

# A Green Bank Telescope Search for Highly Extended HI Disks Around Spiral Galaxies

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**Abstract.** Recent UV absorption line studies suggest that a large fraction of missing baryons are in the warm ionized and neutral phases, with about half of Milky Way-mass galaxies containing absorption systems with HI column densities of  $10^{18}$  cm<sup>-2</sup> or greater. This HI gas, which would have been difficult to detect with previous instruments, could be a significant contributor to the missing baryons. The Green Bank Telescope (GBT) presents a unique opportunity to detect this emission. We present results from GBT 21 cm observations of a sample of ten nearby optically luminous spirals, which reveal extended HI gas in half of our sample. The column densities of this extended HI are typically  $\sim 1 \times 10^{19}$  cm<sup>-2</sup>, as measured at distances of 100 kpc from the center of the galaxies.

**Keywords.** galaxies: spiral, galaxies: structure, galaxies: ISM, galaxies: halos

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## 1. Introduction

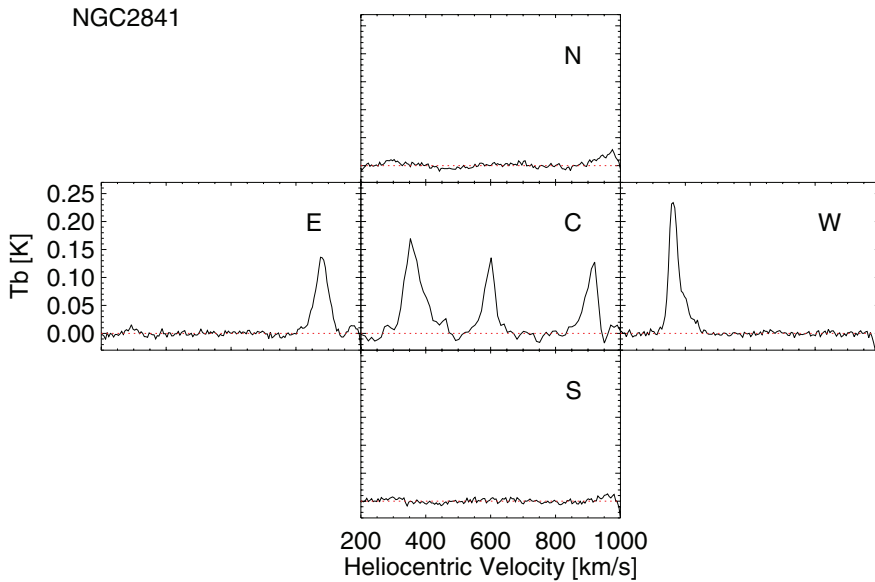
Most of the baryons in galaxies have yet to be identified, as the stars and the easily detected disks of gas comprise 10 to 30% of the baryon content for the amount of dark matter that is inferred from their rotation curves and NFW profiles (models that are supported by weak lensing studies; Bregman 2007). Since baryons must be conserved, investigations focus on the spatial distribution of the gas (stars are largely ruled out as a major baryon component beyond the optical galaxy) and the temperature of the gas. The gas may be distributed out to and beyond the virial radius and may be in a million degree hot phase, a warm ionized phase, and even a neutral phase.

Recent UV absorption line studies suggest that a large fraction of these missing baryons are in the warm ionized and neutral phase. The HST-COS Halos program measures the absorption through galaxy halos with impact parameters less than 150 kpc (Tumlinson *et al.* 2013; Werk *et al.* 2014). They detect absorption in 90% of their sightlines, but the mass budget is dominated by just a few sightlines. For galaxies with stellar masses comparable to or greater than the Milky Way, about half of the galaxies have absorption systems with HI column densities of  $1 \times 10^{18}$  cm<sup>-2</sup> or greater. The authors apply an ionization correction to the absorption systems and derive a mass that is comparable to the missing baryons in galaxies,  $\sim 3 \times 10^{11}$  M<sub>⊙</sub>.

This amount of warm ionized and neutral gas in a halo is not buoyant, and so it has no way of supporting itself hydrostatically and will fall onto the disk on a timescale of 1 Gyr and at an average accretion rate exceeding 100 M<sub>⊙</sub> yr<sup>-1</sup> (Werk *et al.* 2014). This is a preposterously high accretion rate that is in conflict with many different observations. The alternative is that most of the gas is rotationally supported and lies in a disk that extends to 100 kpc around luminous spiral galaxies (the high absorption column densities are not detected beyond an impact radius of 100 kpc).

## 2. Evidence for Extended Gas Disks

We have used the Green Bank Telescope (GBT) to observe a sample of ten local galaxies with  $\log M_* > 10.7$  to search for the 21 cm HI line in their extended disks out to 100 kpc.



**Figure 1.** An example of GBT HI spectra toward one of ten targeted nearby galaxies, NGC 2841. All galaxies were observed along at least four sightlines 100 kpc from the center of the galaxy, in addition to a measurement at the center. Faint HI emission was not detected in the outskirts of half of our targets, while HI emission at a level of  $\sim 1 \times 10^{19} \text{ cm}^{-2}$  was seen in multiple pointings towards the other half of the sample.

Our targets are varied and include several edge-on spiral galaxies, star-forming spirals, and interacting spirals. We have obtained at least four pointings 100 kpc from the centers of each of our targets, and find that half have low-column density gas (typically  $\sim 1 \times 10^{19} \text{ cm}^{-2}$  at 100 kpc) in half of the pointings, with velocities consistent with the rotation of the galaxy (see Figure 1). Detection of this diffuse low column density gas near the high column density disk of the main galaxy required the clean beam and large collecting area of the GBT.

In some cases, the proximity of neighbouring galaxies makes it difficult to unambiguously identify which galaxy the emission is associated with. However, the total rate at which we detect extended HI disks is half of that expected based on the UV absorption studies if the galaxies we have observed are typical. A larger sample that explores a range of galaxy masses and properties will be required to better understand the relation between the extended HI detected in emission vs. absorption.

## References

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