Investigating the Relation between CO (3-2) and Far Infrared Luminosities for Nearby Merging Galaxies Using ASTE (Michiyama+16)

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Abstract

We present the new single dish CO (3–2) emission data obtained toward 19 early stage and 7 late stage nearby merging galaxies using the Atacama Submillimeter Telescope Experiment (ASTE). Combining with the single dish and interferometric data of galaxies observed in previous studies, we investigate the relation between the CO (3–2) luminosity ($L'_{\rm CO(3-2)}$) and the far Infrared luminosity ($L_{\rm FIR}$) in a sample of 29 early stage and 31 late stage merging galaxies, and 28 nearby isolated spiral galaxies. We find that normal isolated spiral galaxies and merging galaxies have different slopes (α) in the $\log L'_{\rm CO(3-2)} - \log L_{\rm FIR}$ plane ($\alpha \sim 0.79$ for spirals and ~ 1.12 for mergers). The large slope ($\alpha > 1$) for merging galaxies can be interpreted as an evidence for increasing Star Formation Efficiency (SFE=$L_{\rm FIR}/L'_{\rm CO(3-2)}$) as a function of $L_{\rm FIR}$. Comparing our results with sub-kpc scale local star formation and global star-burst activity in the high-z Universe, we find deviations from the linear relationship in the $\log L'_{\rm CO(3-2)} - \log L_{\rm FIR}$ plane for the late stage mergers and high-z star forming galaxies. Finally, we find that the average SFE gradually increases from isolated galaxies, merging galaxies, and to high-z submillimeter galaxies / quasi-stellar objects (SMGs/QSOs). By comparing our findings with the results from numerical simulations, we suggest; (1) inefficient star-bursts triggered by disk-wide dense clumps occur in the early stage of interaction and (2) efficient star-bursts triggered by central concentration of gas occur in the final stage. A systematic high spatial resolution survey of diffuse and dense gas tracers is a key to confirm this scenario.

Introduction

- merger は銀河進化を議論する上で重要

  ✓ガスの圧縮により星形成が銀河全体で活発に

  ➡dense gas の観測が不可欠

- FIR luminosity と dense gas tracers (CO (3-2), HCN (1-0)) luminosity に相関

  ✓dense gas が massive な星形成の直接の材料であることを示唆

Introduction

- local quiescent galaxies の SFE は merging ULIRGs より小さい (**Wilson+12**)
- high-z の観測から normal galaxies と starburst galaxies は **bimodality** を示す

