The deep space network/Green Bank Telescope Hydrogen Recombination Line Galactic Plane Survey

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Program: Strategic Initiative

Project Objective:

We conducted an unprecedented radio recombination line survey (RRL) of the Galaxy using the combination of the DSS-43 70 m telescope in Australia and the 100 m Green Bank Telescope in West Virginia (Figure 1) to determine the electron density and nitrogen abundance distribution in the Milky Way by combining RRL spectra with nitrogen far-IR line observations. The key feature of this proposal was to allow that survey to complete a prior initiative foreshortened by the scheduled Depot Level Maintenance period that was conducted on DSS-43 for approximately six months at the end of 2017 and beginning of 2018.

Characterizing the lifecycle of the ISM and the star formation rate in external galaxies is critical for understanding the evolution of galaxies over cosmic time. RRLs are a key probe of the ionized gas that occupies the bulk of the galactic volume and that can be used to measure the star formation rate. While current radio telescopes do not have the combination of sensitivity and spatial resolution to map this gas in distant galaxies, the proposed North American Array (NAA) may have this capability. To establish the validity of this approach toward extragalactic observations, we are conducting a Galactic plane RRL survey at high velocity resolution with the DSS-43 70 m telescope in Australia and the 100 m Green Bank Telescope in West Virginia. Our strategy is to observe the lines-of-sight already surveyed in [C II], CO, and H I as part of the Galactic Observations of Terahertz C+ (GOT C+) Herschel Open Time Key Program. The GOT C+ survey sampled 452 lines-of-sight distributed uniformly in the Galactic plane using high velocity resolution observations. This strategy resulted in sensitive observations of a large number of clouds over a wide range of physical conditions, thus allowing us to determine the statistical properties of several components of the interstellar medium in the Milky Way. Our DSS-43–GBT survey is allowing us to test our recent results from Herschel suggesting that the dense ionized skins of clouds represent an early stage of cloud evolution when ionized gas becomes neutral.

We are using velocity-resolved RRL observations to separate the velocity components of ionized gas along the line of sight. The RRL lines provide an unambiguous determination of the emission measure (neN[H^+]L), which can be combined with the results of our [NII] survey to determine the electron densities (Figure 2). We are also deriving the radial distribution of the RRL emission using the techniques developed by the GOT C+ survey (Pineda et al. 2013) allowing us to study the distribution of ionized gas across the Galaxy. This distribution will be used to relate the RRL emission to the star formation rate in the Galaxy, which is a critical parameter of Galactic evolution.

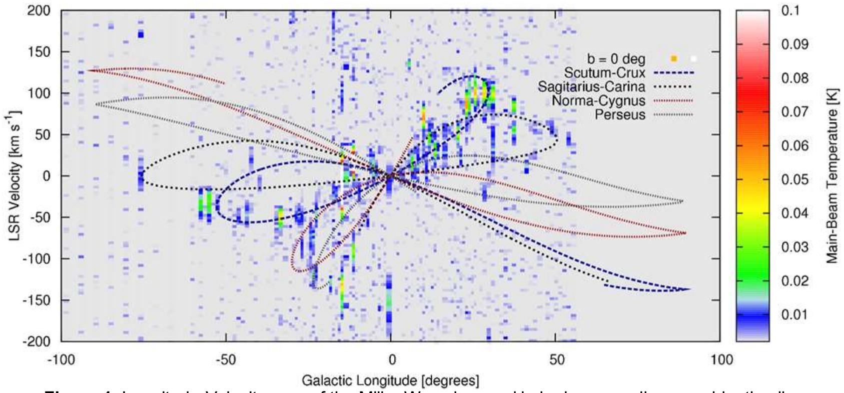

Figure 1. Longitude-Velocity map of the Milky Way observed in hydrogen radio recombination lines with the DSN DSS-43 and GBT telescopes. The straight lines are projections of different spiral arms into the position velocity map.

