CO(4-3) & [CI] Observations in Merging ULIRGs with ASTE

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Abstract

Galaxy mergers play an important role in the evolutionary process of galaxies, as it changes the physical and chemical condition of the ISM, and intensities the starburst activity as seen in the frequent occurrence of mergers in Ultra/Luminous Infrared Galaxies (U/LIRGs). Observations of diffuse and dense gas traces will allow us to investigate the physical condition of the ISM and star formation properties triggered during mergers. We present here the preliminary results of CO(4-3) and [CI](1-0) observations obtained toward merging U/LIRGs with ASTE. Using PDR models, we have constrained the gas density and UV radiation field of systems to be higher than 1.6 × 10^4 cm^{-3} and 3.1 × 10^4, suggesting the highly condensed and energized gas conditions in merging ULIRGs.

Introduction & Observations

It is known that interaction between gas-rich galaxies can effectively remove the angular momentum of gas, allowing large amounts of gas fall into the nucleus of galaxies. As a consequence, the gas density increases, triggering intense star formation (starburst; SB) and/or active galactic nucleus (AGN) from massive accretion of gas to the supper massive black hole. During the process, the physical properties of gas are changed by various large scale processes such as heating, compressing and shocks. It is therefore important to quantify the physical properties of gas in such merging galaxies in order to understand the relation between large scale processes and ISM condition.

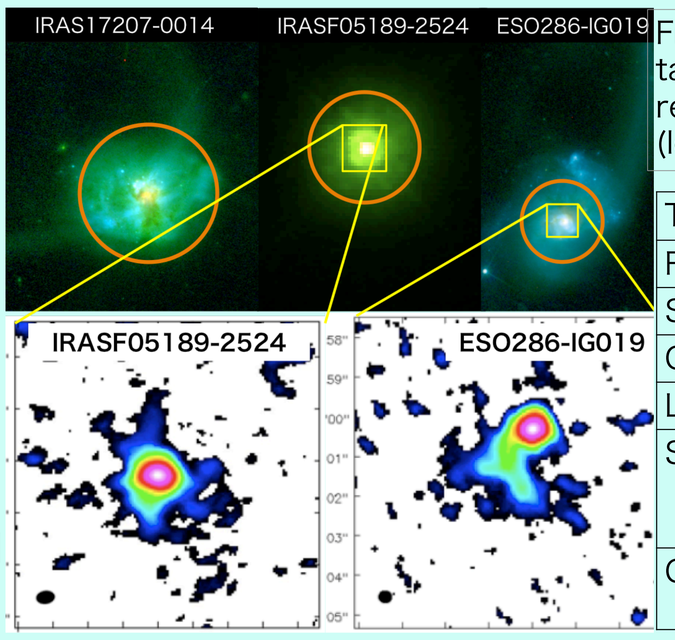

Fig. 1: (upper) HST images of three target ULIRGs. The orange circles represents beam size of ASTE Band 8. (lower) The CO(1-0) images with ALMA.

Telescope	ASTE
Receiver	Band8
Spectrometer	WHSF
Obs. Mode	On The Fly
Lines	CO(4-3), [CI](1-0)
Sources	IRASF 17207-0014 IRASF 05189-2524 ESO 286-IG019
Obs. Date	2016 Sep. 29 – Nov. 15 2017 Jul. 08 – Sep. 01.

In order to study the condition of gas in merging galaxies, our group have been surveying several molecular gas tracers in merging Ultra Luminous Infrared Galaxies (ULIRGs). As one part of this survey, six ULIRGs have been observed with ALMA. In this poster, We present the preliminary results of ASTE observations in three of them. We observed observe CO(4-3) and [CI](1-0) emission lines. CO(4-3) can be used for a tracer of high density gas. On the other hand, [CI] is known as a low density gas tracer like as CO(1-0) line, and also known as a photodissociation region (PDR) tracer. In this study, we estimate the gas density and the strength of radiation field.