✓数値計算 (**Powell+13**) では bimodality なし

➡merger が log L_{FIR}-log L'_{CO} 平面でどこにあるかを確定させることが重要

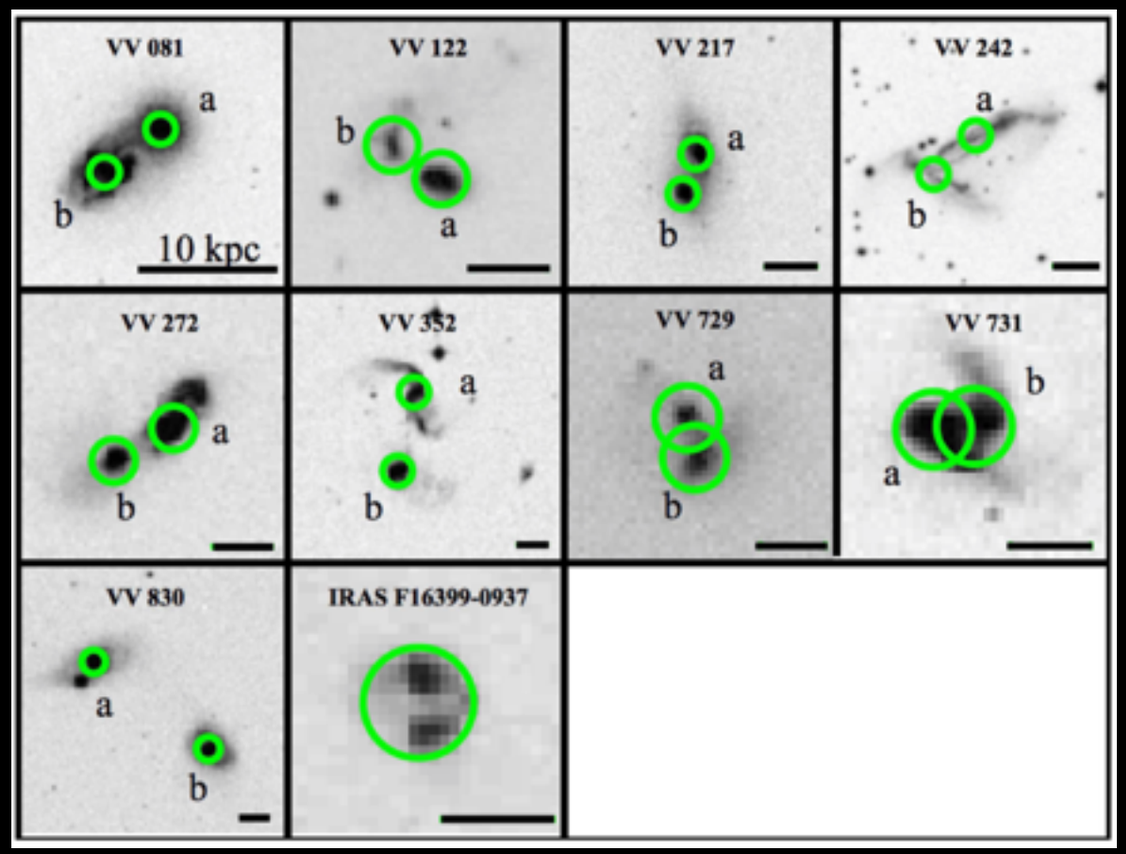
Introduction

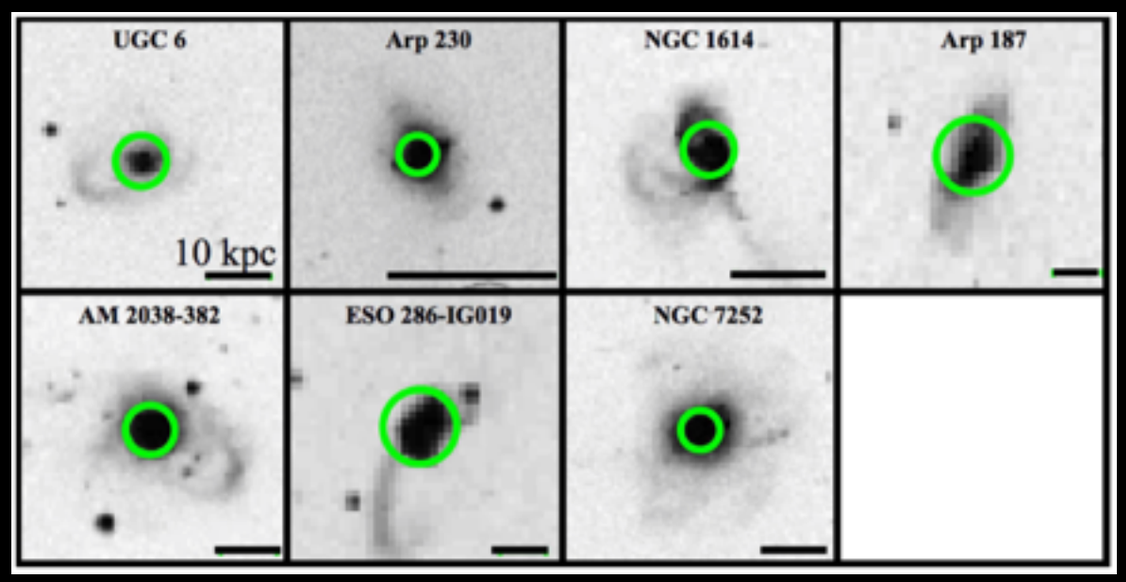
- 既存の観測では late merger で明るいものに注力して観測されている

➡本研究では広い FIR luminosity ($10^{9\text{-}13}$ L_{sun}) で early/late merger の CO (3-2) を観測

Sample Selection

- criteria
  - ✓ $\Delta m_B < 3$
  - ✓ IRAS RBGS
  - ✓ optical V_R が既知
  - ✓ dec. < 30°





Observation

