A NEW METHOD FOR TESTING STAR FORMATION AND METAL TRANSPORT THEORIES IN GALAXIES.

Research and Technology Development Annual Report

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A. OBJECTIVES

The first objective is to quantify the energy and momentum that stellar feedback has injected into the ISM of Galactic star forming regions to test competing star formation hypotheses. This objective will be accomplished by obtaining Hydrogen RRL (H-RRL) measurements, which provide the ionizing and kinetic energy of the gas, in a statistically significant sample of Galactic star forming regions covering a range of masses, luminosities, and evolutionary stages. In the program proposed here we will combine the H RRL measurements with archival [NII] observations in the Carina region to provide the first quantitative assessment of the two competing star formation hypotheses using the nitrogen abundance distribution.

The second objective is to probe the transport of metals in the disk of galaxies. This goal will be accomplished by measuring H-RRL in a representative sample of galaxies, with a wide range of stellar luminosity and type, ranging from massive Milky Way type galaxies to dwarf galaxies. In the program proposed here we will obtain a proof of principle and preliminary assessment of theoretical predictions about the transport of metals in galaxies by combining H RRL observations with archival [NII] data in Galaxy M83.

B. STRATEGIC FOCUS AREA

Topics:

[X] Formation and evolution of galaxies

C. BRIEF BACKGROUND

The regulation of star formation in galaxies plays a fundamental role driving galaxy evolution by determining their stellar mass growth and chemical enrichment. Stars form out of the gravitational collapse of dense molecular gas, and, as they form and enter the main sequence, they produce UV and visible photons that can heat and ionize their surroundings, and stellar winds that push accreting material away from the stars. This feedback can reduce the amount of molecular gas available to form additional stars, or, at the very least, reduce the efficiency at which additional stars might form. At later times (>4 Myr) supernova explosions can inject additional energy and momentum, further slowing star formation and destroying their progenitor clouds. These processes together are known as stellar feedback. A key unknown in our understanding of the role of star formation in galaxy evolution is the coupling of the energy produced by stellar feedback with its surrounding interstellar medium. The distribution of the elemental abundance of nitrogen, which traces metallicity, can be used to determine the efficiency at which energy from stellar feedback is injected into the ISM, and thus we propose that the nitrogen abundance can be used to test competing star-formation theories.

D. APPROACH AND RESULTS

During the first months of fiscal year FY23, we focused on implementing and refining the data reduction and map making pipelines needed to generate maps of H-RRL and [NII]. To test the H-RRL pipeline we used data taken in the Carina nebula during the commissioning period of the DSN ROACH2 spectrometer from 2019 to 2021. This spectrometer provided a 1TB raw data set and we implemented a gain correction to the data by determining the elevation of the source at the time of the observations and a synchronous reading of a radiometer to determine the system temperature of the data which in turn was used to calibrate the observations. We analyzed the data manually as well as developing diagnostics tools to determine whether the receiver IF configuration is correct. These methods were also used to identify anomalous data sets that can have an important effect in the quality of the final data set. In Figure 1a, we show the results of this analysis, with a section of the Carina nebula generated with data, as it was originally reduced, and with our new data reduction pipeline. Figure 1a illustrates that in our new procedure the quality and calibration of the data is significantly improved, removing anomalous stripes in the maps and providing a more accurate calibration. This pipeline can be used with all new data sets produced with the DSS43 and will ensure that the quality of the data is ready for analysis.

We also developed a preliminary implementation of a method to determine electron temperatures from RRL and [NII] observations. The electron temperatures, T_e,are an important parameter used in the determination of nitrogen abundance from observations of their far-infrared emission, and therefore an accurate determination of T_e is needed. We downloaded and reduced SOFIA [NII] data and extracted spectra for 5 positions (Figure 1b). Because of their different masses Hydrogen and Nitrogen are expected to have different thermal line widths, but the same turbulent component. The difference in line widths is used to solve for the electron temperature and turbulent component. We fitted Gaussians for the [NII] and RRL data and used their linewidths to determine the electron temperature. The temperatures range from 7000-12000K, consistent with those expected for HII regions. This work will be expanded to more positions to generate a temperature map and, when the RRL calibration is finalized, we will compare the results from using the ratio of RRL to Radio continuum for deriving electron temperatures to validate the approach. We will also continue working with the external collaborator in preparing the theoretical predictions of the metal transport in galaxies for comparison with data.

E. SIGNIFICANCE OF RESULTS/BENEFITS TO NASA/JPL

The work performed in this task will provide a new observational technique that can become an important science driver of the JPL-led PRIMA probe mission, a new mission class recommended by the ASTRO2020 Decadal Survey, and follow up flights of the JPL ASTHROS balloon project, a long duration Antarctic NASA balloon for launch at the end of 2024, thus giving JPL a competitive lead for the selection of new far-infrared sub-orbital and orbital missions. It will also strengthen the science case for new technology development in important areas of JPL expertise, such as heterodyne and direct detector systems at far-infrared wavelengths, which will enable velocity resolved observations of large samples of star forming regions, and sensitive observations of the disk of large numbers of galaxies, respectively. The proposed work will also showcase the use of the DSN antennas for radio astronomy to support JPL-led NASA missions. The RTD program is the only funding source for ground-based observations, as JPL researchers have no direct access to NSF funding and NASA has removed the possibility of ground-based observations in support of missions from the ROSES APRA/ADAP programs.

