Draft version May 1, 2024
Typeset using LATEX **RNAAS** style in AASTeX631

Probing the HI Dynamics of a Novel Stellar Population in the Virgo Cluster: Insights from ALFALFA Survey Data

Swapnaneel Dey [1]

[1] *Astronomy Department, Steward Observatory, University of Arizona*
933 N Cherry Ave, Tucson, AZ 85719, USA

ABSTRACT

We investigate the H I dynamics of a newly discovered stellar population, termed "Blue Blobs" within the Virgo Cluster using data from the ALFALFA survey. These objects, characterized by their blue color and low stellar mass, pose intriguing questions regarding their formation and evolution in the cluster environment. Our study aims to probe their H I content to shed light on their potential for future star formation. We develop a custom code to analyze and reduce the ALFALFA data cubes, tailored to the positions of Blue Blobs, enabling the identification of H I emission lines. Through a systematic analysis, we classify the Blue Blobs based on their H I detections. Our results reveal a subset of Blue Blobs with clear H I emissions, suggesting ongoing gas-rich processes, while others exhibit tentative or no H I detections. This study provides valuable insights into the gas dynamics of Blue Blobs and sets the stage for further investigations into their origin and evolution within the Virgo Cluster environment.

INTRODUCTION AND MOTIVATION

"Blue Blobs" are a novel class of stellar system recently discovered in the Virgo Cluster (Jones et al. 2022). Blue Blobs are very blue, irregular, and clumpy objects of low stellar mass embedded in the hot environment of the Virgo Cluster. The Virgo Cluster is the nearest galaxy cluster to us, about $\sim 16.5\,\mathrm{Mpc}$(54 million ly) away. It has a Redshift range of -400 km/s to 4000 km/s. The Virgo Galaxy Cluster contains an intracluster medium (ICM), a hot gaseous region composed mainly of ionized hydrogen and helium. Within the ICM of the Virgo cluster, we expect the cold gas of large galaxies to heat up and get stripped. However, the blue color observed in the blue blobs implies the existence of young, hot stars. The strong emission of UV radiation from these objects is another indicator of star formation and the presence of young stars. This suggests that relatively recently, there must have been cold gas present in these objects. This contradicts our general expectations. The Blue Blobs are isolated, far away from any galaxies in the cluster, thereby raising questions about their origin. Blue Blobs have low stellar masses ($M_\star \sim 10^4$ $\mathrm{M}_\odot$) and high metallicity ($8.29 < 12 + \log(\mathrm{O/H}) < 8.73$), which implies they could be the result of a galaxy subjected to ram pressure stripping within the Virgo Cluster. Ram pressure is a scenario where a galaxy falls into a hot cluster while getting stripped of its cold gas. A stripped gas cloud sometimes shoots up to long distances traveling far away from the parent galaxy making them isolated. Imagine belly-flopping into a pool, the water that splashes away from you is like a stripped gas cloud. These remnant cold gas might be the blue blobs that we see. To date, we have identified around 30 of these objects.

When there is an increase in the abundance of neutral hydrogen (H I) in a gas cloud, the increasing gravity and pressure causes it to form molecular hydrogen. Stars are formed in molecular hydrogen clouds, which is a crucial factor for nuclear fusion in stars. Finding H I in blue blobs will help us understand if they have enough gas reservoir for future star formation or if that reservoir is already empty. Hence, the H I content in a blue blob can inform us about its life stage; we expect younger blue blobs will typically possess more H I content.

ALFALFA (Giovanelli et al. 2005) was a low-resolution drift scan survey of the sky to map the H I content. It detected H I content in more than 30000 galaxies with low redshift. I use its data from when it mapped the H I content of the Virgo Cluster. I try to find H I emissions in the sky that might be associated with our blue blob candidates. For this, I get access to ALFALFA data cubes located in the **beast** server at Steward Observatory, University of Arizona.

ALFALFA data cubes have two axes representing the right ascension and declination and a third axis with the flux density values of each of the pixels. The one way to find H I is to spot the H I line peaks in the spectrum made using ALFALFA data cubes. Before this, there was no such code that could take position for our blue blobs and make such a spectrum. I address this **problem** by writing a code that makes the spectrum plots tailored to the position of our blue blobs but could also be used to get a spectrum of any part of the Virgo cluster.

CODE STRUCTURE AND ANALYSIS.

It first reads the *csv* file which is a catalog of all the blue blobs found, with their right ascension, declination, magnitude, etc. In this code, we are only concerned with their positions. We use the position to find which ALFALFA data file to access. This is because ALFALFA data is split into square grids of data cubes for different parts of the sky.

The code involves two main reduction methods of the data before making the spectrum. In the **gaussian_reduction** method, I use a Full Width at Half Maximum (FWHM) of $8'$. I find the separation of each pixel from the target pixel (location of our blue blob). I then use this separation and σ = FWHM/2.335 in the following Gaussian formula;

$$f(x) = e^{-\frac{(x-u)^2}{2\sigma^2}} \tag{1}$$

where x - u is the separation defined above. I use the Gaussian beam of the telescope to normalize the flux values.

In the **square_reduction** method, I simply only consider values of pixels with a certain range of the target pixel, for example, a square of length 5 pixels around the target blue blob.

I use the following equation to convert the radio velocity (which was stored in ALFALFA data cubes) to the optical velocity of the object.

$$V_{opt} = \frac{c * V_{rad}}{c - V_{rad}} \tag{2}$$

where V_{opt} is the optical velocity and V_{rad} is the radio velocity. C is the speed of light.

I use the following equation to normalize the data. This is very important because the telescope's beams' side lobes overestimate the flux observed.