- ASTE で **CO (3-2)** を観測 (t_{total} ~ 120 hrs)
- main beam size = **22”** @ 350 GHz

➡2.5 kpc @ Arp230 (D_L = 19.3 Mpc)

✓典型的な LIRGs の CO size は 0.3-3.1 kpc (**Iono+09**) なので全体を観測するには十分

- velocity resolution = **0.86 km/s** @ 350 GHz

Supplementary Data

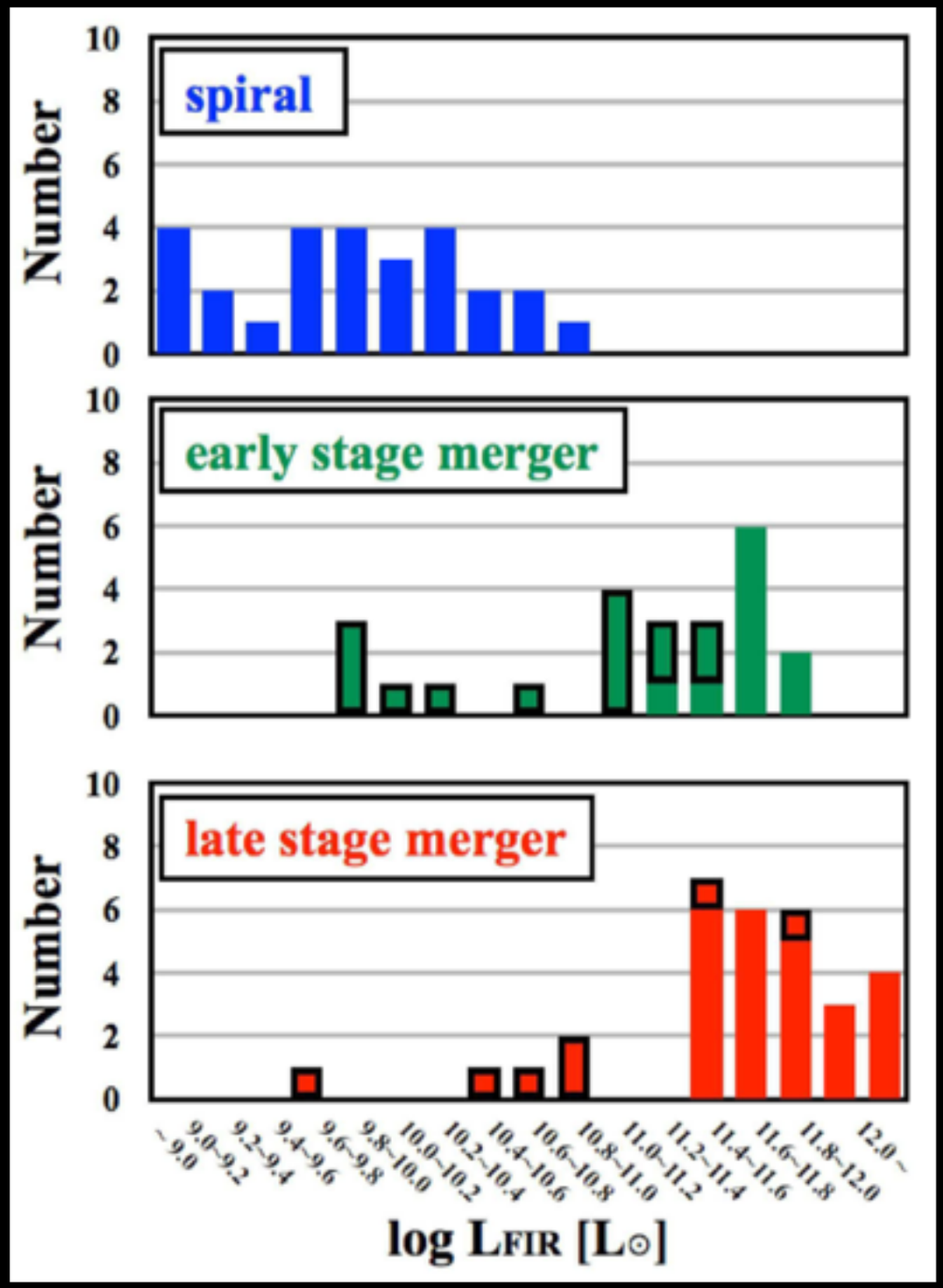
- 10 early stage merger using SMA (**Wilson+08**) and JCMT (**Leech+10**)
- 24 late stage merger (**Wilson+08, Leech+10**)
- 28 isolated spiral galaxies using JCMT (**Wilson+12**)

