Baryonic Tully Fisher Relation for Galaxies with Supernova Distances

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Abstract

The Baryonic Tully-Fisher Relation (BTFR) is an empirical correlation between the baryonic mass of a spiral galaxy and its rotational velocity. As the equation for baryonic mass is dependent on the luminosity of a galaxy, it is also true to state that it is an empirical correlation between distance and the mass of the galaxy. By using the BTFR, we avoid using so-called "standard candles," such as Type Ia supernovae or Cepheid variable stars, which are limited to use in relatively nearby galaxies. The BTFR provides an alternate approach for measuring distance that is then applicable to a much larger sample. We present an update on the data collection and analysis pipeline for an ongoing project of the Undergraduate ALFALFA Team (UAT), for which the primary science objective is to generate a well-defined BTFR. We used the Green Bank Telescope (GBT) to observe and measure the HI 21-cm emission line profiles of 200 galaxies in our observing sample with accurately known distances from the Democratic Samples of Supernovae (Stahl et al. 2021). Here, we will focus on the observing sample and show: (1) progress to date on obtaining the HI 21-cm measurements; (2) preliminary outcomes of our newly developed analysis tools; and (3) statistical analysis of sample signal-to-noise, including non-detections.

Background

Our primary goal is to reduce the scatter of the template Baryonic Tully Fisher Relation (McGaugh et al. 2000). The BTFR is an important method for measuring distances to galaxies independently of their redshift. It is of particular importance, for example, to studies of peculiar velocities shown in galaxies under the gravitational influence of large-scale structures (O'Donoghue et al. 2019). In order to improve our template BTFR, we observe a sample of supernova host galaxies with known distances at radio wavelengths using the Green Bank Telescope (GBT).

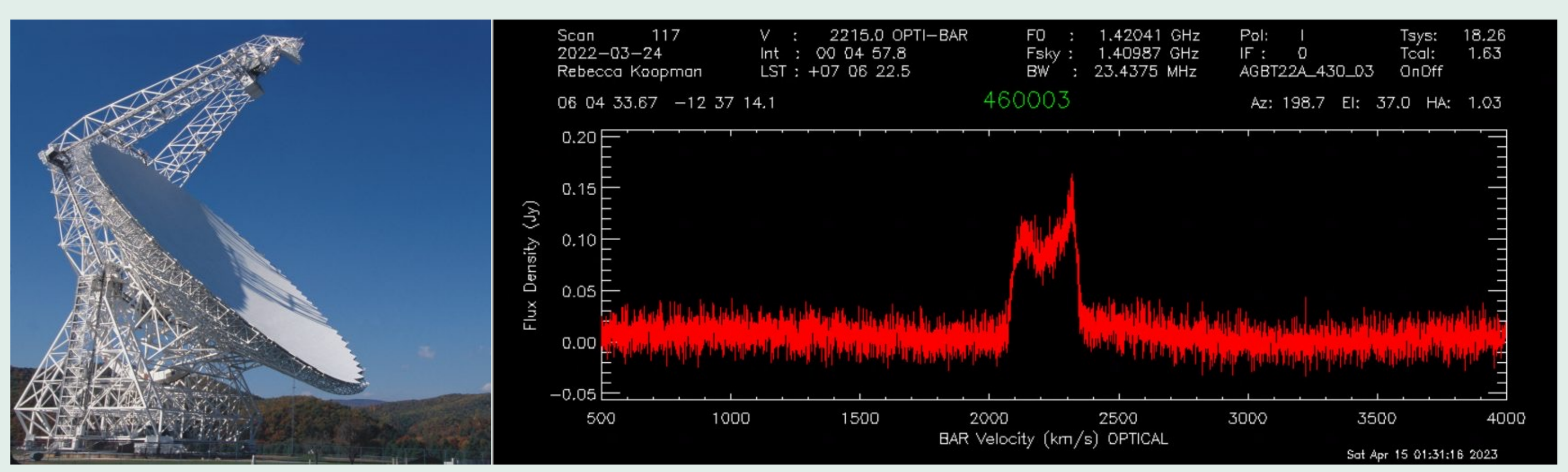

Image from greenbankobservatory.org/science/telescopes/gbt/

Figure 1. A sample scan of galaxy AGC460003 from the GBT

We measure the flux of the 21-cm HI profiles of these galaxies to determine the gas mass, including corrections for the inclination of the galaxy and resolution of the scan as described by Master et al. (2019). The stellar mass is estimated using optical photometry from the Sloan Digital Sky Survey (SDSS) using the technique described by Taylor et al. (2011), including corrections for Milky Way extinction, internal reddening (Durbala et al. 2020) and K-corrections (Chillingarian et al. 2010). The sum of these two masses gives the total baryonic mass of each sample galaxy.

