Research and Creative Experience for Undergraduates Program (RCEU)
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Hunting for Ultra Diffuse Galaxies in the Hubble Space Telescope Data Archive

Nicholas Schragal, Ming Sun
Department of Physics & Astronomy

Introduction

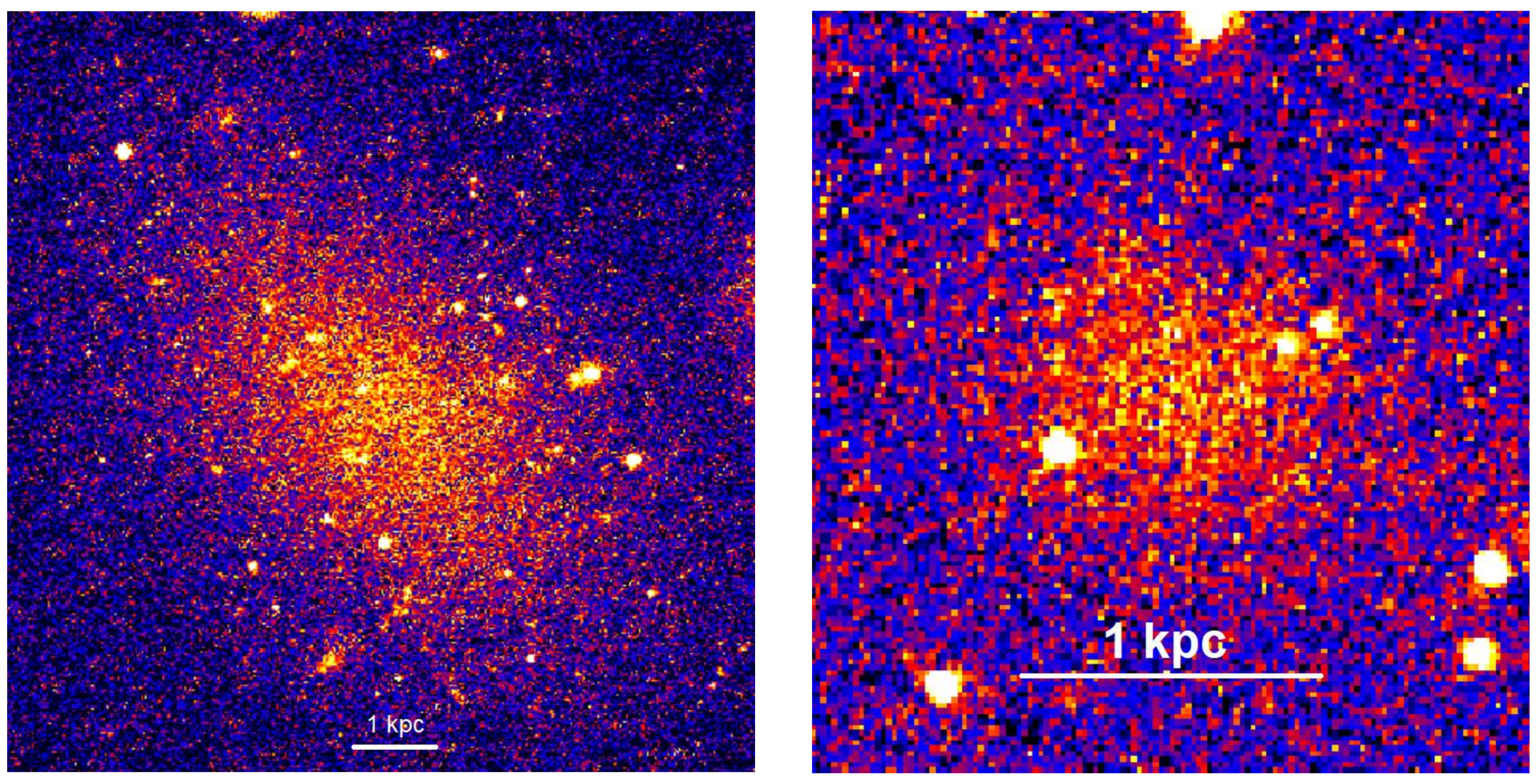
Ultra-Diffuse Galaxies (UDGs) are, as the name suggests, low surface brightness, diffuse galaxies normally found in galaxy cluster. They were first defined in 2015 and are characterized by:

- Half-light radii ≥ 1.5 kpc
- Surface brightness ≥ 24 mag/arcsec[1]
- Widely variable dark matter content, ranging from having little to no dark matter[2] to predominantly dark matter.[3]

The formation process for these galaxies is still under debate and hypotheses include:

- Tidal gas stripping due to intracluster galaxy interaction[4]
- Dwarf galaxies with unusually high angular momentum[5]
- Stellar outflow and early galactic quenching (star formation stops early due to lack of cold gas)[6]

Learning more about these galaxies can help us understand intra-cluster dynamics, galaxy formation, and dark matter.