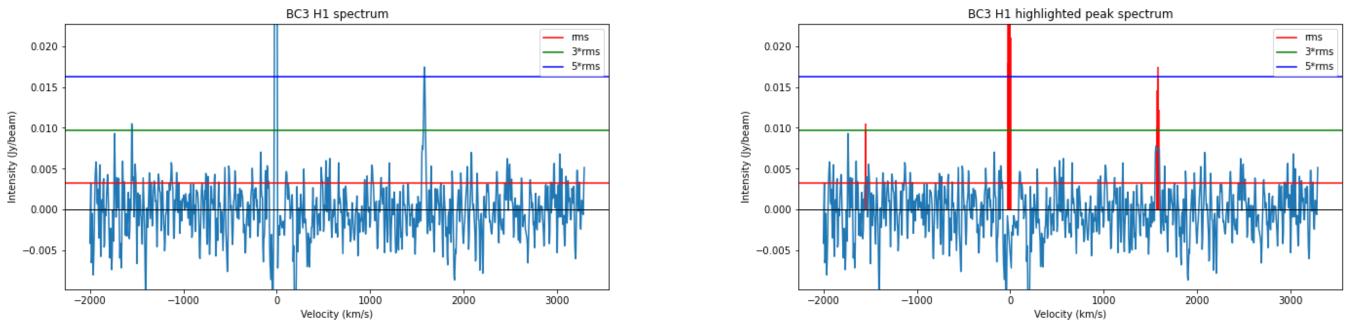
$$\Omega = \frac{\pi\, \theta_{maj}\, \theta_{min}}{4 \ln 2} \tag{3}$$

where the θ is the beamwidth of the telescope. After reducing the data, I plot the spectrum for every blue blob. Since the main problem to address is that if we see any H I lines or not, I write code that will highlight any spike in the spectrum that is more than 3 $\times$ **root mean square** of the flux data like in figure 1(b). This figure is one of the spectrum plots. It is of our candidate **BC3**. It has been analyzed before as well and we do a sanity check if my peaks are at the correct location. I compared my result to that in Jones et al. (2022) and it was accurate. We then distribute the H I spectrum into 3 categories:-

- Hit: Blue blobs with clear H I emission >3*rms.
- Tentative: Blue Blobs with H I emission <3*rms, but is still evident.
- Non-detection: Blue Blobs with no H I emission lines.

RESULTS OF THE ANALYSIS

The code was successfully able to plot the spectrum of all the blue blobs. Since there were 30 blue blobs I only include some of the blue blob spectrum here. For the blue blobs that had previously been analyzed, we do a series of sanity checks to see if all the spikes are present. These results will help us in the future select specific candidates that contain H I content and then include it in proposals asking for telescope time for more detailed analysis. This also helps us pick out the false positive blue blobs whose spectrum may not have any H I spike and hence might not be an actual blue blob candidate. This was the case for some of the blue blobs in the CSV files. By looking at the x-axis where the spike is we can figure out the velocity of the object which is a crucial result. By figuring the velocity we can determine if the candidate is with the Virgo Cluster. There is a case where a candidate might have a velocity



(a) Full spectrum

(b) BC peaks

Figure 1. *Left*: Full spectrum plot of our blueblob candidate called BC3. We see a spike around 1500 km/s. The spike at 0 km/s is just the Milky Way so we ignore it in all our calculations. We also deem spikes to the edges of the plot as not real because the sensitivity of the survey sometimes drops there. *Right*: We highlight the peaks which cross the 3 × rms line shown in green. The line at 1500km/s is highlighted accurately.

Hit	Tentative	Non detection
BC3	BC4	BC1
BC6	BC5	BC28
BC12	BC14	BC7
BC16	BC8	BC9

Table 1. H I possibility table of some of the Blue Blobs. Hit columns are for detections. Tentative columns are for further analysis of those blue blobs. Non-detection is for no emission detected.

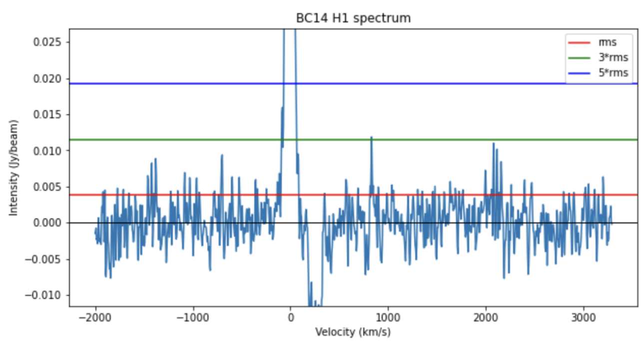


Figure 2. A blue blob with a tentative emission.

$>$ 4000 km/s or velocity $<$ -400 km/s but this would mean that the candidate is not inside the Virgo cluster. We can also use this result to get H I mass calculation, by simply integrating through the area under the spike. This however is for future work since this project was more focused on correctly reducing the flux data and plotting and finding H I spikes in the ALFALFA H I spectrum. This gives us a fast way to sample which blue blobs are gas-rich and which are not.

ACKNOWLEDGMENTS

I would like to thank Prof. Kenneth Johns for his teaching in computational physics. His classes have inspired me to write code like I have never before.

REFERENCES

Giovanelli, R., Haynes, M. P., Kent, B. R., et al. 2005, AJ, 130, 2598, doi: 10.1086/497431

Jones, M. G., Sand, D. J., Bellazzini, M., et al. 2022, ApJ, 935, 51, doi: 10.3847/1538-4357/ac7c6c