We have composed our sample to contain galaxies that are known supernova hosts, again to reduce the reliance on a redshift parameter. We started with the Democratic Sample of Supernovae (Stahl et al. 2021) and narrowed our sample by cross referencing with the Extragalactic Database (Tully et al. 2009) in order to identify the host galaxy and then with the ALFALFA Survey and the Arecibo General Catalog. Sources with available high quality archival spectra are removed from the observing sample, as well as sources with a near face-on inclination, a neighboring galaxy within the beam of the telescope, and sources not visible from Green Bank, West Virginia.

References and Acknowledgements

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We acknowledge the support of the Undergraduate ALFALFA Team and NSF Award AST-2045369

GBT Observing

- Proposal GBT22A-430:
  - Request for 133 hours on the Green Bank Telescope to observe 220 galaxies. (Sample now reduced to 206 galaxies due to factors such as nearby neighbors or a large angular size.)
  - Observations made in 5 minute on/off pairs, some objects observed multiple times to acquire a sufficient signal-to-noise ratio (S/N).
  - As of January 3rd, 2023
    - 172 galaxies have been observed over 26 sessions
    - 69 of which were non-detections with a S/N below 2
    - 67 were weak detections with a S/N between 2 and 8
    - 36 were strong detections with a S/N above 8

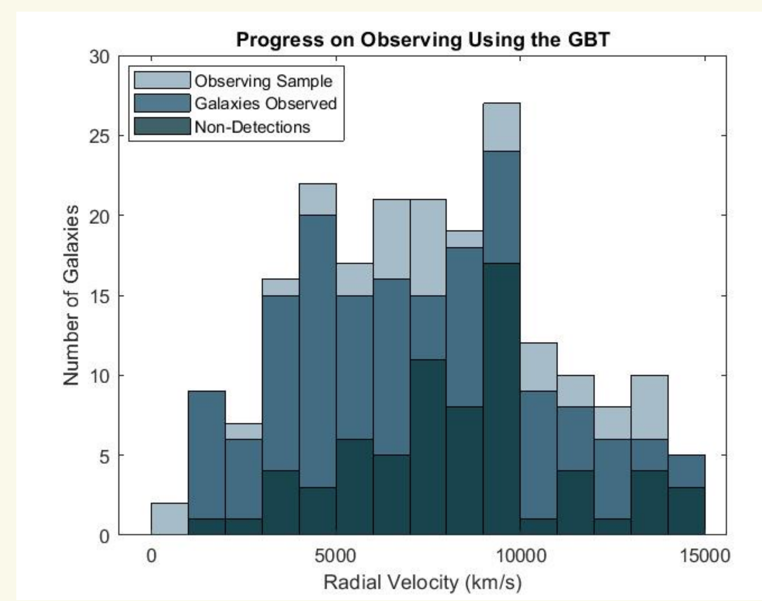


Figure 2. A summary of the progress made on observing our sample consisting of 206 galaxies. Of the observing sample, 172 galaxies have been observed so far, 69 of which have been called non-detections.