FIR Luminosity

- AKARI 90/140 um FIS BSC を利用
- 分解能が悪く early merger の flux を個別に求められない

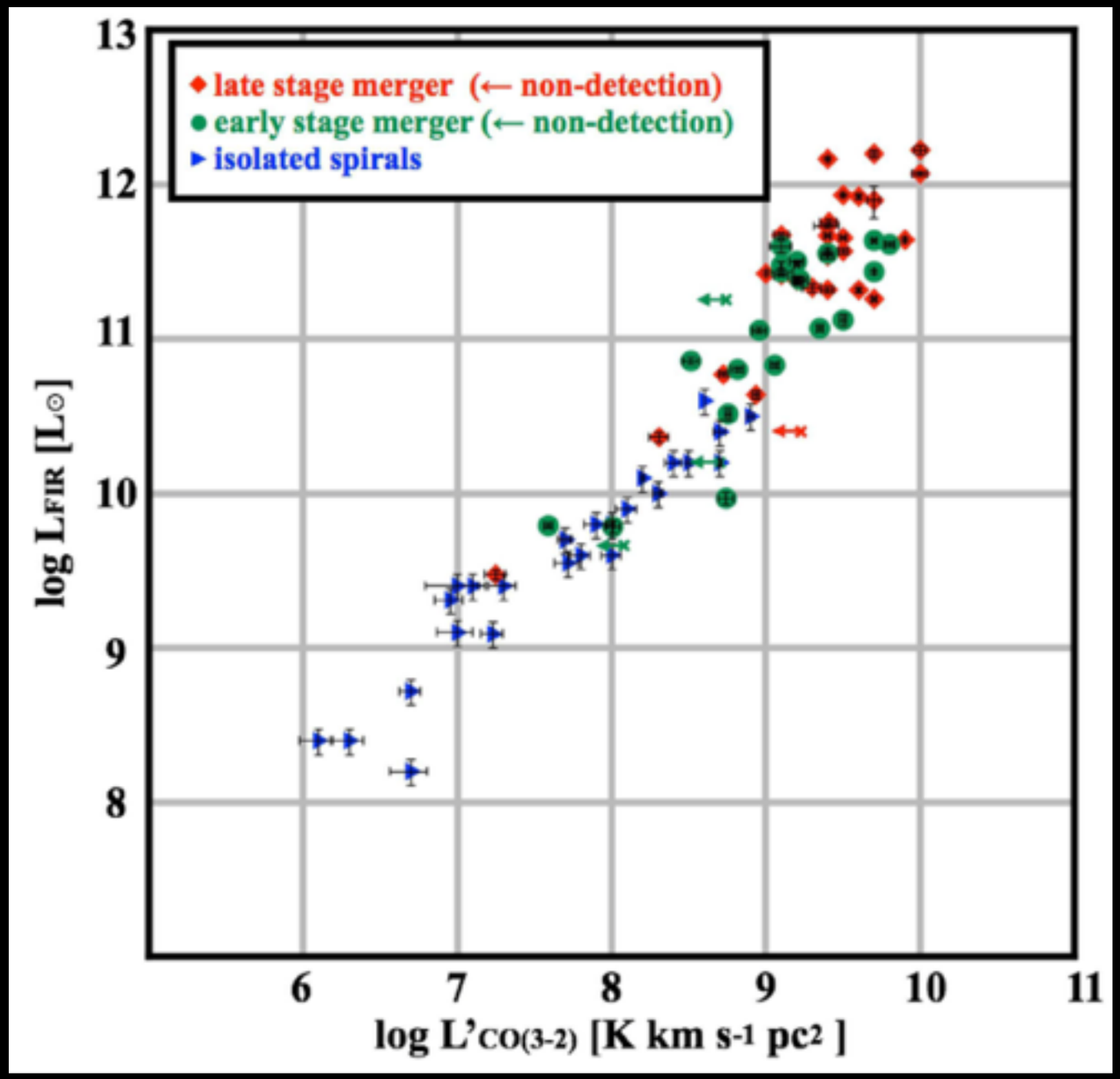
➡FIR-radio ratio

➡FIR-K-band ratio



L_{FIR} v.s. $L'_{CO(3-2)}$

- best fit
  - α = 1.10 ± 0.07
- previous research
  - α = 1.18 ± 0.03 (**Kamenetzky+15**)
  - α = 0.99 ± 0.04 (**Greve+14**)

