Dynamical Masses of Local Group Galaxies
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Census of Northern Local Group Dwarf Galaxies using UNIONS

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Abstract.
In this work we present preliminary results from a systematic search for new Local Group dwarf galaxies in the deep, wide-field Ultraviolet Near-Infrared Optical Northern Survey (UNIONS). The first major result from this work is the discovery of a candidate ultra faint dwarf galaxy, Boötes V. This satellite of the Milky Way has a physical half-light radius of $26.9^{+7.5}_{-5.4}$ pc, an absolute V-band magnitude of -4.5 ± 0.4 mag, and resides at a heliocentric distance of approximately 100 kpc. We also announce the discovery of a faint, compact star cluster, UNIONS 1. The end goal of this work will be to put firm constraints on the detectability and completeness of Local Group dwarf galaxies given the broad sky coverage and excellent photometric depth of UNIONS.

Keywords. galaxies: dwarf, Local Group, galaxies: stellar content, techniques: photometric

1. Introduction

The known dwarf galaxy population of the Local Group has grown rapidly since the inception of wide-field photometric surveys using digital telescopes (e.g. Sloan Digital Sky Survey, Pan-Andromeda Archaeological Survey, Dark Energy Survey: York *et al.* 2000; McConnachie *et al.* 2009; Abbott *et al.* 2018). The faintest of these systems have been called "ultra-faint dwarf galaxies" (UFDs; e.g. see review by Simon *et al.* 2019), defined as galaxies with total $M_V > -7.7$ mag. They are the smallest, least massive, and most metal-poor galaxies yet observed and their very existence tests current theories of galaxy formation. In particular, UFDs probe the physics of stellar feedback and gas retention, and they trace the Local Group dark matter distribution at parsec length-scales (Bullock *et al.* 2017).

The work we present here is a search for new Local Group dwarf galaxies in the deep, wide-field photometric Ultraviolet Near-Infrared Optical Northern Survey (UNIONS), a consortium of northern imaging surveys all based in Hawaii. The 5000 deg^2 *ugriz* survey consists of the Canada-France Imaging Survey (CFIS) collaboration that uses the Canada-France-Hawaii Telescope (CFHT), team members from the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS), and the Wide Imaging with Subaru Hyper Suprime-Cam (HSC) of the Euclid Sky (WISHES). We have conducted this work on the current data releaseof UNIONS, specifically with the r- and i-bands being provided by CFIS and Pan-STARRS respectively, jointly covering 3600 $\deg^2$ at median 5σ point source depths of 24.7 and 24 mag in r and i.

We have performed a systematic search for dwarf galaxies using a matched-filter methodology that scans the UNIONS footprint for stellar overdensities consistent with an old (12 Gyr), metal-poor ([Fe/H] $= -2$ dex) stellar population. The matched-filter methodology has proven to be effective (e.g. Belokurov *et al.* 2007; Bechtol *et al.* 2015) and the full details of our search algorithm can be found in Smith *et al.* (2022).

2. Discoveries in UNIONS

Our full sky search has recovered all known dwarf galaxies that had been previously discovered using matched-filter techniques in shallower surveys within 1.9 Mpc of the Milky Way, along with many globular clusters and nearby galaxies in the Local Universe. Therefore, we have turned to our list of detected stellar overdensities with no prior association and discovered two prominent stellar overdensities, an ultra-faint dwarf galaxy candidate, and a faint star cluster.

Boötes V (Smith *et al.* 2022) was discovered in the combined CFIS-r and Pan-STARRS-i dataset as a resolved overdensity of stars with the characteristics of a faint Milky Way satellite dwarf galaxy. We derive structural properties for this system, finding it to have an angular half-light radius of $0.93^{+0.26}_{-0.19}{}'$ and an ellipticity of $0.35^{+0.17}_{-0.21}$. Using several Blue Horizontal Branch stars, we constrain the distance to the dwarf galaxy to be 100 ± 20 kpc and calculate an absolute V-band magnitude of -4.5 ± 0.4 mag. In turn, we derive a physical half-light radius of $26.9^{+7.5}_{-5.4}$ pc and an effective surface brightness of 25.7 ± 0.7 mag arcsec^{-2}. We further refine the parameters of the stellar population by eye, finding that a 13 Gyr, [Fe/H]$= -2.2$ dex isochrone, the most metal-poor isochrone available in our set, is a good fit to the resolved stars on a Colour-Magnitude Diagram (CMD).

Following McConnachie & Venn (2020), we identify several stars in the Third Data Release from *Gaia* as likely members of Boötes V based on their spatial coherence, position on a CMD, and proper motion. From these members we derive the systemic proper motion of the dwarf to be $(\mu_\alpha \cos\delta, \mu_\delta) = (-0.23 \pm 0.04$ (stat) $\pm$ 0.033 (sys), -0.28 ± 0.07 (stat) $\pm$ 0.033 (sys)) mas year^{-1}. Additionally, we obtained follow-up spectroscopy of the brightest member star, a Red Giant Branch star near the tip of the RGB, using the Gemini Multi-Object Spectrograph at Gemini North. From our long-slit spectroscopic observations centered on the Calcium II infrared triplet absorption feature, we measure the radial velocity of the star to be $+5.1 \pm 13.4$ km s^{-1} and the metallicity to be [Fe/H] $= -2.85 \pm 0.10$ dex. See Fig. 1 for the spatial position and CMD of Boötes V in UNIONS with *Gaia*-identified member stars overplotted.