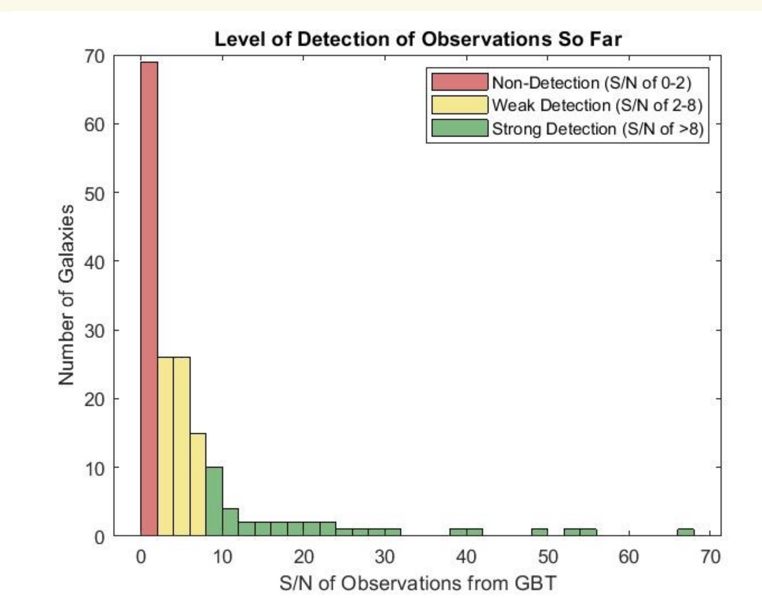


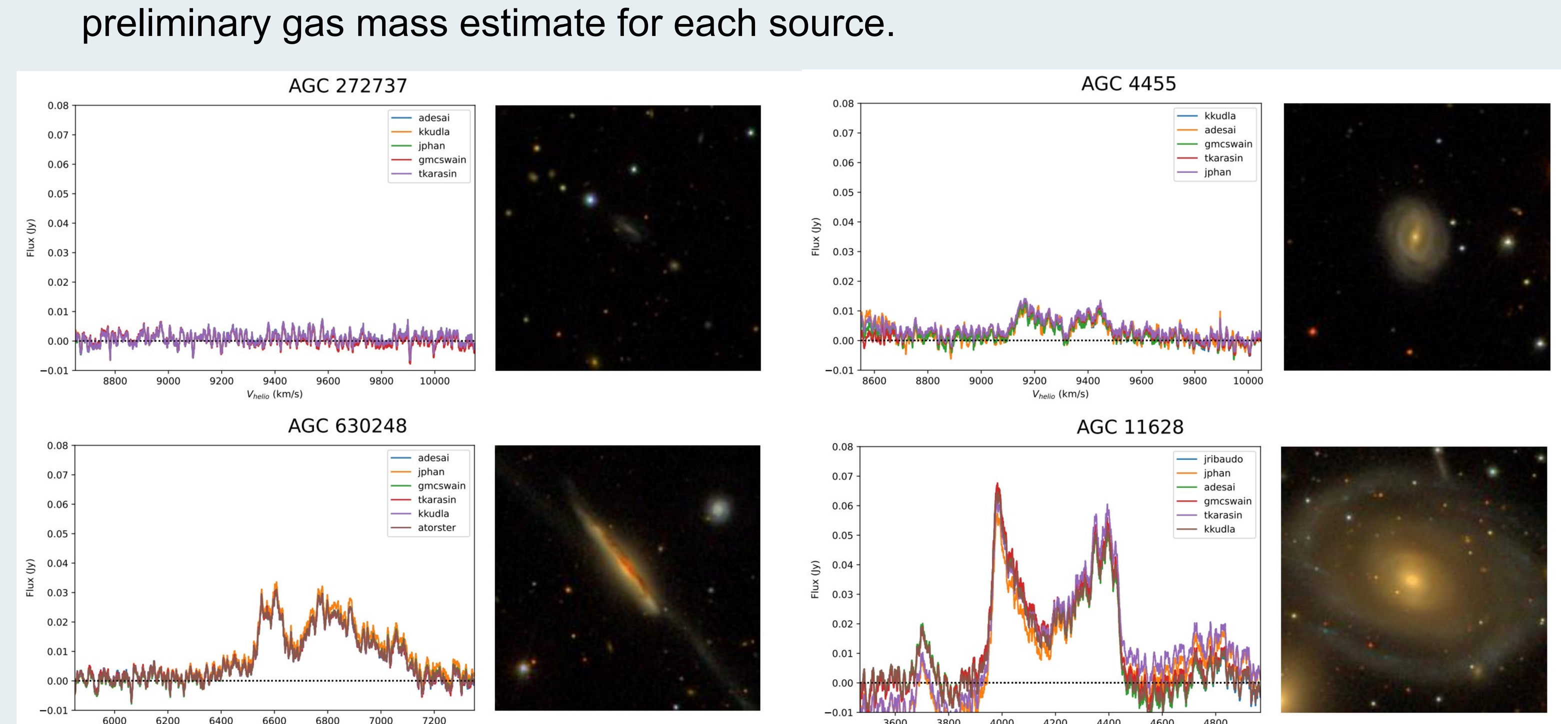
Figure 3. Signal-to-noise measurements from observations made as of Jan. 3rd, 2023. Details on the distribution shown in this figure is found above.

  - Initial reduction and baselining was done using GBTIDL which also allowed us to average multiple scans of the same object across multiple sessions in an attempt to emphasize any profile present. At this point, a S/N calculation was made by hand for each source using each of two methods.
    - Flux of the lower of two peaks divided by the baseline root mean square.
    - The average of the mean and median flux of the lower peak divided by the baseline root mean square.
  - The second method accommodates for the presence of noise at the peak.