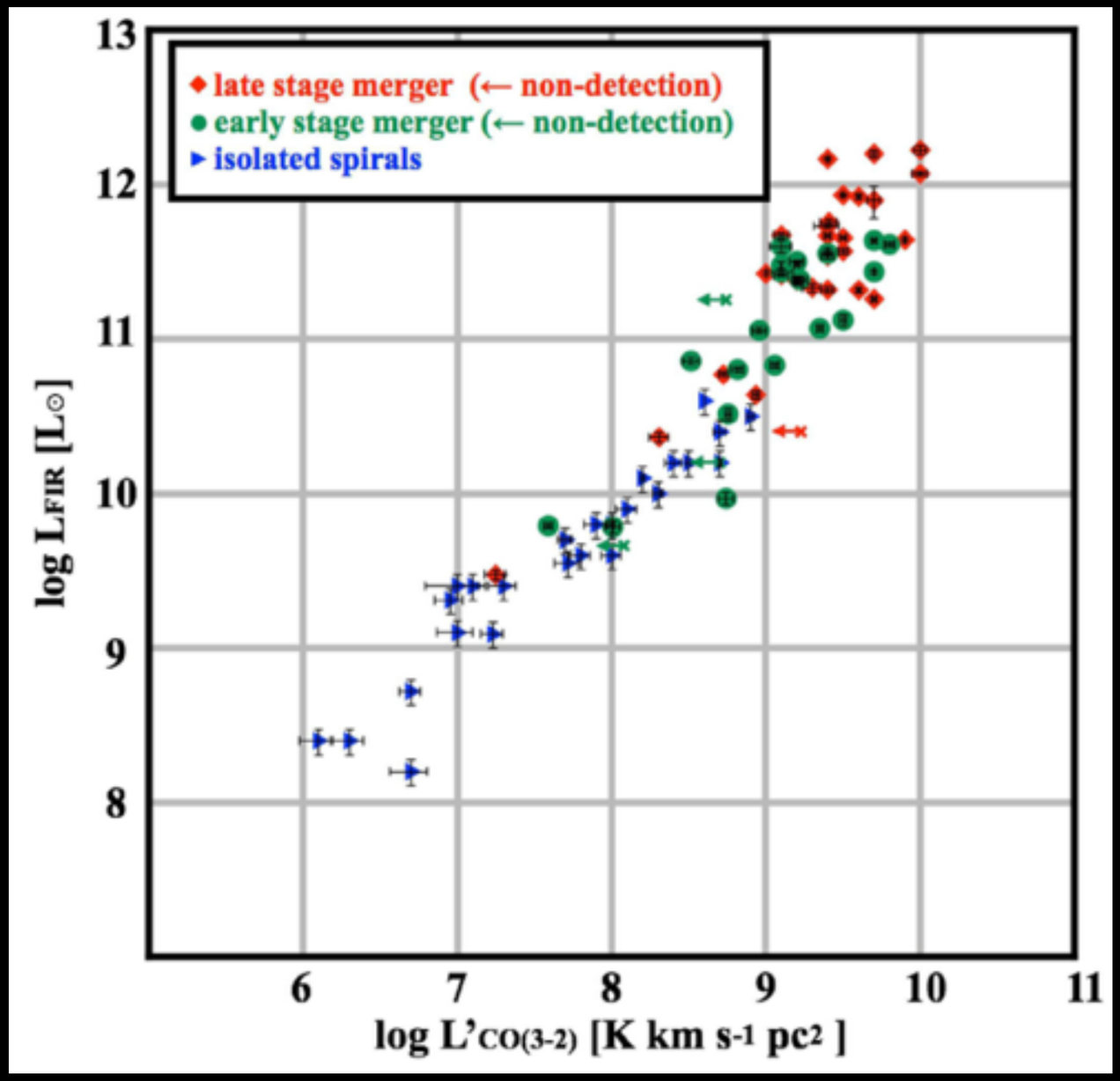


L_{FIR} v.s. $L'_{CO(3-2)}$

- disks と starbursts の間の bimodality (**Daddi+10**) はなし

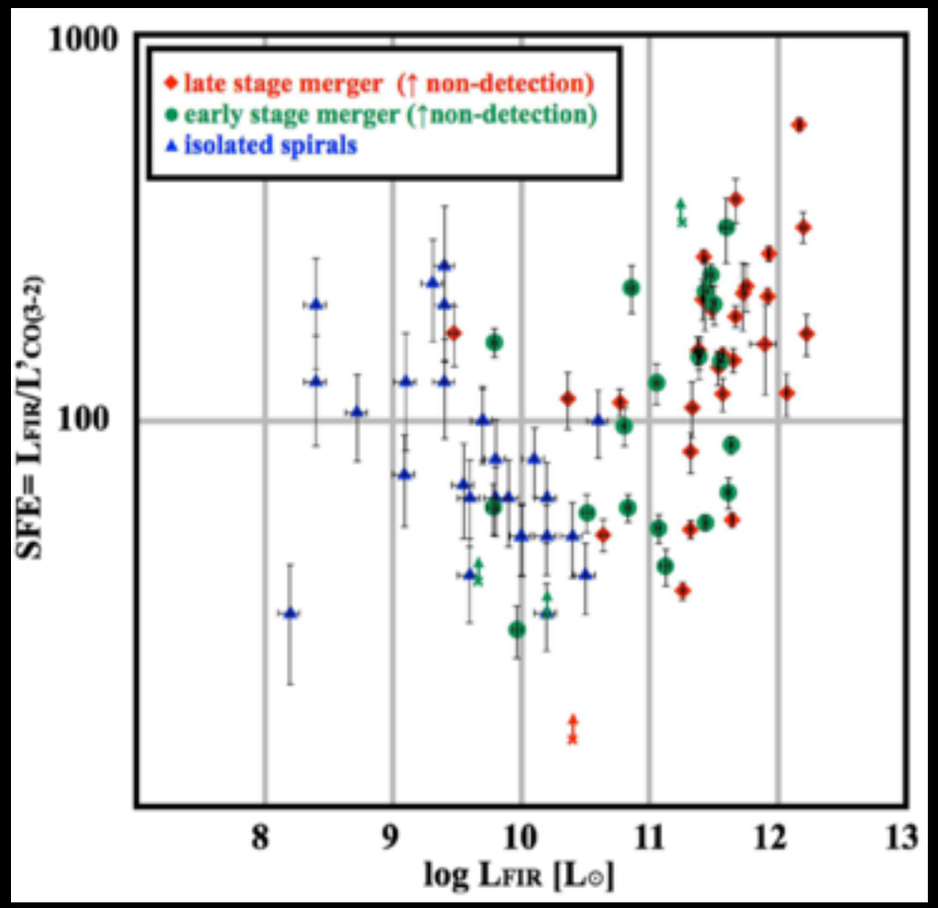
➡starbursts は high SFE にバイアス

