3109 (Penny et al. 2012) mean that the time is right for a search for additional members of the association. While the region is covered by existing and planned survey data, none are deep enough to detect faint galaxies and structures at this distance. The most well-known recent examples of nearby dwarf galaxy discovery are from the SDSS (e.g., Koposov et al. 2008). Despite lying within the SDSS footprint, Leo P was discovered as part of a blind H I survey; it is too faint to be well-detected at the SDSS depth ($g = 22.2$, $i = 21.3$), and using LBT imaging, McQuinn et al. (2013) measured the tip of its red giant branch to be at $i = 22.1$. A wide-field optical survey has the potential to detect additional faint members of the group as well as tidal debris from interactions between members.

The outcome of a search for additional members of the NGC 3109 association has implications for understanding galaxy evolution. A lack of additional tidal debris would constrain the timescales and progenitor galaxy masses involved in a tidal dwarf origin. A lack of additional bound-galaxy members of the group would constrain the mass of a possible dark-matter filament or progenitor halo. On the other hand, finding additional members of the group and subsequent follow-up would allow a better characterization of the group’s spatial and kinematical extent; current studies suffer from small-number statistics. If additional group members lie close to the same plane as the existing members, this would tend to confirm Pawlowski & McGaugh’s (2014) claim that the non-satellite galaxies to the north of the Milky Way are confined to a single plane. Identification of new members as potential ‘backsplash galaxies’ (Teyssier et al. 2012) or not could also test Pawlowski & McGaugh’s claim that there is an ‘overabundant backsplash galaxy’ problem with Λ CDM. Additional group members would also allow better constraints on the group’s luminosity function and subsequent comparison to CDM simulations of galaxy formation in low-density environments (as in Garrison-Kimmel et al. 2014). Using a Local Group formation simulation, Benítez-Llambay et al. (2013) suggested that gas removal through stripping by the ‘cosmic web’ of filaments and pancakes could explain the diversity of properties of local dwarf galaxies; identification of additional galaxies possibly associated with a filament could provide additional tests of this idea. Finally, the tidal-dwarf characterization of the group can be tested with follow-up spectroscopy in order to determine whether additional group members are dark-matter dominated.

We propose here to map the northern portion of the NGC 3109 filament with CFHT/MegaCam. Deeper imaging than the available SDSS data ($g = 22.2$, $i = 21.3$) is required in order to detect

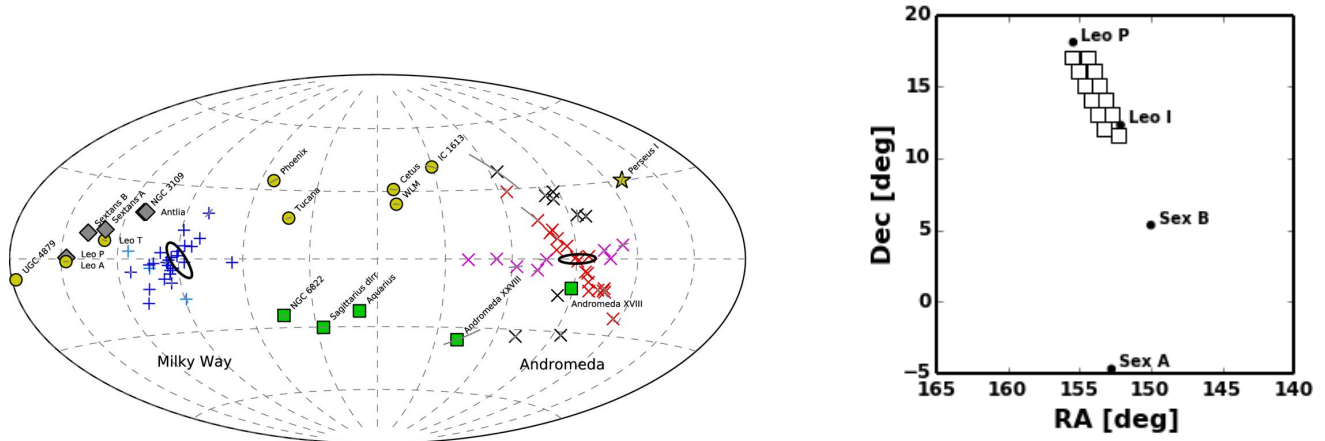


Figure 1: (Left) From Pawlowski & McGaugh (2014): Local Group galaxies on the sky as seen from a position half-way between M31 and the Milky Way. The NGC 3109 association members are shown as grey diamonds. (Right) Sky projection of the proposed observations. The boxes are 1-degree MegaCam fields; the black circles at the galaxy locations have 15-arcminute radii.

dwarf galaxies at distances beyond 1 Mpc. CFHT/MegaCam’s ability to go both wide and deep is essential for such observations: the nearby nature of the filament means that it covers a large area of sky, yet the expected faint dwarf galaxies are resolved into individual stars. The area to be mapped, defined by the direction from Leo P to Sextans A/B, happens to pass quite close to the more nearby (240 kpc) Local Group dSph Leo I. Peñarrubia et al. (2009) predicted the location of a tidal break in this galaxy’s surface brightness profile which is beyond the radius currently mapped (Sohn et al. 2007); the MegaCam imaging can be used to probe the outer reaches of Leo I and test this prediction, as well as searching for additional nearby low-surface-brightness features.