F. NEW TECHNOLOGY

None

G. FINANCIAL STATUS

The total funding for this task was $187,596, all of which has been expended.

H. ACKNOWLEDGEMENTS

None

I. PUBLICATIONS

None

J. REFERENCES

None

K. APPENDIX

None

L. FIGURES

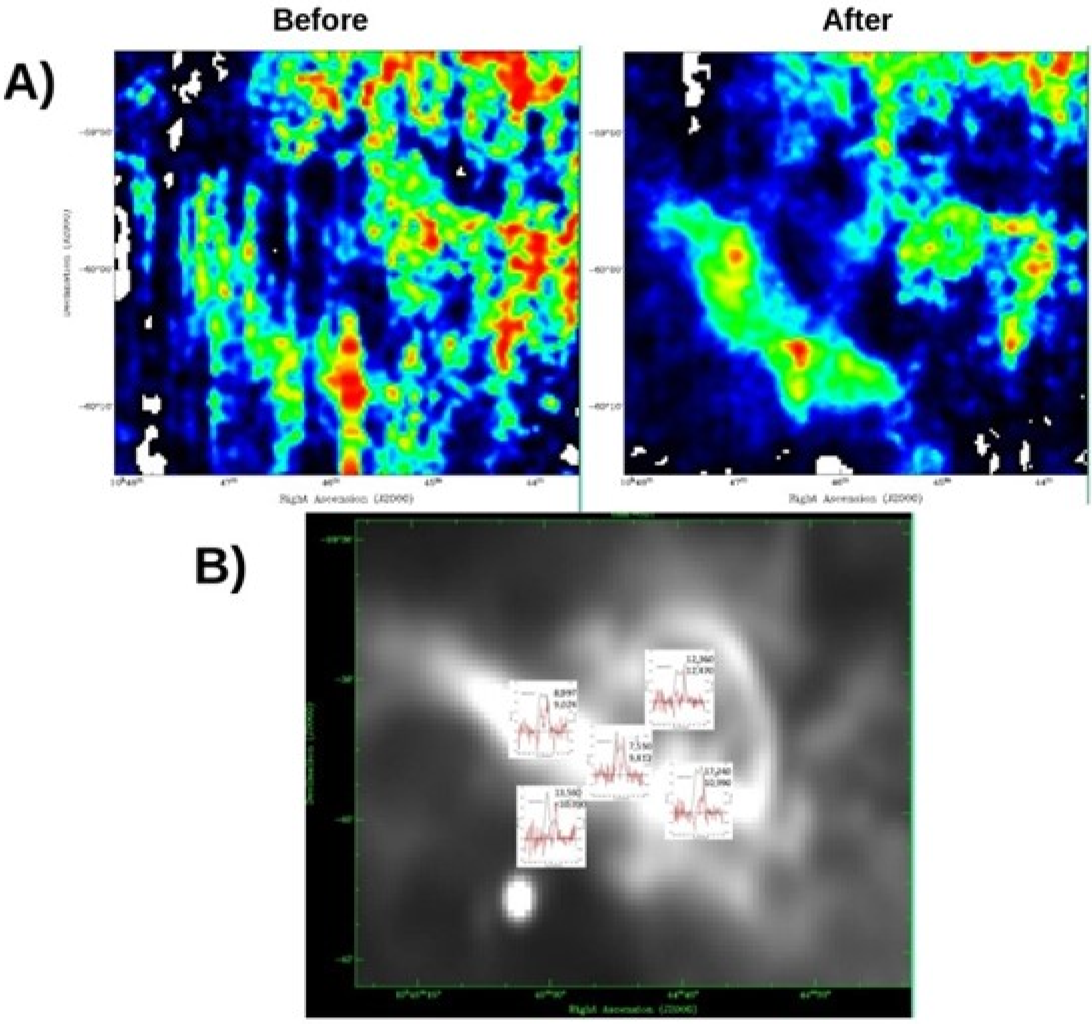

Figure 1.

Figure 1a: Sample region in the Carina Nebula observed with the DSS43 antenna in RRL emission. In the left panel we show the result of the original data reduction pipeline and in the right panel we show the map resulting from the data analysis tools developed under this task. It can be seen that significant improvements on the signal-to-noise ratio are obtained. Figure 1b: Sample positions in the Carina II region where RRL and [NII] 205micron spectra were combined to determine the electron temperature. We identified two velocity components having slightly different electron temperatures in this region.

M. COPYRIGHT STATEMENT