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PHYSICS REVEALED BY BROAD-RANGE CO LADDERS AND FINE-STRUCTURE LINES IN M83

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ABSTRACT

Since the launch of the Herschel Space Observatory, our understanding about the photo-dissociation regions (PDR) has taken a step forward. In the bandwidth of the Fourier Transform Spectrometer (FTS) of the Spectral and Photometric Imaging REceiver (SPIRE) on board Herschel, ten CO rotational transitions, including $J = 4-3$ to $J = 13-12$, and three fine structure lines, including [CI] 609, [CI] 370, and [NII] 205 μm, are covered. I present our findings from the FTS observations at the nuclear region of M83, based on the spatially resolved physical parameters derived from the CO spectral line energy distribution (SLED) map and the comparisons with the dust properties and star-formation tracers. This article discusses (1) the potential of using [NII] 205 and [CI] 370 μm as star-formation tracers; (2) the excitation mechanisms of warm CO in the nuclear region of M83.

Key words: Galaxies: individual (M83) ; Submillimeter: ISM ; Techniques: imaging spectroscopy

1. INTRODUCTION

M83 is a nearby grand-design galaxy located 4.5 Mpc away in the southern hemisphere. Structure-wise, it is very similar to our Milky Way, and its face-on orientation makes it ideal to study the star-forming regions in its nucleus and along the spiral arms. It is also one of the most active nearby starburst galaxies. In the past century, at least six supernova events have been detected in this galaxy. M83 has been found to be a molecular gas rich galaxy compared to the Milky Way. Morphologically, observations of CO have demonstrated that the structure of molecular gas in M83 is quite complex. However, ground-based studies of physical conditions for molecular gas in M83 have been restricted by the difficulty of observing CO transitions in the *higher–J states.* The highest transition detected with groundbased telescopes is $J = 6-5$, which may be at or near the peak of the CO spectral line energy distribution (SLED) of M83 (Bayet et al., 2006).

In this work, we investigate how the spatially–resolved physical conditions of the molecular gas compares with the dust properties and star formation with data observed by the Herschel SPIRE FTS.

2. OBSERVATION

The SPIRE FTS field of view (FOV) is indicated on the star formation rate (SFR) map of M83 in Figure 1. In this map, each pixel is equal to $15'' \times 15''$ ($\sim 330 \times 330\,\mathrm{pc}^2$). The dark-gray–masked pixels are not covered by bolometers. The cyan and magenta crosses indicate the pointings of bolometers from short ($194-324\,\mu$m) and long ($316-672\,\mu$m) wavelength modules. In Figure 1, the SFR is calculated based on the FUV and 24 μm maps using the relationship calibrated by Hao et al. (2011). In this work, the gray-masked pixels are truncated after convolving all CO line maps to a common beam with full-width-half-maximum (FWHM) of $42''$ ($\sim$ 920 pc), which is the beam FWHM of the SPIRE FTS at the CO $J = 4-3$ line. The effective FOV of this observation is $\sim 2' \times 2'$ ($\sim 2.5 \times 2.5\,\mathrm{kpc}^2$).

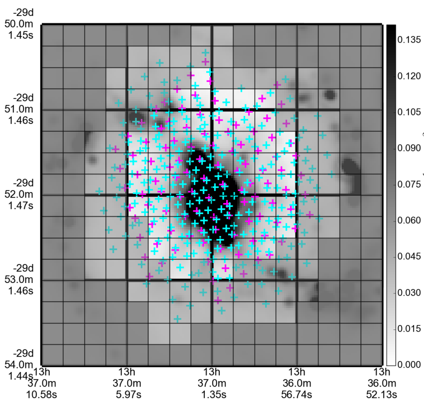

Figure 1. An indication of the FOV of the observation used in this work.

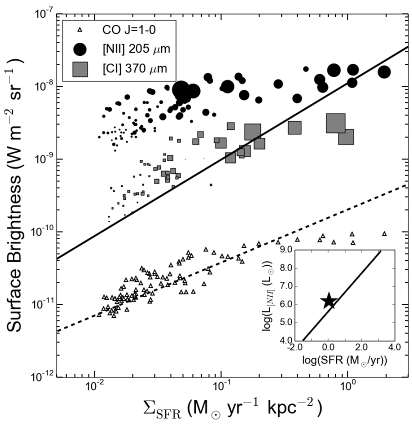

Figure 2. Comparison of different SFR tracers in M83.

