National Aeronautics and Space Administration

Quantifying radiative feedback in regulating galactic star formation with the [NIII] 57um line

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Objectives and Background:

A key goal in modern astrophysics is understanding the physical processes governing galaxy evolution, which is in turn driven by star formation. Star formation is an inefficient process in which only a small fraction of available gas in galaxies is converted into stars. Theoretical simulations show that radiative and mechanical feedback from massive stars plays a fundamental role in slowing and suppressing star formation by dissipating star forming interstellar clouds. The key for understanding feedback in regulating star formation is to determine the coupling of radiative energy and momentum to the interstellar gas. In this project we searched the ISO/Herschel/SOFIA archives for observations of [NIII] 57um, [NII] 122um and 205um, and [OIII] 52um and 88um, far-infrared (FIR) emission in galactic and extra galactic sources to identify a data set in which we can characterize and understand the role of radiative and mechanical feedback in the regulation of star formation in galaxies. There is a rich database of observations of these, and other, far-infrared emission lines in galactic and extra galactic sources available for exploitation. We will use these data to determine the ionization structure of these regions which can then be used to quantify the amount of extreme ultraviolet energy that is injected by massive stars in a variety of environments. These results are important for testing and validating numerical models of the evolution of galaxies.

Approach and Results:

A preliminary search found a large data set of these observations are available from ISO surveys (227 galaxies), Herschel (52 galaxies), and SOFIA (25 galaxies) . Figure 1 is a histogram summarizing the number of detections of FIR lines, [CII], [NII], [NIII], [OI], and [OIII] in the ISO and Hecschel surveys representing nearly 1800 lines-of-sight (LOS). It shows the rich data base in [NII] (542 LOS), [NIII] (222 LOS), and [OIII] (337 LOS). We also located similar data sets in the Sagitarius A, Orion, and Carina Galactic star forming regions. As the bulk of these observations have not been analyzed in detail there is huge potential for future analysis and supplemental observations. In a subsample of this data set, we used the [NII] 205um and 122um lines to determine electron densities, n(e) and column densities of N+. It was combined with the [NIII] 57um line, to derive the N2+ column densities, and thus the N2+/N+ ratio in these galaxies/regions. To derive the electron density appropriate to the regions giving rise to [NIII] emission we needed to use a probe of dense n(e) appropriate to high ionization states. Analysis of the excitation properties of O2+, which has two FIR lines, [OIII] at 52um and 88um, and must be present in the N2+ region. Figure 2 plots the ratio of the intensity of the [NII] 122 to 205um and [OIII] 52 and 88um lines versus n(e), showing that each probes different density range. The left panel of Figure 2 shows n(e) solutions for 16 extragalactic line-of-sight sources using the [OIII] lines, which combined with [NIII] would yield the N2+ column density in dense EUV environments. In Figure 3, we show a preliminary analysis of the data set in the Sagitarius A region. In the left panel we show the electron density derived used two different methods, the [NII] 122um/205um ratio and the [OIII] 52um/88um. These two ratios trace different volume density and ionization regimes in the observed region, and the observations suggest electron densities that differ by a factor 10-100 from the low ionization region traced by [NII] and the high ionization region traced by the [OIII] and [NIII] lines. In the left panel we show a comparison between N+ and N++ column densities, which are derived from the electron density derived using the [NII] 122um/205um ratio, and the intensity of any of these lines, for N+, and using the densities derived using the [OIII] 52um/88um ratio, and the intensity of the [NIII] 57um, for N++. We find that N++ represents only a small fraction of the total N++N++, suggesting that most of the ionized gas mass is at a low ionization state and that most of the nitrogen in this region is singly ionized.

Significance/Benefits to JPL and NASA:

This work will give us a head start, and thus a big advantage, in obtaining ROSES/ADAP funds to analyze and publish archival [NIII] 57um and [OIII] 88um and 52um data and for identifying sources that can be proposed for follow up observations at higher angular resolution with the future JPL-led PRIMA far-infrared probe mission. This research will also be used to support the development of the science case for instrumentation that will enable the first high spectral resolution observations of the [NIII] 57um line and [OIII] 88um and 52um lines in balloon missions, Smallsats, or MIDEX class space missions, and the far-infrared probe (PRIMA) and flagship missions recommended by the ASTRO2020 decadal survey.