We determine that Boötes V is likely a dwarf galaxy given its large scale radius and large heliocentric distance compared to known globular clusters. Additionally, while we have only measured a single star, the very metal-poor nature of this star is a good indication that the system as a whole is metal-poor. This provides a good starting point for future, focused spectroscopic studies of Boötes V, which will ultimately be necessary to definitively classify this distant, resolved stellar system. We note that this dwarf galaxy candidate was independently co-discovered by Cerny *et al.* (2022).

We have also identified a very compact group of co-moving stars with a physical half-light radius of $\sim$4 pc which we name UNIONS 1, under the assumption that it is a star cluster, not a dwarf galaxy. However, this system will be presented and it's classification will be further assessed in an upcoming study. We note that these two stellar systems are the only two stellar overdensities whose reality could be confirmed with a combination

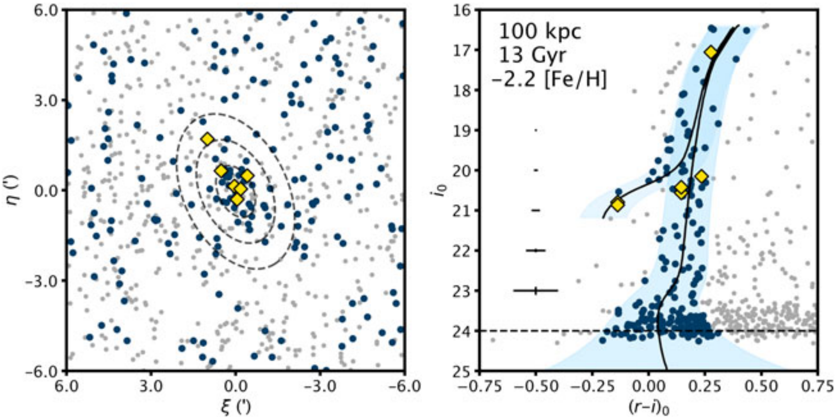

Figure 1. *Left*: Sky positions of all stars in a $12' \times 12'$ region about Boötes V, projected onto the tangent plane centered at RA, Dec = (14h 15m 38.6s, +32° 54′ 42′′). Dark blue (dark grey) sources are those that meet the isochrone selection criterion (Right). Yellow (light grey) diamonds are stars identified in *Gaia* DR3 as sources with complete astrometric information, and are selected as high confidence members. The concentric black ellipses indicate 1×, 3×, and 5× the half-light radius. *Right*: Colour-magnitude diagram of extinction-corrected CFIS-r and Pan-STARRS-i for all stellar sources in a $12' \times 12'$ region about Boötes V. We overlay an old (13 Gyr), metal-poor ([Fe/H] = −2.2) isochrone, shifted to a distance of 100 kpc. We use a broad color selection criterion, selecting all stars with $(r-i)_0 \leq 0.1$ from the isochrone and we add, in quadrature, the empirical photometric errors from each band. Stars consistent with this selection criterion are highlighted in dark blue (dark grey). Photometric uncertainties are shown for integer magnitudes in black. Again, yellow (light grey) diamonds are high confidence members observed by *Gaia*. If printed in greyscale, refer to shades denoted in brackets.

of UNIONS and *Gaia* data, but there are a plethora of other candidates that we are investigating further with follow-up observations.

3. Outlook on Local Group Census

There are exciting prospects for the future of this work, namely the completion of UNIONS and synergy with the *Euclid* space telescope. UNIONS is not yet at full depth nor coverage. With final 5σ point source depths of 24.3, 25.2, 24.9, 24.3, 24.1 across *ugriz* bands, UNIONS is an ideal dataset for probing resolved stellar populations with multi-band photometry out to 1 Mpc within the Local Group. Additionally, UNIONS was in part conceptualized to support the *Euclid* space mission. This work will be able to take advantage of the space-based seeing capabilities of *Euclid* to improve upon our current star-galaxy separation, allowing us to distinguish faint stellar populations from background contamination.

Each newly discovered dwarf galaxy provides a unique opportunity to study physical processes and predictions such as star formation, the effects of feedback, tidal perturbations, and dark matter structure on the smallest known scales, but a concerted effort to build up the dwarf galaxy population of the Local Group works towards a bigger goal. A statistically significant sample of dwarf galaxies allows for the study of broad trends and properties of the Local Group, down to the lowest observed limits of the galaxy luminosity function.

Some studies have performed a census of dwarf galaxies around the Milky Way (e.g. Koposov *et al.* 2008; Drlica-Wagner *et al.* 2020) and around M31 (Doliva-Dolinsky *et al.* 2022, 2023). The end goal of this work will be to constrain the detectability and completeness of satellite and isolated dwarf galaxies out to 1 Mpc within the Local Group, predicting the number of discoveries that may lie in wait beyond the edge of current observational limits. This Local Group census will also allow for meaningful comparisons between the observed population of dwarf galaxies and predictions from both cosmological and zoom-in hydrodynamical simulations.

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