Atomic Hydrogen-Bearing Ultra-diffuse Galaxies: A Look Into AGC 749290

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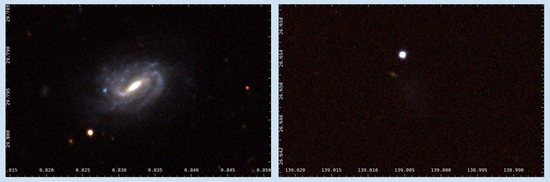
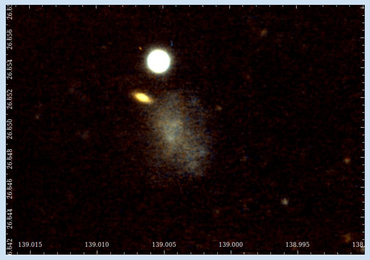
What is an ultra-diffuse galaxy?

- A galaxy that has very few stars for its given radius (low surface brightness).
- Appears very dim in optical images.



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.



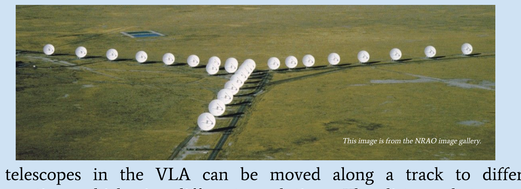
This is an optical image of AGC 749290 taken with the WIYN One Degree Imager (ODI) on the 3.5 m telescope. The galaxy was observed for 1.5 hours using this telescope compared to the previous image where it was observed for ~60 seconds on SDSS.

Our Question: Why are UDGs so diffuse?

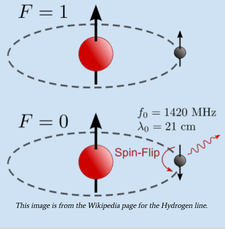
- Are there other characteristics of the galaxy that could explain its diffuseness?
- Could the galaxy's motions explain its diffuseness?

What is HI gas and how do we observe it?

- Can observe gas in the galaxy in radio wavelengths.
- HI gas is atomic hydrogen that emits at a wavelength of 21 cm.
- Very Large Array (VLA) is an array of radio telescopes that allows for higher resolution radio images to be taken.
- Worked on data from one UDG, AGC 749290 in two different resolutions.



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.



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.

Main Points

- The stars in an ultra-diffuse galaxy are too spread out, making the galaxy appear very dim.
- AGC 749290 is an ultra-diffuse galaxy, but has a defined disk of atomic hydrogen (HI) gas.
- The gas is misaligned from the stars.
- The galaxy is rotating but at a slower rate than expected.

How do we process radio data?

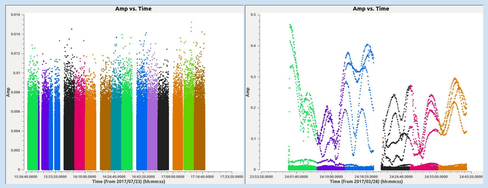


Figure 1. On the left is a plot showing data after radio interference was removed. On the right shows data before interference was removed. (Radio interference comes from cell phone, GPS, etc. waves being picked up by the telescope.)

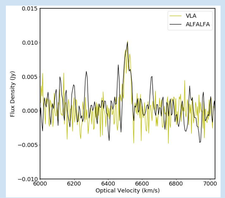


Figure 2. This plot shows spectra of the galaxy taken from the VLA and from ALFALFA measurements. These are compared to verify the amount of gas in the galaxy.

- Remove interference in CASA.
- Create radio images.
- Fit spectrum and compare.

What are AGC 749290's Characteristics?

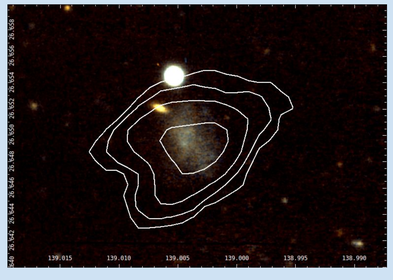


Figure 3. This figure shows the WIYN optical image of AGC 749290 with contours overlaid. The contour lines correspond to column density levels at 0.5, 1, 2, and 4 10^20 atoms per square centimeter.

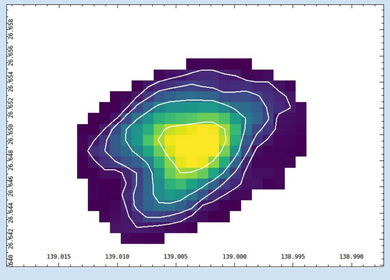


Figure 4. This figure shows a map of the HI gas in the galaxy. The colors correspond to different column densities (amount of HI gas per area). The contours are the same as in Figure 3.

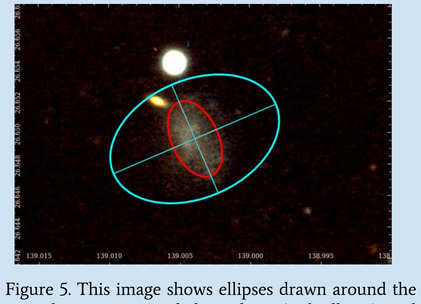
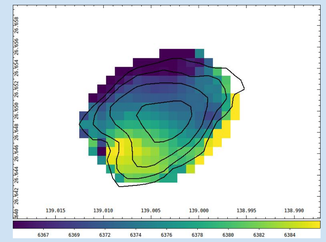


Figure 5. This image shows ellipses drawn around the optical component of the galaxy (red ellipse) and around the gas content of the galaxy (blue ellipse).

- The gas in the galaxy extends past the stars.
- The optical extent of the stars is misaligned from the gas content observed in radio wavelengths.
- Gas and stars are normally in the same disk, but these stars do not follow the gas, which is odd.

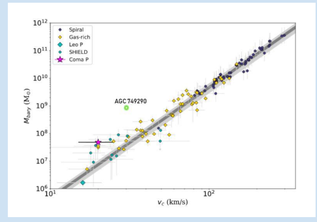
How is AGC 749290 moving?

- When a source is moving away from an observer, the waves become elongated, making them appear redder than they actually are (redshift).
- Variations in redshift can be observed for a single galaxy and are indicative of rotation.



- Clear gradient shows the rotation of the gas.
- Darker colors are moving toward us and lighter are moving away.

Figure 6. This image shows a map of the redshift across AGC 749290 in units of km/s. The position of the galaxy is plotted here with right ascension on the x-axis and declination on the y-axis, both in units of degrees.



- Rotation rate is proportional to mass.
- AGC 749290 is rotating at a slower rate than expected given its mass.

Figure 7. This is a Tully-Fisher plot showing rotation velocity on the x-axis in km/s and the log of baryonic mass (total mass of gas and stars) on the y-axis. AGC 749290's placement is shown with the green circle.

- 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.

Future Work

- Further compare this galaxy to typical sources based on different properties such as color, dark matter content, and gas mass ratios.
- Analyze other HI-bearing UDGs in similar ways to better understand why and how these galaxies behave.

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
- Ball et. al 2018, AJ, 155, 65