Confirmation of Stellar Halos Built By Accretion at the Dwarf Galaxy Scale: The Case of NGC 300

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Do dwarf galaxies have stellar halos?

In the standard ΛCDM framework, structure grows hierarchically. These interactions influence galactic evolution by thickening the host galaxy's disk, potentially enhancing star formation, and contributing to the formation of a stellar halo composed of accreted stars and visible substructures such as stellar streams and plumes and shells. Studies of the Milky Way's stellar halo, despite it constituting only about 1% of the galaxy's total stellar mass, have significantly advanced our understanding of galactic evolution, providing insights into the galaxy's history and the properties of its dark matter halo.

While the formation of stellar halos in massive galaxies is well understood, the processes in lower-mass galaxies remain largely unexplored. Dwarf galaxies are much more subject to both internal and external processes given their shallow gravitational potential well depth, and dwarf mass dark matter halos are much less understood leading to uncertainty on whether these galaxies contain stellar halos at all. If dwarf galaxies due have stellar halos they could form one of two ways:

1. Accretion – capturing lower mass dwarfs, much like more massive galaxies
2. In situ – stars displaced from the disk

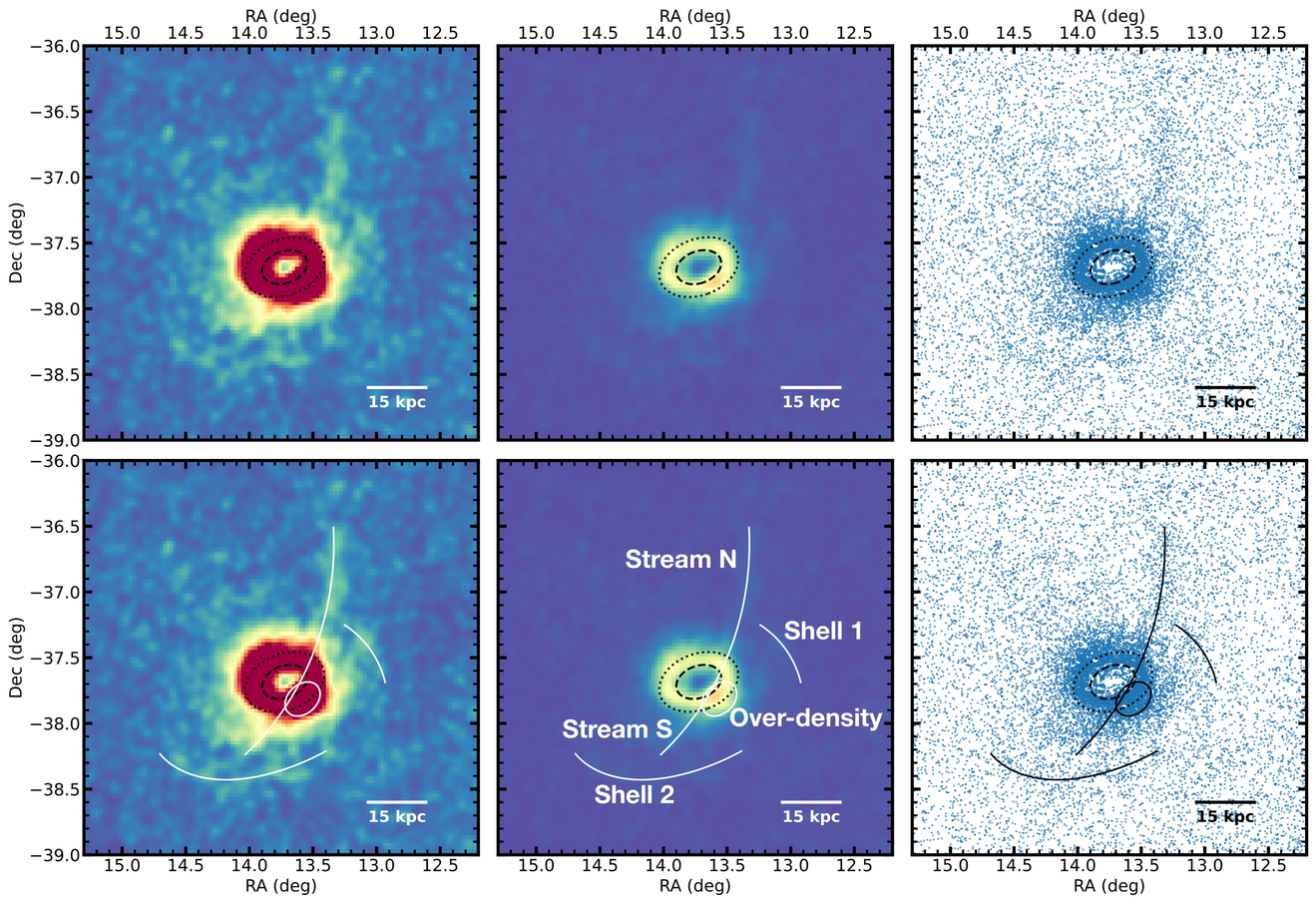
DELVE-DEEP

The DELVE survey is a comprehensive imaging program aimed at covering the southern sky with DECam on the 4m BLANCO telescope. The DELVE-DEEP component conducted deep *g* and *i*-band imaging within the virial radius of 4 nearby and isolated Magellanic Cloud analogs in the Local Volume $\gtrsim$ 1.5 mag below the tip of the red giant branch to 5σ. In NGC 300 this corresponds to 26.1 in *g* and 25.3 in *i*.

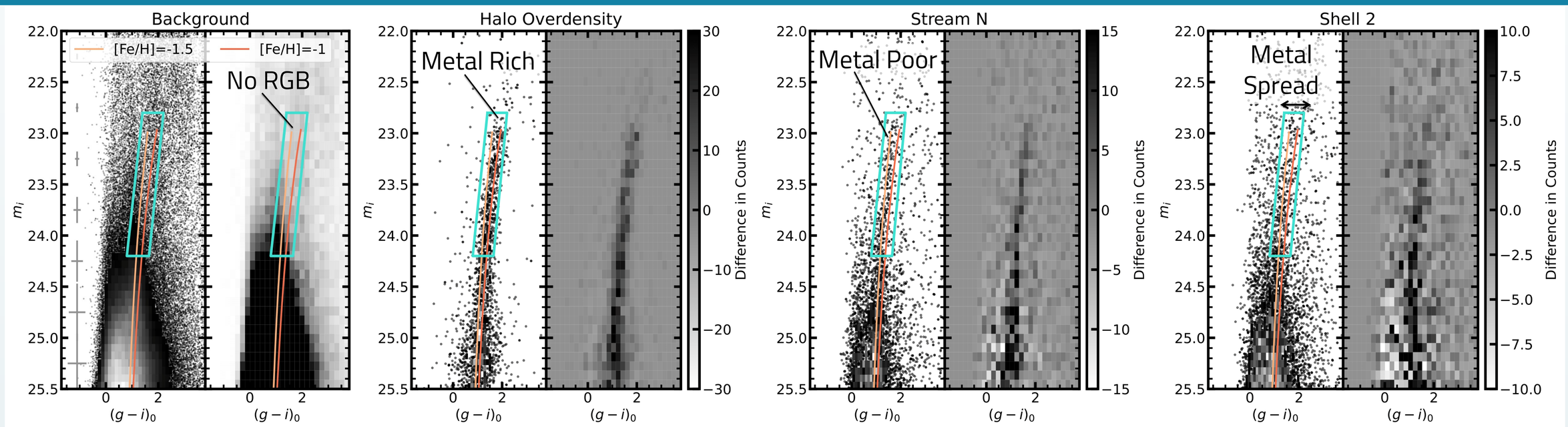
NGC 300

NGC 300 is an LMC-mass spiral galaxy at the edge of the Sculptor group (D = 2 $\pm$ 0.07 Mpc). Historically NGC 300 has been a titular example of a galaxy with a near perfect exponential disk in luminosity and stellar density, out to ~25′. DELVE-DEEP data expands out to ~189′, near the virial radius of NGC 300, and reveals a plethora of faint stellar structures within the halo of NGC 300.