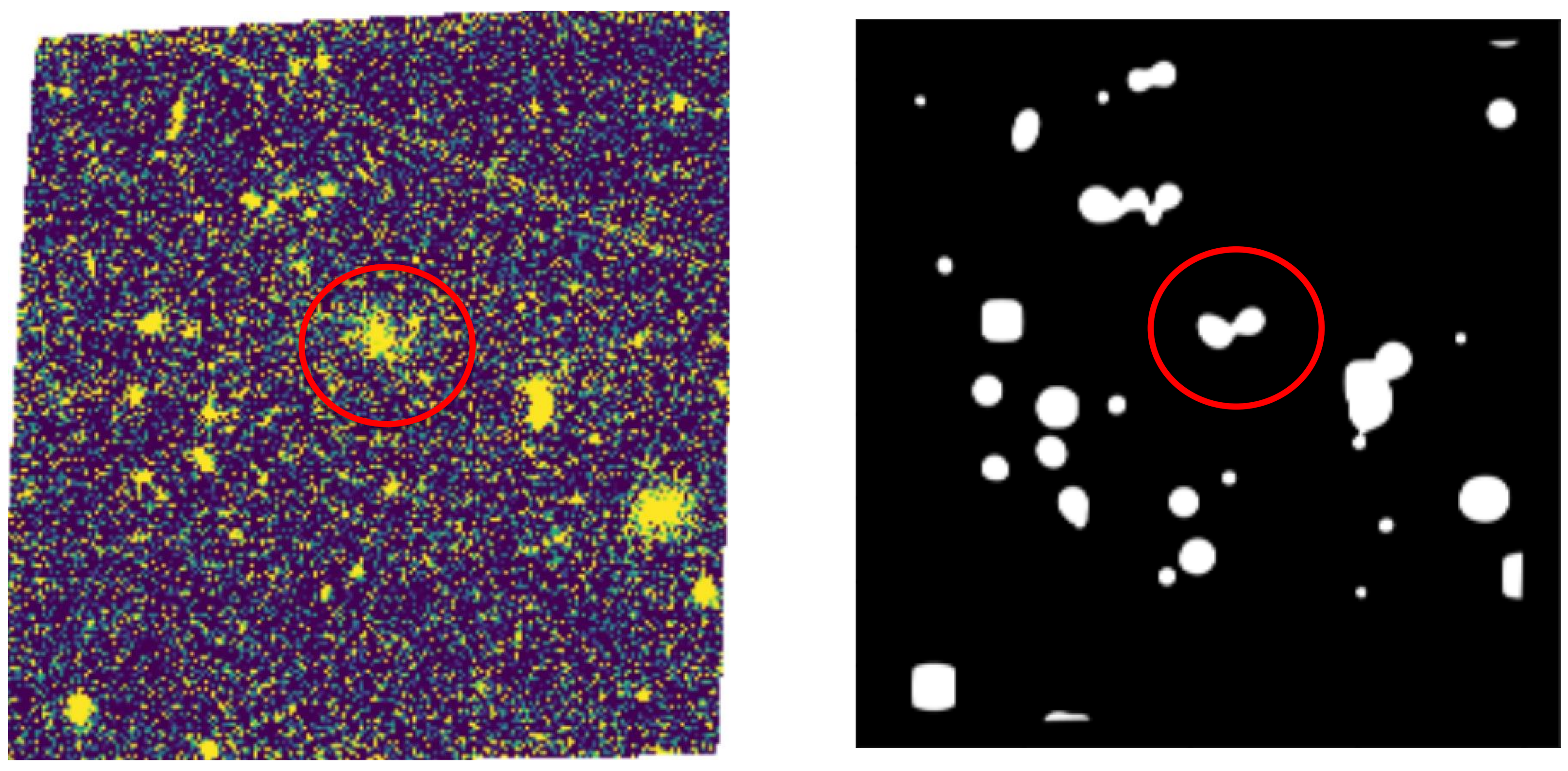
Left: UDG DF44. Right: A dim dwarf galaxy near galaxy ESO 137-002 too small to be a UDG (1/2 light radius < 0.4 kpc)

Identification

The first step in studying UDGs is finding them. Source Extractor for Python (SEP) is a package that does source detection based off the well-known Source Extractor . The key SEP input parameters that proved successful in identifying them were:

- Detection threshold (σ): ~1.5
- Square gaussian convolution kernel
  - Diameter: ~6 kpc
  - FWHM: ~3 kpc (2 * minimum UDG half-light radius)
- Large square background estimation (>20 kpc wide)

These values need to be tweaked on a case-by-case basis for best results, but in general they are a good starting point. Note: Due to how dim UDGs are, only their brighter cores are reliably identified by SEP.