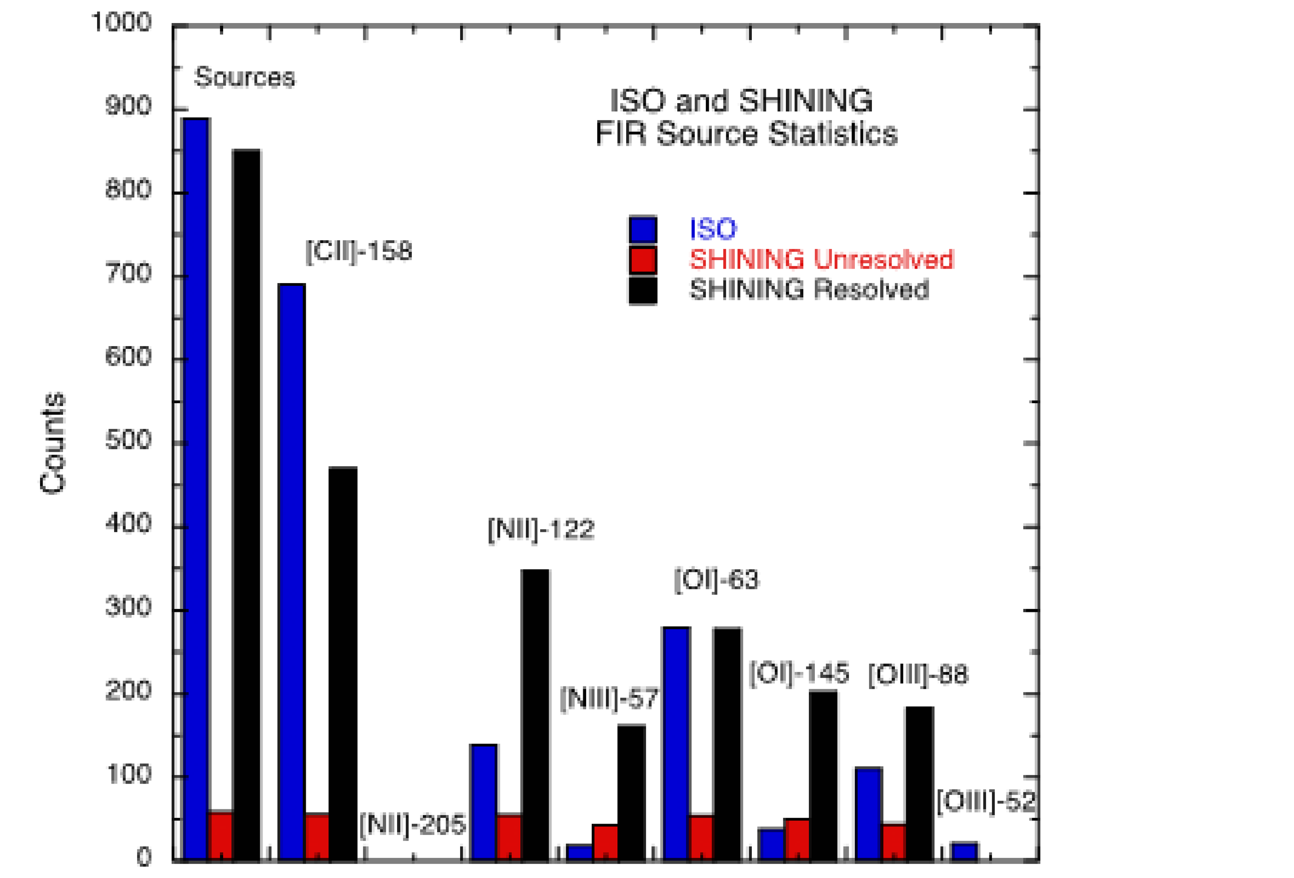

Figure 1: This histogram plots the number of detections in the ISO and Herschel surveys where the FIR lines of ionized carbon ([CII]), nitrogen ([NII] and [NIII]), and oxygen ([OIII]), and of atomic oxygen [OI] were detected out of about 1800 extragalactic lines-of-sight.