The goal of this proposal is to complete the substructure census and probe the faint end of the luminosity function in a portion of the nearest filamentary structure in the universe. Detected structures will be characterized in terms of structural properties and their association to the sub-group will be pursued via tip-of-the-red-giant-branch (TRGB; Lee et al. 1993) measurements and, where possible, spectroscopic measurements (e.g. with Gemini/GMOS). Multi-wavelength follow-up can be pursued with the ALFALFA HI survey and other wide-area surveys. The key first step is identifying additional NGC 3109 group galaxies, for which MegaCam is ideally suited.

References

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Technical Justification

As defined by Bellazzini et al. (2013), the NGC 3109 filament is distributed along a line extending from Leo P in the north ($\delta = +18^\circ$, $b = +54^\circ$) to Antlia in the south ($\delta = -27^\circ$, $b = +22^\circ$); Sextans B is about 3° to the west of this line (see Figure 1). While galaxies belonging to the NGC 3109 association might not lie along the filament defined by the 5 known members, the structure provides the most obvious ‘lamp post’ under which to search for new members. The southern part of the filament will be observed with LSST (coverage to $\delta < +10^\circ$ to the necessary depth), but the northern portion is out of LSST’s reach. The SDSS coverage of the northern portion of the filament is of insufficient depth for our purposes. We have defined a series of Megacam pointings covering a $2^\circ \times 6^\circ$ region south of Leo P in the direction towards Sextans A and B; (Figure 1, right panel). This area subtends 44×136 kpc at the distance of the NGC 3109 association; for comparison, the tidal truncation radius of Sextans A is about 3 kpc (Bellazzini et al. 2014). As the Figure shows, our defined fields are also quite close to Leo I and will be used to probe the outer regions of this galaxy. The position of the MegaCam field nearest Leo I has been adjusted slightly to avoid the bright star Regulus.

MegaCam imaging in two filters is important for separating the giant branches of additional NGC 3109 members from both foreground Galactic stars and background unresolved galaxies. Bellazzini et al. (2013, 2014) successfully demonstrated the ability to effectively remove contamination using colour information in an LBT study of Sextans A and B in g and r . Of the MegaCam filters, the r band is best-matched to the SED peak of red giants in an old stellar population. The imaging depth is set by the requirement to detect enough stars for a significant measurement of overdensity. With data reaching 3 magnitudes below the TRGB, McQuinn et al. (2013) found Leo P to have a *central* surface brightness of $\mu_V = 24.5$ mag arcsec² and only a few hundred RGB stars. We aim to reach a depth of two magnitudes below the TRGB ($M_r = -3.1$, or $r = 23$ at 1.7 Mpc), meaning $r = 25$; this is shallower than the Bellazzini et al. data, but their fainter objects were dominated by background galaxies. The $g - r$ colour found by Bellazzini et al. at $r = 25$ was $g - r \approx 1.0$ so the required g -band depth is $g = 26$.

We will search for new, faint members of the NGC 3109 association using the standard methods in the field: searching for spatial overdensities of resolved stars within magnitude and colour ranges expected for the stellar populations. The resolved stellar population studies of known NGC 3109 group members (Bellazzini et al. 2014, McQuinn et al. 2013) provide excellent templates for this work. Foreground and background (stellar and galaxy) populations are also well-characterized in these studies and others, so filtering out only the populations of interest is feasible. Finding and accounting for distant members of Leo I will be important in the southern-most fields; these should be significantly brighter than those belonging to NGC 3109 group members since Leo I is about 4 times closer. Combining the Leo I star counts with published surface brightness data will allow a search for the predicted tidal break.

To estimate exposure times, we assume less-than-ideal conditions (dark time, 1 arcsec seeing, airmass 1.2, 90% transparency) since our proposed observations overlap in RA with Large Programs MATLAS and LUAU and we have not tightly constrained the observing conditions. Assuming overheads for 4 dithered exposures per filter, reaching $r = 25$ and $g = 26$ at $S/N = 5$ requires 1.5 hours per field, 0.5 in r and 1.0 in g . This is consistent with the successful MegaCam detection of more than a dozen dwarf galaxies in the M81 group by Chiboucas et al. (2009), who had somewhat better conditions than assumed here and reached $r = 25$ in approximately 1200 s exposures. We therefore request a total of 18 hours of exposure time.