A SEP run on the image of DF44 at 814nm. Left: The background-subtracted image of DF44. Right: The SEP "segmentation map" output. DF44 is in a red circle in both. The two-lobed appearance in the segmentation map is due to a star to the upper-right of DF44.

Verifying UDGs

The two principle characteristics of UDGs are their half-light radius and surface brightness. Calculating surface brightness is relatively simple with Hubble data:

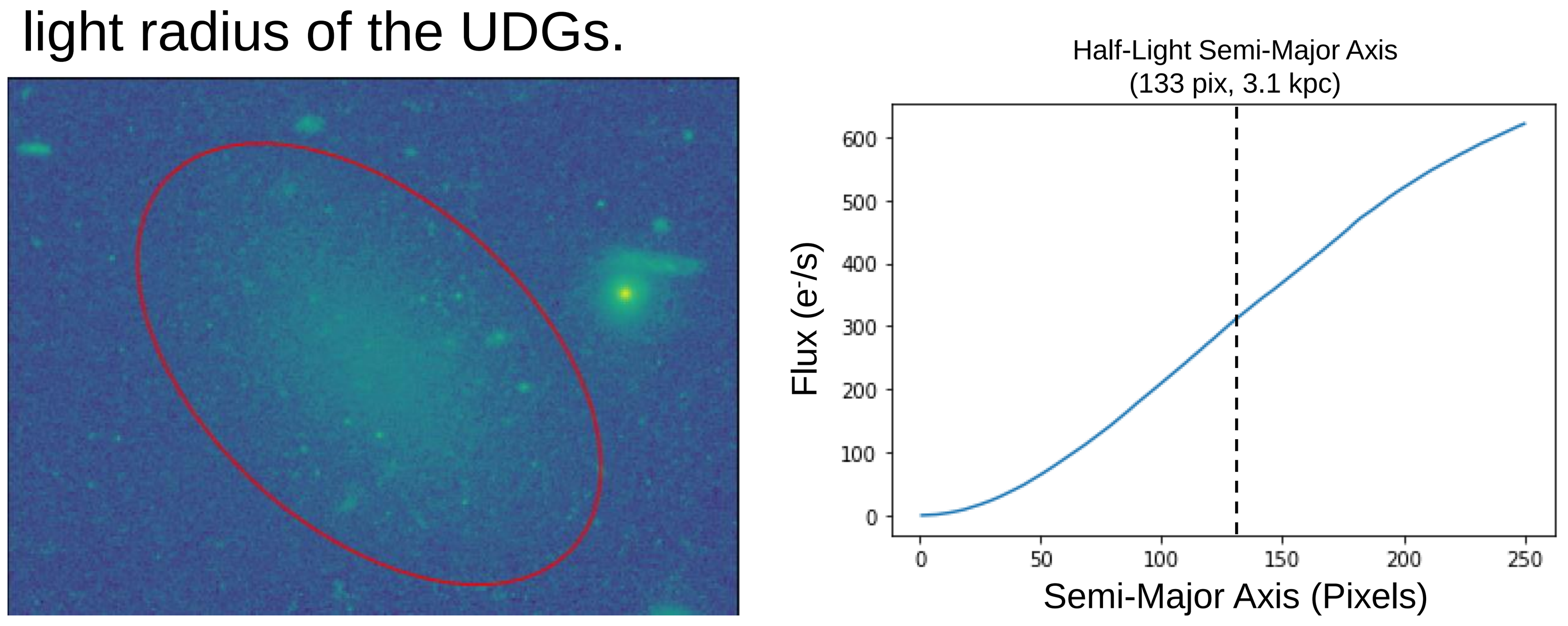
$$\mu = M/A$$
$$M = -2.5\log(\mathrm{f}) - Z$$
$$Z = -2.5\log\mathrm{PHOTPLAM} - 21.10$$

μ: Surface Brightness (mag / arcsec^2)
M: Magnitude
A: Area (arcsec^2)
f: Total flux of object (e^-/s)
Z: Magnitude zero-point
PHOTPLAM: Photometry parameter from Hubble data for calculating the zero point.

Calculating half-light radius poses more of a challenge. This is normally done by modeling the light profile of a galaxy using some Astropy libraries. Since UDGs are extremely dim, these libraries struggle and ultimately fail in identifying what is galaxy and what is background. Instead, we used what I like to call "iterative aperture photometry":

1. Draw an ellipse around the entire galaxy
2. Sum the flux within the ellipse
3. Shrink the ellipse a bit and repeat

With the values from this process, we could find the half-light radius of the UDGs.



Half-light radius calculation for DF44. Left: DF44 with the largest ellipse used. Right: Plot of flux vs. semi-major axis with half-light semi-major axis marked. The geometric mean of the semi-major and semi-minor axes gives a half-light radius of 2.4 kpc

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References

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