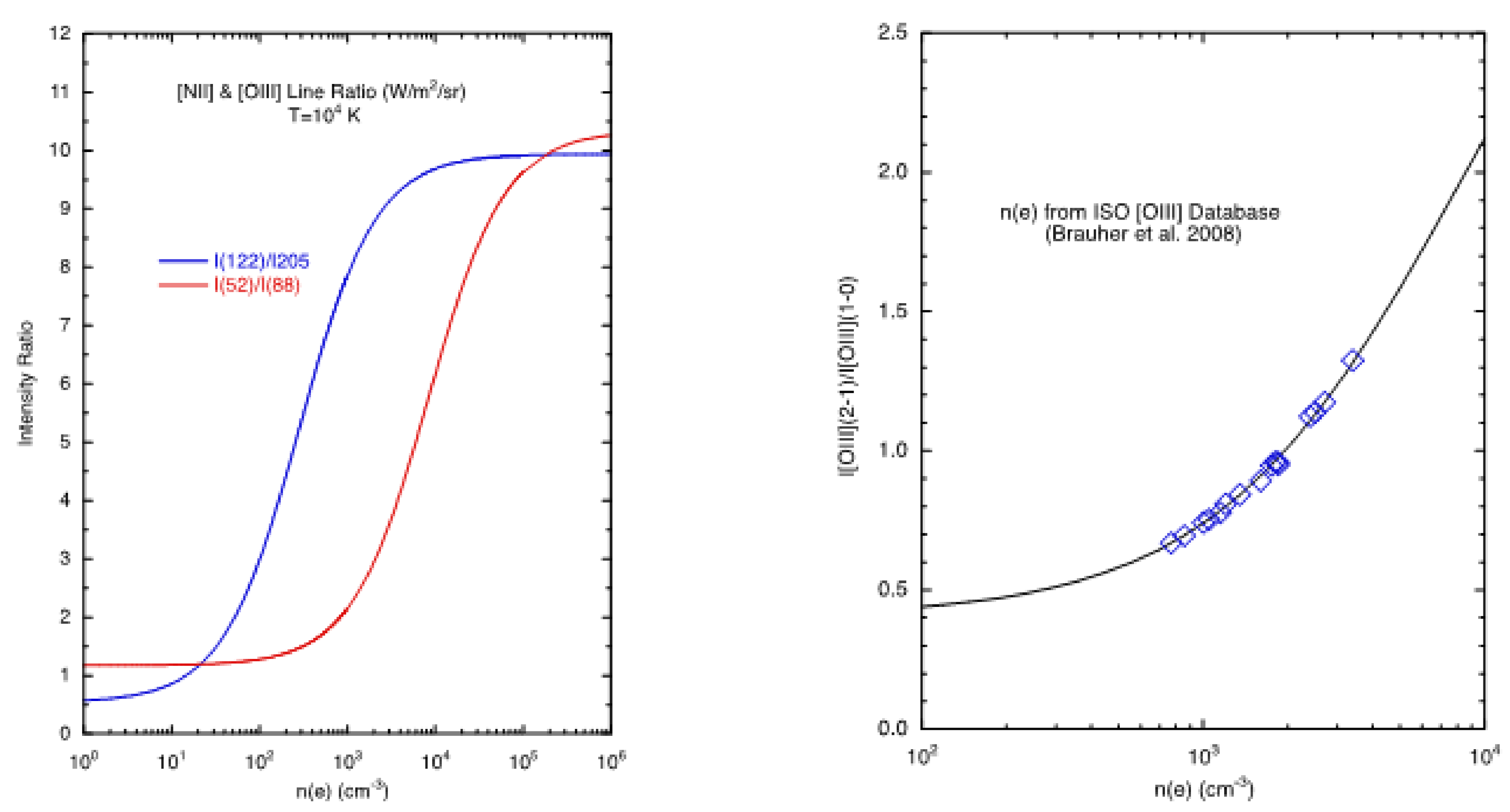

Figure 2: (left) Intensity ratios of [NII] 122 and 205mm and [OIII] 52 and 88mm lines versus n(e), showing that these probe different electron density regimes, 10 – 102 cm-3 for N+ and 102 – 104 cm-3 for O2+. The [OIII] lines of O2+ are, therefore, excellent probes of n(e) where [NIII] arises. (right) Electron density derived for 16 extragalactic sources (boxes) using the [OIII] lines, which probe the dense EUV ionized regions from which [NIII] arises. The curve is the solution for the ratio of intensities of the [OIII] 52mm to 88mm lines at 104 K. Combining the n(e) solutions with the [NIII] intensity yields the column density of doubly ionized nitrogen, N2+.