Results & Discussion

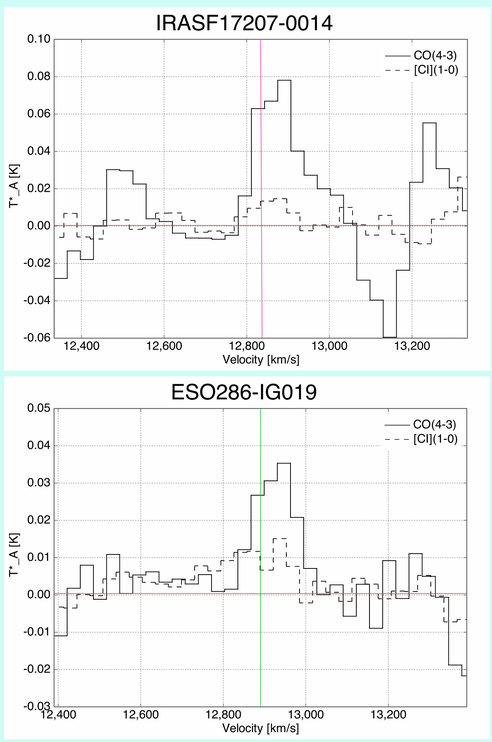

Fig. 2: The CO(4-3) (solid line) and [CI](1-0) (sparse line) spectrum in IRASF 17207-0014 (upper-left), IRASF 05189-2524 (upper-right) and ESO 286-IG019 (lower-left). The vertical lines represent the systematic velocity of systems.

	$L'_{CO(4-3)}$ [K km/s pc^2]	$L'_{[CI](1-0)}$ [K km/s pc^2]	FIR [$L_\odot$]
IRASF 17207-0014	5.0(±0.3)×10^9	7.9(±0.5)×10^8	2.5×10^{12}
IRASF 05189-2524	3.6(±0.2)×10^9	7.7(±0.4)×10^8	1.3×10^{12}
ESO 286-IG019	2.1(±0.1)×10^9	9.4(±0.5)×10^8	1.0×10^{12}

CO(4-3)/[CI](1-0) flux ratio as an indicator of mergers/disk galaxies

The $L_{CO(4-3)}/L_{[CI](1-0)}$ can be used as a tracer of dense gas mass fraction, and it is known that this ratio is systematically higher in merger driven systems.

Papadopoulos+12 find that the $L'_{CO(4-3)}/L'_{[CI](1-0)}$ ratio (in units of K km/s pc^2) is 4.55 ± 1.5 for the merger-driven ULIRGs and 0.45-1.3 for the disk-dominated galaxies. We find $L'_{CO(4-3)}/L'_{[CI](1-0)}$ of 6.3±0.8, 4.6±0.5 and 2.2±0.2 for IRASF 17207-0014, IRASF 05189-2524 and ESO 286-IG019 respectively. These results are consistent with Papadopoulos+12's findings and thus suggest the dominance of dense gas in these merging ULIRGs.

Gas density and radiation field from PDR model

We constrain the gas densities and the strengths of far-UV radiation field of systems globally, by comparing the luminosity ratios to the values from PDR model by Kaufman et al. (1999). The estimated values for three merging ULIRGs are similar:

- n > 1.6-7.9 × 10^4 [cm^{-3}]
- G_0 > 3.1-7.1 × 10^4

※G0: the UV radiation field in the Milky Way in Habing units (1.6 × 10^{-3} erg s^{-1} cm^{-2}).

These properties are comparable to those of the local ULIRGs determined by using other lines. Both n and G_0 are higher than those of normal star-forming and starburst galaxies.

Alaghband-Zadeh+13 conducted the same analysis for z > 2 sub-millimeter galaxies, finding n of 1.3-3.2 × 10^4 [cm^{-3}] and G_0 of 0.3-1.2 × 10^4. We therefore derive higher gas density and radiation field in merging ULIRGs than in the high-z SMG through the same analysis using CO(4-3), [CI](1-0) and the luminosity of far infrared.

