How low can we go?
Ursa Major III/UNIONS 1, the faintest known satellite of the Milky Way

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Dwarf Galaxies, Star Clusters, & Streams in LSST Era

In collaboration with: Will Cerny, Marla Geha, Ting Li, Raphael Errani, as well as Alan McConnachie, Jaclyn Jensen, Christian Hayes, Julio Navarro, Stephen Gwyn, and the UNIONS Team
Dwarf Galaxy Discovery
A Brief History

Ultra-Faint Dwarf Review; Simon (2019)

Digital Surveys:
SDSS, PAndAS, Pan-STARRS, DES, DELVE, the DESI Legacy Imaging Survey, HSC-SSP, KiDS, and now UNIONS have each contributed to this growing catalogue of faint systems.

13 new LG dwarf galaxies discovered since I started grad school 3 years ago:
Martínez-Delgado+ (2022), Collins+ (2022), Cerny+ (2022, 2023), Sand+ (2022), Smith+ (2023, 2024), McQuinn+ (2023, 2024), Homma+ (2024), Gatto+ (2024)
Dwarf Galaxies vs. Globular Clusters

A question of dynamics

‣ Globular clusters (Harris 2010)
  ‣ Dyn. M/L ratios ~ 1 – 4
  ‣ Dominated by matter

‣ Dwarf galaxies (McConnachie 2012)
  ‣ Dyn. M/L ratios > ~100s — 1000s
  ‣ Not explainable by baryons alone
    ‣ Dominated by dark matter?
  ‣ Well resolved velocity dispersions are the key observable, additional evidence from metallicity spreads (Willman & Strader 2012)
Dwarf Galaxies vs. Globular Clusters
A question of dynamics

- Faint ambiguous satellites (compiled)
  - ~30 systems lacking strong dynamical evidence either way
  - For most, no deep imaging or spectroscopy
  - Typically assumed to be a star cluster unless demonstrated to be a dwarf
  - Presumably, each will prove to be either a star cluster or a galaxy
  - Incredibly hard to confirm...

![Graph showing dwarf galaxies and globular clusters compared to faint ambiguous satellites.](image-url)
UNIONS
The deepest photometric survey of its scale

UNIONS The Ultraviolet Near Infrared Optical Northern Survey

- A collaboration of four wide field imaging surveys using telescopes based in Hawai‘i
  - **CFIS**: Canada-France Imaging Survey (u = 24.5, r = 24.85) [all 5-sigma point source depths]
  - **Pan-STARRS**: Panoramic Survey Telescope And Rapid Response System (i = 24.3, z= 24.1)
  - **WISHES**: Wide Imaging with Subaru HSC of the Euclid Sky (z = 24.1)
  - **WHIGS**: The Waterloo-Hawaii-IfA G-band Survey (g = 25.2)
- Mapping ~4800 square degrees of the extragalactic sky (dec>30)
- Supporting Euclid (photometric redshifts) in the North
- Will benefit from Euclid star/galaxy separation
- Roughly the depth of LSST DR1!
Stand-alone science (outside of Euclid) resulting from outstanding seeing (IQ ~ 0.7” in r) and depth

- Major contributions in Galaxy Evolution, Weak Lensing, Data Analysis/Techniques, etc.
- And... Galactic Archaeology

Testbed for the discovery space of LSST?
- How small a galaxy/satellite can there be?
- What will we learn from extreme systems?
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The faintest known Milky Way satellite

**Ursa Major III/UNIONS 1:**
The faintest known Milky Way satellite

**Half-light radius (r_h) = 3 ± 1 pc, Distance = 10 ± 1 kpc**

**Shown:** 2, 4, 6 x r_h

**Within 4 x r_h**

**Offset field**
An incredibly sparse stellar population...

Gaia proper motions, Keck/DEIMOS velocities
→
stars are co-moving
(McConnachie & Venn 20a,b; Jensen+ 24)
Total stellar mass is estimated from:

- Best-fit isochrone (12 Gyr, [Fe/H] = -2.2)
- Assumed IMF (Kroupa)
- Measured distance (10 ± 1 kpc)
- N stars at $i < 23.5$ mag (21 ± 5.5)

\[ M_\star \sim 16 \, M_\odot \]
\[ M/L \sim 1.4 \, M_\odot/L_\odot \]
\[ M_V \sim +2.2 \, \text{mag} \]

Expected velocity dispersion: 50 m/s!
Intrinsic line-of-sight velocity dispersion measurement
Ursa Major III/UNIONS 1: The faintest known Milky Way satellite

Intrinsic line-of-sight velocity dispersion measurement

- All Candidate Member Stars
  - $\langle v_0 \rangle = 88.6^{+1.1}_{-1.0} \text{ km s}^{-1}$
  - $\sigma_v = 3.7^{+1.4}_{-1.0} \text{ km s}^{-1}$
Ursa Major III/UNIONS 1: The faintest known Milky Way satellite

Intrinsic line-of-sight velocity dispersion measurement

\[ \langle v_0 \rangle = 88.6^{+1.1}_{-0.9} \text{ km s}^{-1} \]

\[ \sigma_v = 3.7^{+0.8}_{-0.6} \text{ km s}^{-1} \]

All Candidate Member Stars

\[ \langle v_0 \rangle = 89.7^{+0.9}_{-0.7} \text{ km s}^{-1} \]

\[ \sigma_v = 1.9^{+1.1}_{-0.5} \text{ km s}^{-1} \]

Excluding Star #2
Intrinsic line-of-sight velocity dispersion measurement

Complicating factors: binary stars, dynamical equilibrium, rv uncertainties

Extremely sensitive, cannot confidently resolve dispersion: Faint Ambiguous Satellite
Ursa Major III/UNIONS 1:
The faintest known Milky Way satellite
Takeaways

- Ursa Major III/UNIONS 1 is incredibly small ($M_V \sim +2.2, 3$ pc) and it is real!
- Current medium-res spectroscopy cannot definitively classify this object; its dark matter content remains unknown
- Each ambiguous system deserves spectroscopic follow-up to get a handle on this regime
- The depth and breadth of UNIONS is letting us do LSST DR1 science now!
Thanks for your time!