- What's Next:
  - Maintenance on the GBT has prevented us from completing our observations. We have ## hours left on the GBT and new scans will need to be reduced in the same procedure outlined above.

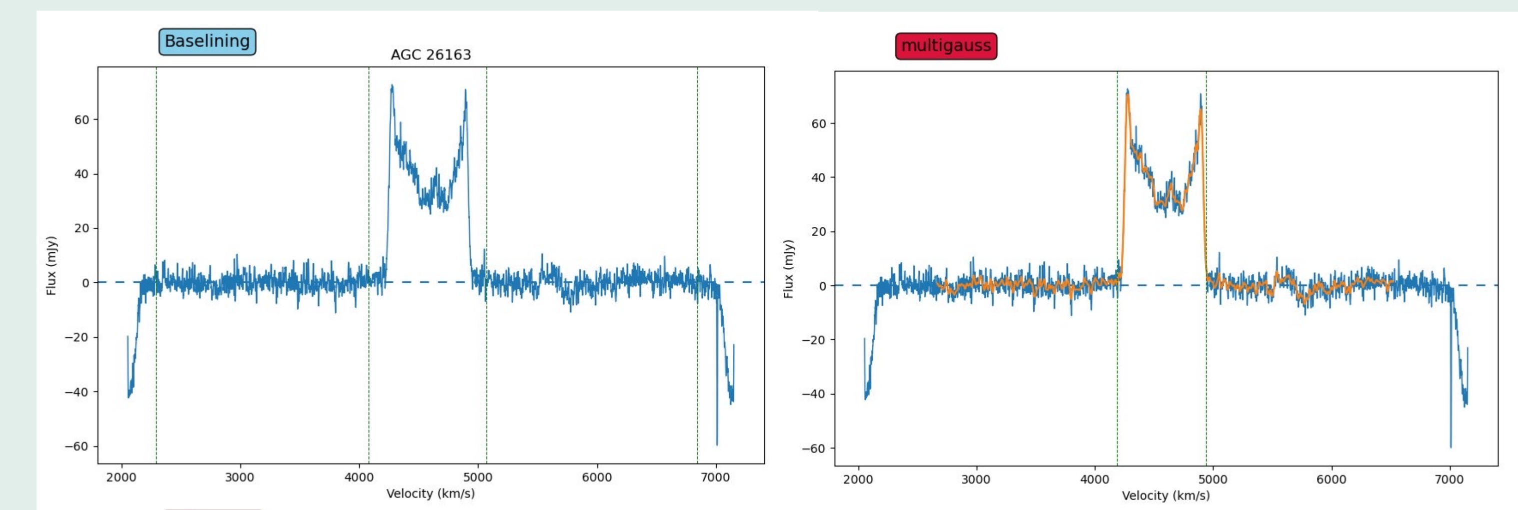
Data Processing: Jupyter Notebook

- The images below feature a sample of the results from a custom Jupyter Notebook program, designed to overlay data processed by members of the project team.
- In addition, it includes an optical image of the source from the SDSS, which is useful for determining sources of contamination.
- From these plots, the notebook measures the incoming HI flux and calculates a preliminary gas mass estimate for each source.



Data Processing: pyAPPSS

- The pyAPPSS Python package is being programmed to accomplish three main goals:
  1. Determine the width of the double-horned profile. This tells us the systemic velocity and the rotational velocity.
  2. Determine the HI 21-cm flux of the object, measured in Jy km s^{-1}. Flux describes the strength of the detection and we use this to find the mass of the hydrogen in the galaxy.
  3. Measure the S/N of the profile. pyAPPSS measures this by determining the ratio between the velocity with the highest flux and the flux of the background noise.



