VLA Imaging of Atomic Hydrogen-Bearing Ultra-diffuse Galaxies and the HI Size-Mass Relation

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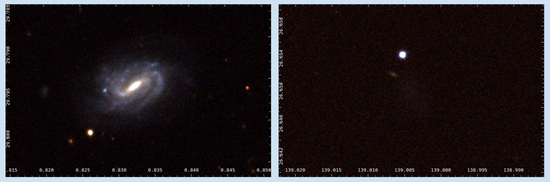
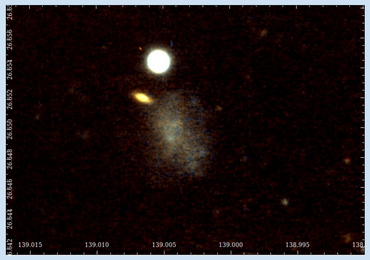
What is an ultra-diffuse galaxy?

- A galaxy that has a star content similar to that of dwarf galaxies but a radius similar to that of a large spiral galaxy.



On the left is an image of a typical gas rich galaxy observed in the Sloan Digital Sky Survey (SDSS). On the right is an image of AGC 749290, a gas rich ultra-diffuse galaxy observed in SDSS. Both images are set to the same color parameters, and these galaxies are at roughly the same distance.



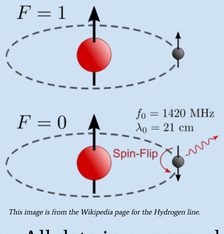
This is an optical image of AGC 749290 taken with the WIYN One Degree Imager (ODI) on the 3.5 m telescope. The galaxy was observed for 1.5 hours using this telescope compared to the previous image where it was observed for ~60 seconds on SDSS.

Our Question: Why are UDGs so diffuse?

- Are there other characteristics of these galaxies that could explain their diffuseness?
- Could the galaxies' motions explain their diffuseness?

What is HI gas and how do we observe it?

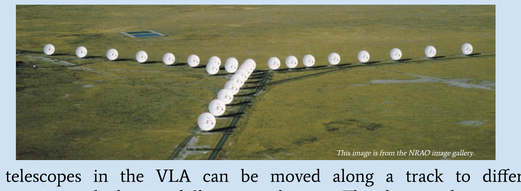
- We can observe gas in the galaxy in radio wavelengths.
- HI gas is atomic hydrogen that emits at a wavelength of 21 cm.



This image is from the Wikipedia page for the Hydrogen line.

Atomic hydrogen, HI, can undergo a change in energy state, which involves a spin-flip transition. When this transition occurs, the atom releases energy at a wavelength of 21 cm. This emission is what is observed by radio telescopes in order to study the gas in UDGs.

- All data in our sample of 12 UDGs was taken with the Very Large Array (VLA), an array of radio telescopes that allows for high resolution radio images.



This image is from the NRAO image gallery.

The telescopes in the VLA can be moved along a track to different configurations which give different resolutions. The distance between the most separated telescopes determines the overall resolution of the image taken.

Main Points

- We observed ultra-diffuse galaxies (UDGs) with the VLA in order to understand their characteristics and motions.
- Hydrogen gas in UDGs appears undisturbed and normal.
- UDGs have ordered velocity fields.
- UDGs are rotating at slower rates than expected.
- Hydrogen gas in UDGs is not ultra-diffuse.

What are characteristics of these UDGs?