3. RESULTS

We compare the [NII] 205 μm (solid dots), [CI] 370 μm (gray squares), CO $J = 1 - 0$ surface brightness (triangles) to the SFR surface density at $FWHM = 42''$ in Figure 2. In this figure, the solid line indicates the converted calibration of [NII] 205 μm as a SFR indicator given in Zhao et al. (2013). The *CO J=1-0* map is observed by SEST (Lundgren et al., 2004). The black dashed line indicates the relationship between the CO surface brightness and SFR surface density calibrated from M51 (Kennicutt, 2007). To investigate how this relationship appears in a larger scale, we compare the integrated properties of the [NII] 205 μm luminosity ($L_{[\mathrm{NII}]}$) and the total SFR of M83 as the black star in the embedded plot of the Figure 2. The calibration given by Zhao et al. (2013) is indicated in the embedded plot by the dashed line. Our result shows that although [NII] 205 μm and [CI] 370 μm might show the potential as SFR tracers on a global scale, their spatial distributions within the galaxy appear to differ from the FUV and 24 μm emission.

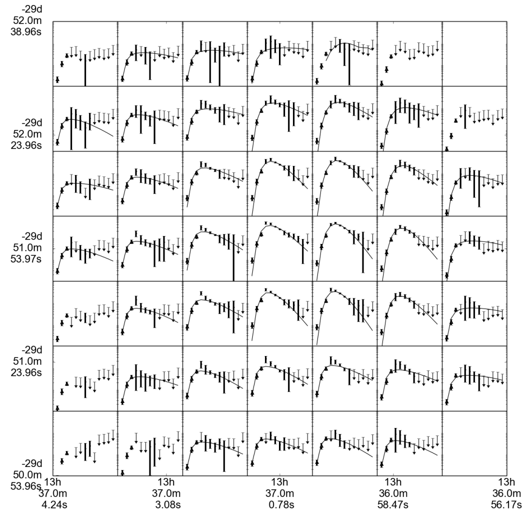

Figure 3. A map of CO SLEDs from M83 with the best-fit results from RADEX. The graphs in all pixels are within the same dynamical range with the horizonal axes (J_{up}) range between 0 and 14 and the vertical axes (I_{CO}) in log-scale ($10^{-10} < y < 10^{-8}$ W m^{-2} sr^{-1}).

To derive the physical parameters, the observed CO SLEDs from the un-masked region in Figure 2, are fitted by a non-LTE statistical equilibrium radiative transfer code, RADEX (Van der Tak, 2007). Based on the observed CO SLED (see Figure 3), Wu et al. (2015) show that the derived kinetic pressure, $P_{\mathrm{kin}} = n(\mathrm{H}_2) \times T_{\mathrm{kin}}$, shows a gradient toward the north-west of the starburst nucleus. This gradient coincides with an observed (possibly background) radio-jet. As a comparison, the intensity of the interstellar radiation field (ISRF, $\langle U \rangle$) is independently derived from fitting the SED to the 9 photometry bands (IRAC, MIPS, Herschel PACS, and SPIRE), assuming that the distribution of starlight intensities heating the dust follows a power law and the Galactic grain composition (Galliano et al., 2011). Comparison of P_{kin} with $\langle U \rangle$ shows that P_{kin} is about 30 times the radiation pressure of the ISRF, hinting that the interstellar starlight might not be sufficient to provide the required energy budget for the observed higher-J CO transitions. The peak of the derived molecular hydrogen density, $n(\mathrm{H}_2)$, shows an offset toward the north-west of the nucleus, where very young (~ 2 Myr) star clusters are observed, hinting the observed CO transitions may be associated with recent starbursts (Wu et al., 2015).

4. CONCLUSION

Although the observed [NII] 205 μm demonstrates its potential as a SFR indicator on a global scale, more spatially-resolved study is needed. The observed SLEDs show the excitation of the CO lines from $J = 4 - 3$ to $13 - 12$ is dominated by the region north-west of the nucleus, where very young star clusters are observed. Our results suggest that the higher–J CO lines is more likely associated with recent starbursts in the nucleus.

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