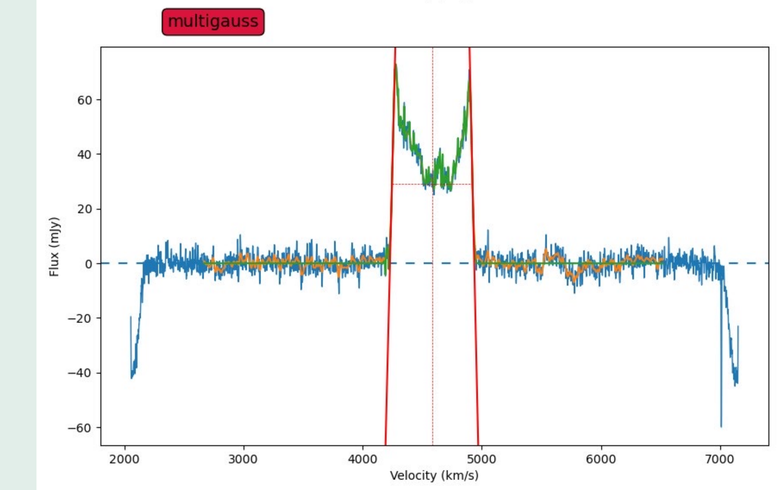


Figure 4. Screenshots of the pyAPPSS user interface.
Top left shows the user selected baseline regions prior to baselining.
Top right shows the automated multigaussian fit that then prompts for the users approval.
Bottom left shows two lines fit to the edges of the profile, once approved by the user, the program then calculates the width of the profile, the systemic and rotational velocity, the HI flux of the galaxy, and the S/N of the profile.

- Currently, the pyAPPSS package runs on user input. While this helps the user understand the analysis, this results in biases and inconsistencies from user to user. In the future, we will be implementing a new Curve-of-Growth method (Ball et al. 2022), which will be an automatic method of measuring the quantities described above. Still, this only gives us a measurement for the gas content of a galaxy. Other methods, described in the background section, give us measurements for stellar mass and the sum of the two can then be used in the BTFR.

Preliminary Results

Below we summarize our HI mass measurements of the GBT sample and archival supernova host galaxies in the SDSS footprint with existing high quality HI profile data. We estimate upper HI mass limits from non-detections according to Masters et al. (2019).

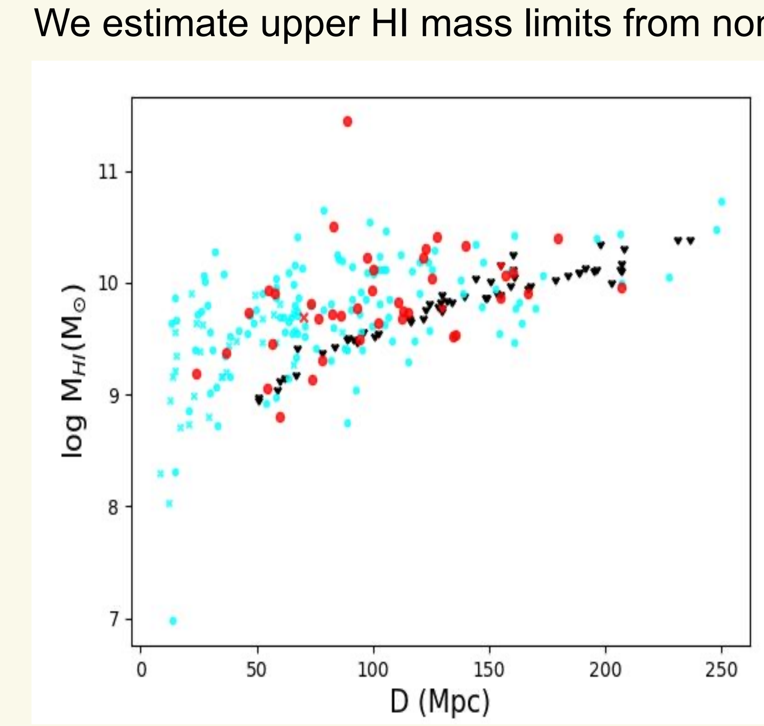


Figure 5 (left). SN host galaxy HI mass measured from 21-cm line profile fluxes, with corrections for inclination and resolution (Masters et al. 2019). Red points show results from the newly acquired GBT data. Cyan points are from ALFALFA (Haynes et al. 2018). Circles mark Type Ia hosts and crosses mark Type II hosts. Black points are upper limits from the RMS in the GBT spectrum, with one red upper limit from a marginal detection.

Figure 6 (right). Template BTFR from full ALFALFA galaxy sample with results for SN hosts using preliminary new GBT (red) or archival ALFALFA (cyan) HI profile measurements. Circles mark Type Ia hosts and crosses mark Type II hosts.

At the right, we present the mass and rotation velocity measurements for the new GBT and archival supernova host galaxies in the SDSS footprint as a preliminary template BTFR, with the full ALFALFA-SDSS galaxy sample (Durbala et al. 2020).