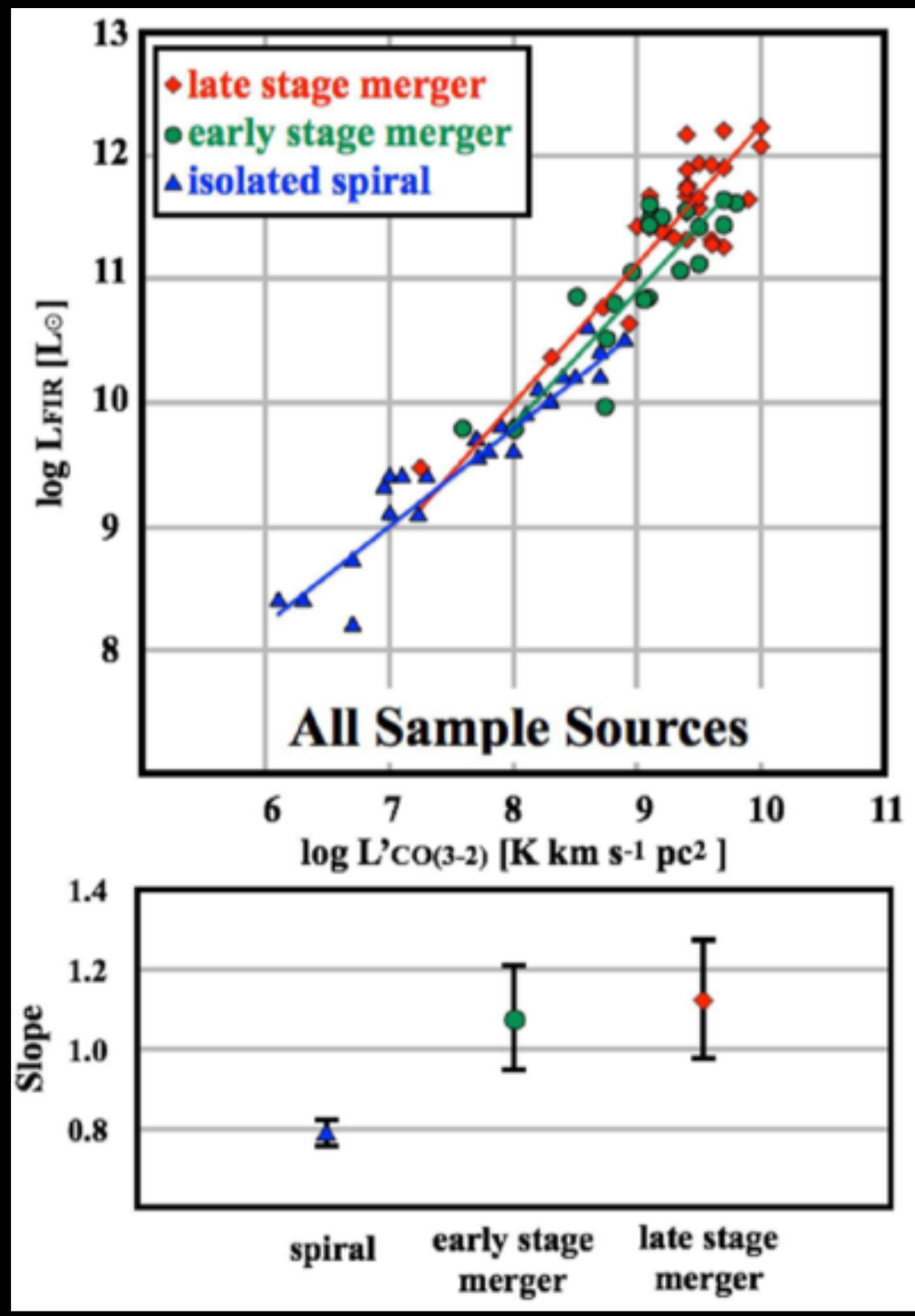
➡励起状態に不定性



L_{FIR} v.s. $L'_{CO(3-2)}$

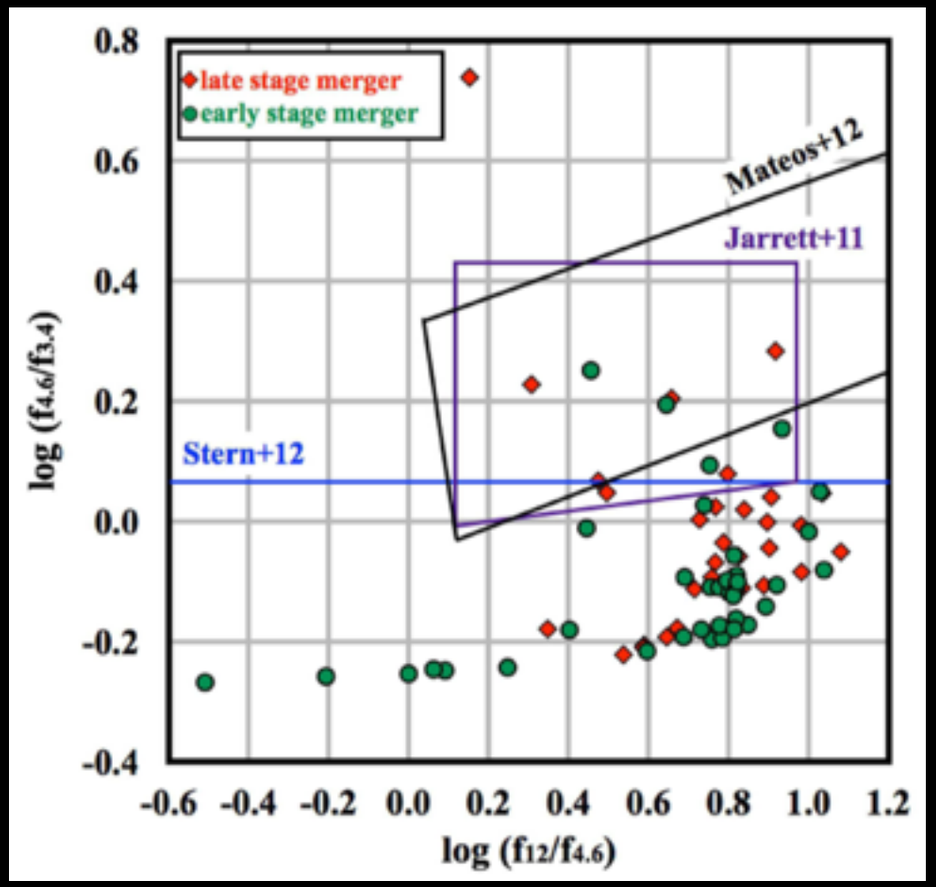
- $\alpha < 1$ for spirals
- $\alpha > 1$ for mergers