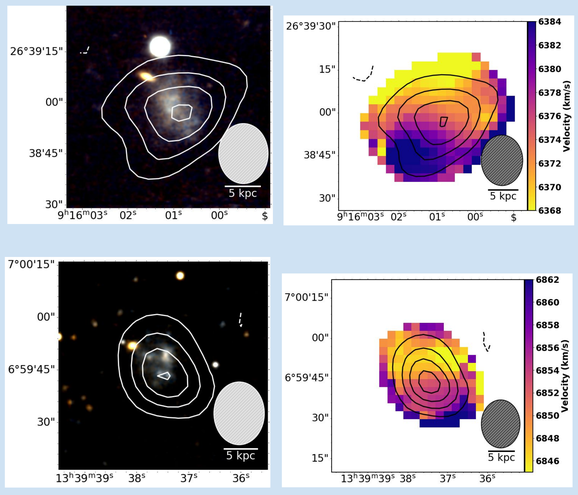


Figure 1. This figure shows optical images in the left hand panel and velocity maps in the right hand panel of galaxies AGC 749290 and AGC 238764. The white and black lines represent contours showing the amount of HI gas (at column density levels of 0.2, 0.4, 0.8, 1.6, 3.2, and 6.4 x 10^{20} atoms cm^{-2}). The grey circles represent the size of the beam (resolution). Images are plotting dec on y-axis and RA on x-axis. The color gradient in the right hand panel shows the variation in redshift across the galaxies in units of km/s.

- Gas in the galaxies extends past the stars.
- HI gas in the galaxies is more reliable in measuring inclination.
- Galaxies are bluer in color which is indicative of star formation.
- Galaxies have irregular and clumpy star morphologies
- Clear velocity gradient shows galaxies are rotating (darker colors are moving away and lighter are moving toward us).

How are these UDGs rotating compared to typical galaxies?

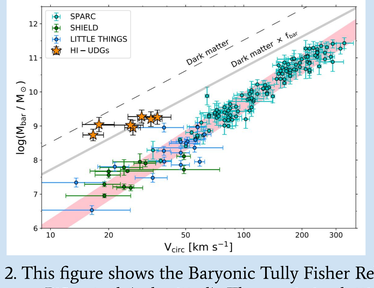


Figure 2. This figure shows the Baryonic Tully Fisher Relation in Mancera Piña et. al (submitted). The y-axis is plotting the baryonic mass (total mass of gas and stars), and the x-axis is plotting the rotational velocity in km/s.

- Rotation rate is proportional to mass.
- UDGs rotating at slower rates than expected given their masses
- This rotation may indicate that:
  - There is less dark matter than usual.
  - The dark matter is more spread out than usual.
- This behavior may be a clue as to why UDGs are so diffuse.

How do these UDGs' radii compare to typical galaxies?

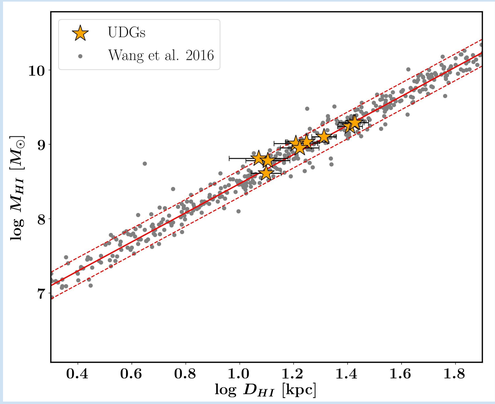


Figure 3. This plot shows our sample of UDGs plotted over the Wang et. al 2016 HI size-mass relation. The y-axis plots the HI diameter and the x-axis plots the HI mass. The red solid line represents the fit of the Wang et. al 2016 data, and the red dashed lines show the scatter in the relation to 3σ.

- HI diameter is proportional to the HI mass for regular galaxies (all sizes).
- UDGs fall on the relation, which means:
  - UDGs have a similar average HI surface density as typical galaxies.
  - Though the stars in UDGs are ultra-diffuse, the HI gas in these galaxies is not.
- Since the gas is normal, it is likely that the star formation is normal; their diffuseness cannot be explained by lack of new stars.

Future Work

- .Take observations in a higher resolution of the largest and brightest UDGs from this sample.
- Create detailed rotation curves for those galaxies.
  - Rotation curves will reveal the dark matter content of these galaxies, which can then be compared to typical galaxies.

Acknowledgements and References

- Valparaiso University
- ALFALFA Survey
- VLA
- Sloan Digital Sky Survey
- Undergraduate ALFALFA Team
- Haynes et. al 2011, AJ, 142, 170
- Leisman et. al 2017, ApJ, 842, 133
- Mancera Piña et. al (submitted)
- Wang et. al 2016

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