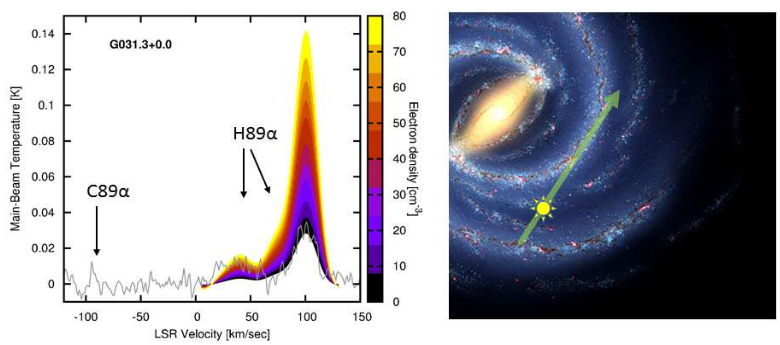

Figure 2. : (left) Sample sightline observed in [NII] and hydrogen recombination lines where the electron density is determined using the [NII]/RRL ratio. The color coded lines are the predicted RRL emission for the observed [NII] spectra and a given electron density. By comparing this predicted spectra with the observed RRL emission, we can identify two velocity components, one with a density of ~60 cm^{-3} at 50 km/sec and another with density of ~5 cm^{-3} at 100 km/sec. The carbon recombination line seen at -100 km/sec is associated with the higher density 50 km/sec component. (right) Graphical representation of the likely location of the two observed components in our Galaxy. The 50 km/sec appears to be a relatively compact dense HII region, while the 100 km/sec covers a long path-length across the Scutum spiral arm.

FY18/19 Results:

In FY19, we finalized a first publication of the project that demonstrates a new technique to derive electron densities using the ratio of [NII]/RRL (Pineda et al. 2019; Figure 2). We also continued using the DSS43 and GBT to collect hydrogen radio recombination lines at X-band in the galactic plane. A representation of the entire data set is shown in Figure 1, in the form of a position-velocity diagram of Milky Way's Galactic plane. We also obtained deep follow up observations in selected sightlines to detect the satellite carbon recombination line, which provides further constraints on the properties of the observed clouds. The new data was calibrated and made suitable for scientific analysis. We expanded our previous work on deriving the electron density along the line of sight with the [NII]/RRL ratio (Pineda et al. 2019) to all observed line of sights, by combining the RRL observations with Herschel/PACS observations of the velocity un-resolved [NII] 122μm and 205 μm lines (Goldsmith et al. 2015). We derived the sightline-averaged electron density using the [NII]/RRL ratio and compare it to that derived using the [NII] 122 μm/205 μm ratio by Goldsmith et al. 2015.
We used the results produced in this task to submit a follow up proposal to the ROSES ADAP program with focus on expanding the electron density derivation techniques developed in this task to a variety of regions In the Milky Way which were observed with Herschel and SOFIA. **We have recently been notified by NASA that this proposal has been funded at the requested level.** We also used results from this task to submit a SOFIA proposal to observe higher ionization states of nitrogen. We expect that the outcome of SOFIA proposals will be announces by Dec 2019.

Publications:

Pineda, J.L., Horiuchi, S., Anderson, L.D., et al., 2019, "Electron Densities and Nitrogen Abundances in Ionized Gas Derived Using [NII] Fine-structure and Hydrogen Recombination lines", arXiv:1905.06935

Significance of Results:

This study will set the stage for similar surveys focusing on characterizing the life cycle of the interstellar medium in external galaxies. Currently it is only possible to study this life cycle locally, but NAA's proposed sensitivity and angular resolution will probe the ISM at much greater distances. Additionally, studying the relationship between RRLs and the star formation rate in the Galaxy, similar to our study linking [C II] and the star formation rate (Pineda et al. 2014), will allow us to establish the reliability of RRLs as tracer of star formation, which could be a powerful application of the NAA for characterizing galaxies in the distant Universe. The work on this task has demonstrated a new technique that combines radio and far-infrared observations to characterize the properties of ionized gas in the galaxy. This technique will significantly enhance the science return from the recently selected ASTHROS balloon (P.I. Pineda), which will observe far-infrared nitrogen lines that can be combined with DSS-43 data.

The DSN/GBT hydrogen recombination line galactic plane survey is an important addition to the science case for the North American Array and provides valuable information for defining the science requirements for this new facility. Our program will put JPL in a strong position for possible scientific and technological contributions to the North American Array project. This task opens the possibility of new funding through the ROSES ADAP program and NASA/SOFIA observing proposals.

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