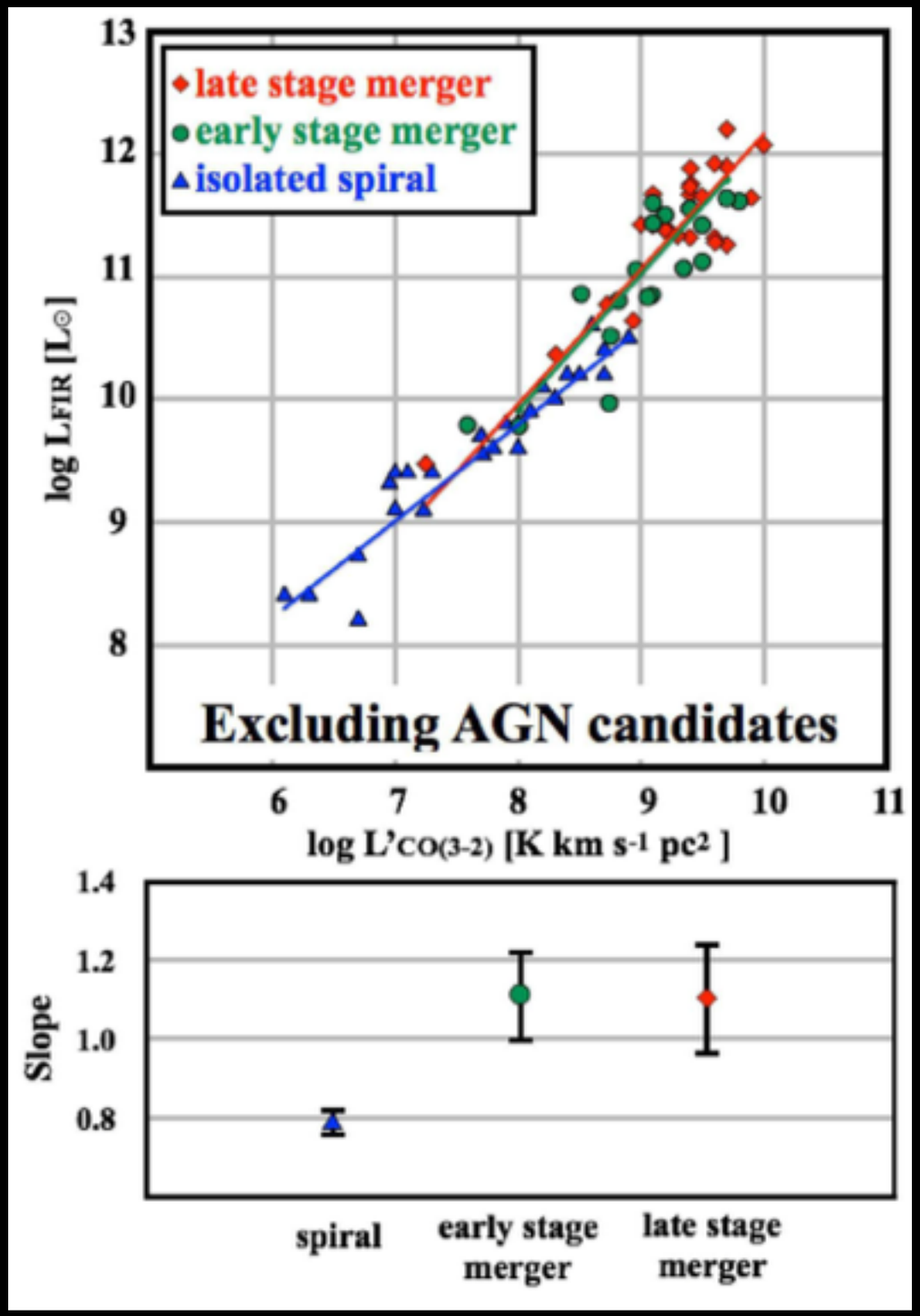




AGN contribution

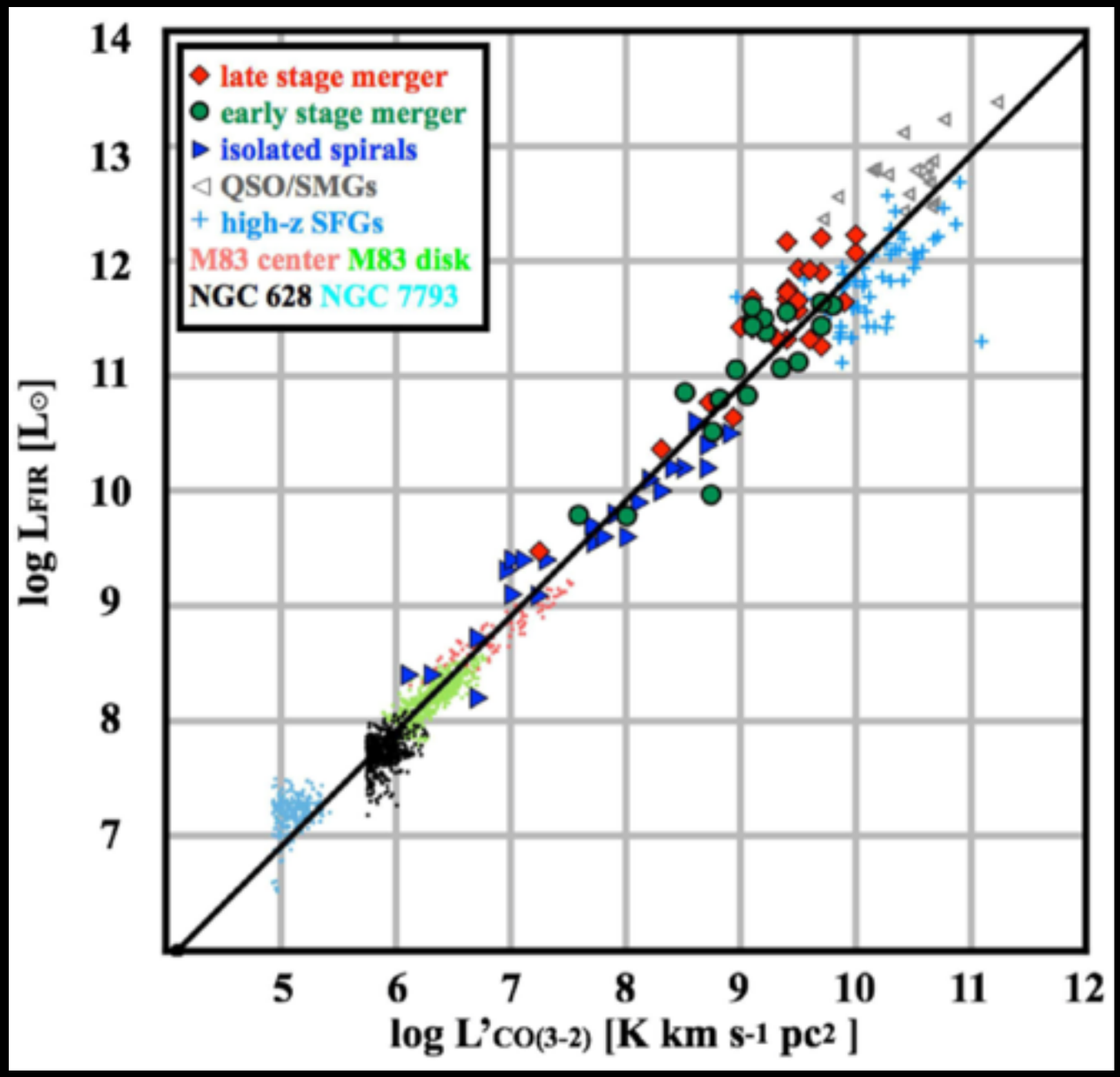
- AGN の影響は無視できる





L_{FIR} v.s. $L'_{CO(3-2)}$

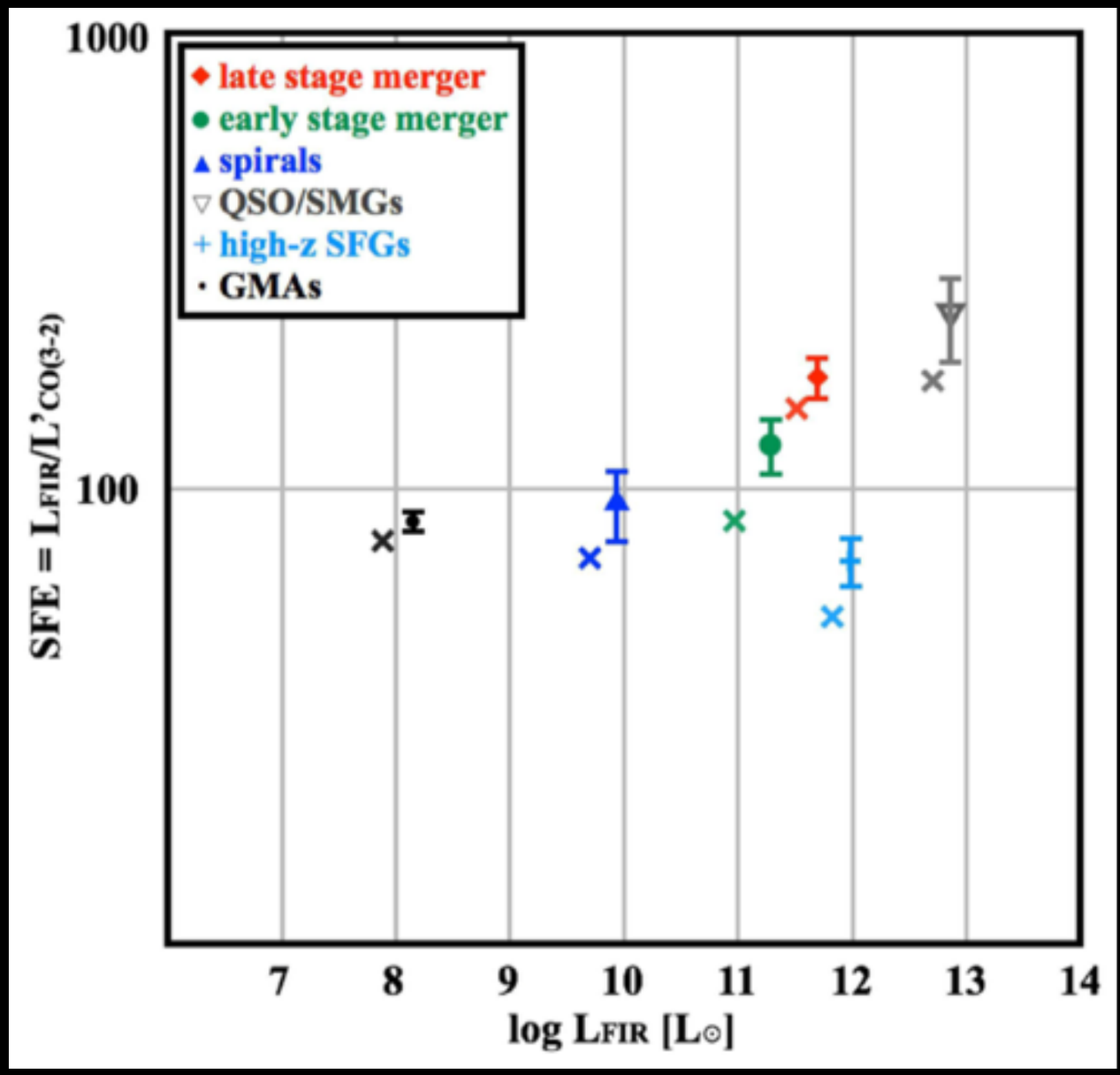
- high-z SFGs, QSO/SMGs, GMA-scale star-forming regions を合わせてプロット



Evolution of SFE

- averaged SFE が spiral~merger で徐々に上昇

✓high-z SFGs の星形成は local spirals よりも長い時間続く



Evolution of SFE

- simulation によると disk-wide starburst が merger 初期に生じる (**Teyssier+10**)
  - 観測と consistent (**Iono+13, Saito+15**)
- early stage merger の SFE < late stage

  ➡このような星形成は**非効率**
- late stage には中心核に dense gas が供給

  ➡より効率的な星形成を行なう

Summery

- L_{FIR} と L'_{CO} は spirals と mergers 共に相関しているが、bimodality は見えなかった
- slope は spirals では < 1, mergers では > 1
- mergers の SFE は L_{FIR} と緩やかに相関
- averaged SFE は spirals~mergers で上昇
- merger 初期は disk-wide starburst が生じ、後に中心核での starburst が dominant となる