Diversity of Stellar Structures Around NGC 300



Properties of the Stellar Structures Around NGC 300



A primary goal of the DELVE-DEEP imaging campaign is to find possible dwarf galaxy companions and/or the remainder of destroyed satellites. Thus, red giant branch stars are selected where we expect a metal poor stellar population to lie, comprised of the remnants of these objects (see teal boxes above). These stars are plotted at their coordinates in the images presented in the upper-right. The left two panels are Gaussian smoothed, and the right panel shows all RGB point sources. The ellipses mark 10.9′ and 21.8′ along the major axis, where most of the spiral structure of the galaxy falls within 10.9′ (the central hole is due to extreme crowding).

The RGB density map reveals several structures previously undetected around NGC 300. The CMDs above display the stars that fall within the halo feature selections indicated on the RGB density map, as well as a binned and background subtracted CMD of the same feature. The background box covers 5 square degrees 45 kpc away from the center of the galaxy. Over-plotted are 2 metal-poor 10 Gyr isochrones at the distance of NGC 300 most consistent with the data. Prior metallicity studies of the outer disk of NGC 300 (R = 24′) find a metallicity of [Fe/H] ~ -1.

- **Halo over-density:** Relatively close to the disk of the galaxy there is a stark over-density of RGB stars in the southwest. Compared to other fields at similar distances within the inner stellar halo the metallicities are similar and somewhat metal-rich, with [Fe/H] ~ -1. This is also consistent with previous studies of the metallicity of the outer extent of the disk of NGC 300.
- **Stream north:** A prominent stellar stream extends north of NGC 300 for $\gtrsim$40 kpc. The CMD is notably more metal poor than the inner stellar halo, consistent with 1.5 < [Fe/H < 1. An initial estimate of its total RGB luminosity is $M_V \approx -7$, similar to faint dwarfs of the Milky Way. The low metallicity and presence of the stream are highly indicative of an accretion event.
- **Stream south:** There appears to be a smaller stream extending southeast of the disk of NGC 300 and roughly $180^{\circ}$from the northern stream. While fainter than the northern stream, this stream displays a similar metallicity, indicating that this may be a wrap or extension of the northern stream.
- **Shells:** Two low surface brightness shell features are also visible to the south and northwest of NGC 300. The CMDs of both features are relatively contaminated but separate out as over-densities from the background and contain stars with a range of metallicities, more similar to a `clean' halo region than the stream features. Shell-like morphologies are associated with galaxy minor mergers on radial orbits but could also be associated with in situ extended disk star formation. Additionally, the morphology in the southwest of NGC 300 is complex, where it also appears that disk flaring may be present and potentially associated with this shell features.

The stellar structures within NGC 300 are the richest seen in a Magellanic Cloud analog to date.

Conclusion

NGC 300, which previously appeared as a perfect exponential disk in optical observations, has revealed unexpected complexities. Jang et al. (2020) found the first piece of evidence that this may be the case, detecting two humps in the outer stellar density profile from archival HST imaging along the western major axis. Our deep DECam imaging corroborates this, showing stellar density variations leading along the major axis towards the shell 1 structure. An HI study by Westmeier et al. (2011) with ATCA identified an inner HI disk well aligned to the optical disk, in addition to a twisted outer HI disk. Such a twisted disk is suggestive of tidal interactions, but no companion was detected at the time to account for this. DELVE-DEEP imaging has now uncovered a large stellar stream in NGC 300's outer halo, more metal-poor than the galaxy's outer regions, indicative of an accretion event. Additional revealed structures beyond the stellar disk of NGC 300 suggest a complex history. However, the story of NGC 300 is just beginning. For example, differentiating the metallicity of the faint shell-like features requires space-based imaging, and modeling of dwarf interactions may better unravel the history of NGC 300. Regardless, for the first time, we have direct evidence of a stellar halo forming around a dwarf-mass galaxy via accretion.

Contact

We are currently analyzing the metallicity distribution functions of the various halo features and constructing radial profiles in multiple directions from the disk to gain a deeper understanding of the stellar halo density. I invite you to discuss your thoughts on NGC 300 with me and to explore more detailed plots. Please feel free to reach out or visit me for further insights.
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