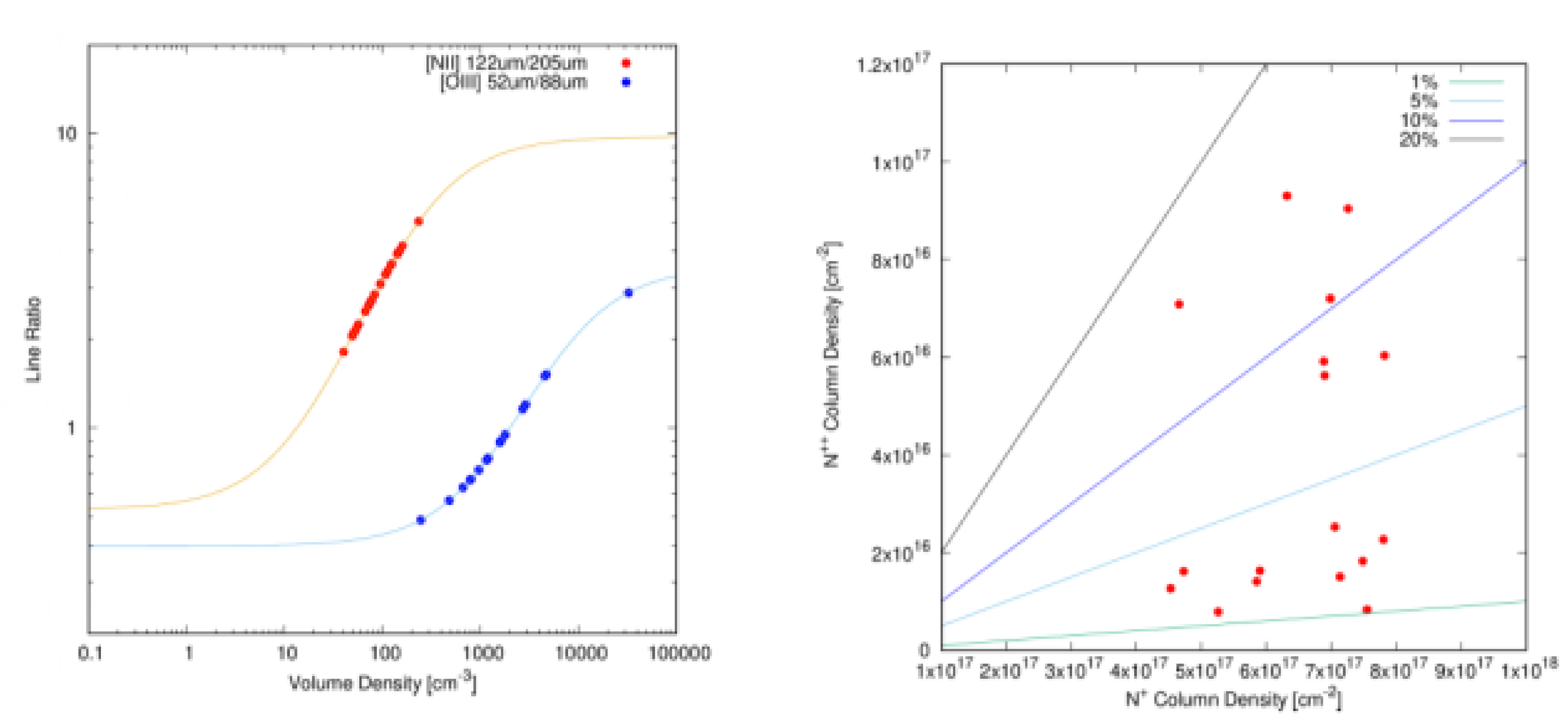

Figure 3: (left) Electron density derived for 25 positions in the Sagittarius A region at the Milky Way's center using the [NII] and [OIII] lines, which probe moderate density, low ionization regions, and dense GUV ionized regions from which [NIII] arises, respectively. We see a large density difference between the low ionization and high ionization regions. (right) Comparison between singly and doubly ionized nitrogen column density derived using the electron densities for each region, and the [NII] 205um and [NIII] 57um emission. We see that while dense the high ionization region has a small contribution to the total nitrogen mass in the region.

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