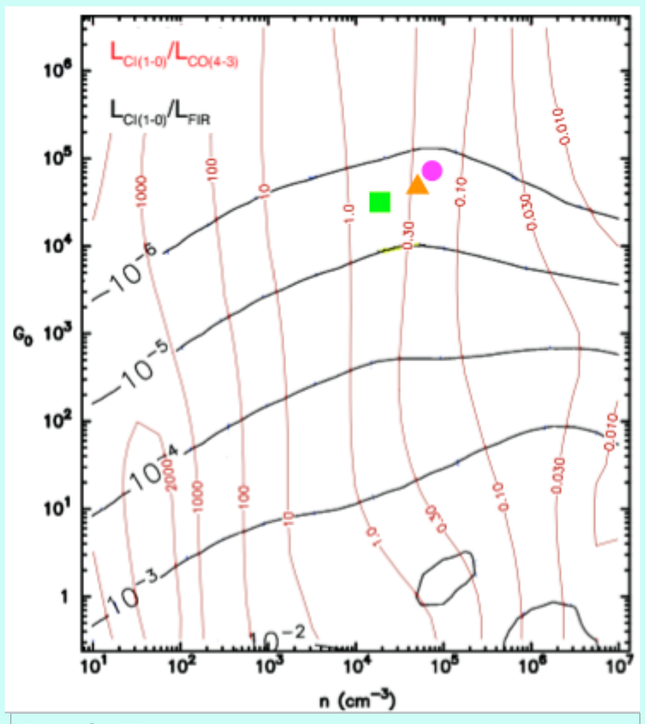

Fig. 3: The contours represent $L_{[CI]}/L_{CO(4-3)}$ (red line) and $L_{[CI]}/L_{FIR}$ (black line) (in units of $L_\odot$) at various levels of gas density (n) and FUV radiation field (G_0) from PDR models of Kaufman+99. The pink circle, orange triangle and green square shows n and G_0 in IRASF 17207-0014, IRASF 05189-2524 and ESO 286-IG019 respectively.

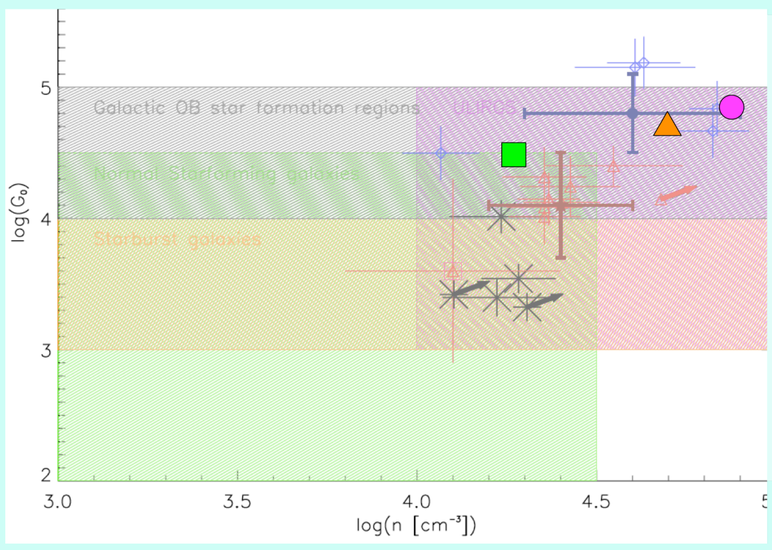

Fig. 4: The far-UV radiation field G_0 against the gas density n from Alaghband-Zadeh+13. The pink circle, orange triangle and green square represents IRASF 17207-0014, IRASF 05189-2524 and ESO 286-IG019 respectively. The other points are from the previous studies.