z = 0.1 - 2 での
星形成銀河内の分子ガス

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銀河内分子ガス

分子ガス = 星形成の母体

- 銀河進化

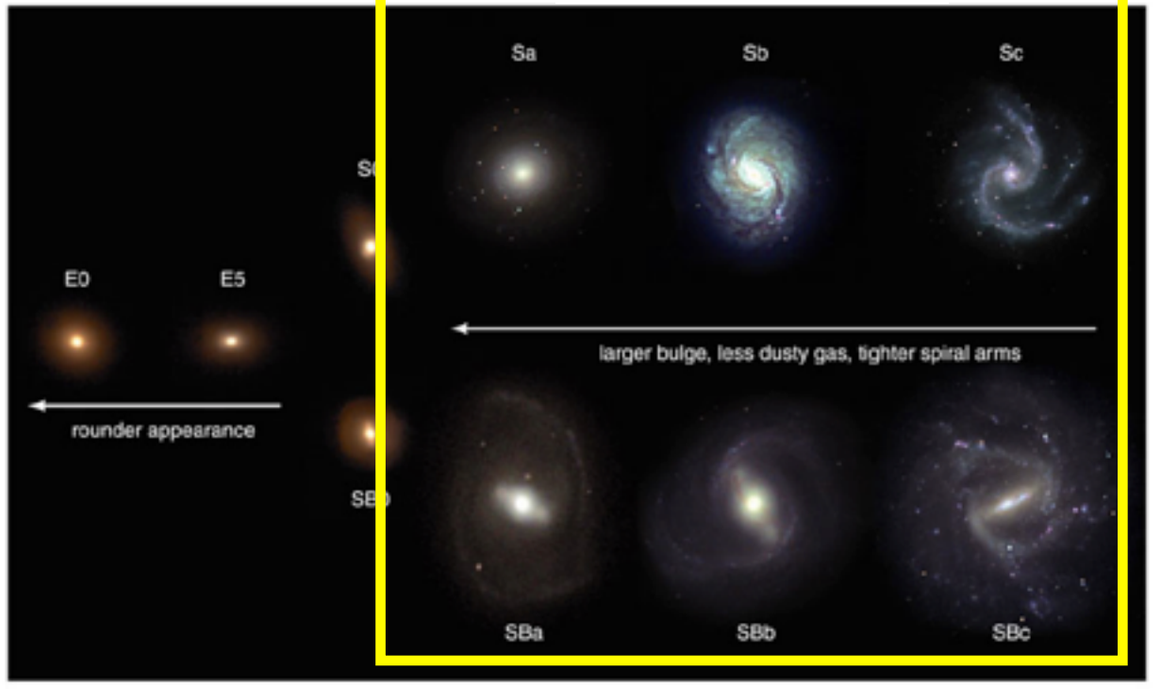
  ガスから星への転換史

銀河形成/進化の理解には
分子ガスの研究が不可欠

gas rich

=

円盤銀河



Scientific Motivation

- 銀河のガス獲得/消費の歴史
  - ガスの割合の進化 $f_{mol\text{-}gas}(z,M_\star) = M_{H2}/(M_{H2}+M_\star)$
  - 星形成効率 $SFE(z,M_\star) = SFR/M_{H2}$

- ガス円盤の内部構造の進化
  - 円盤の分布 (ガスの面密度プロファイル)
  - 円盤の力学状態
    - V_{rot}, $\sigma_V \rightarrow V_{rot}/\sigma_V$ (thin/thick disk)
    - Q_{Toomre} (stable/unstable)

近傍銀河の分子ガス観測

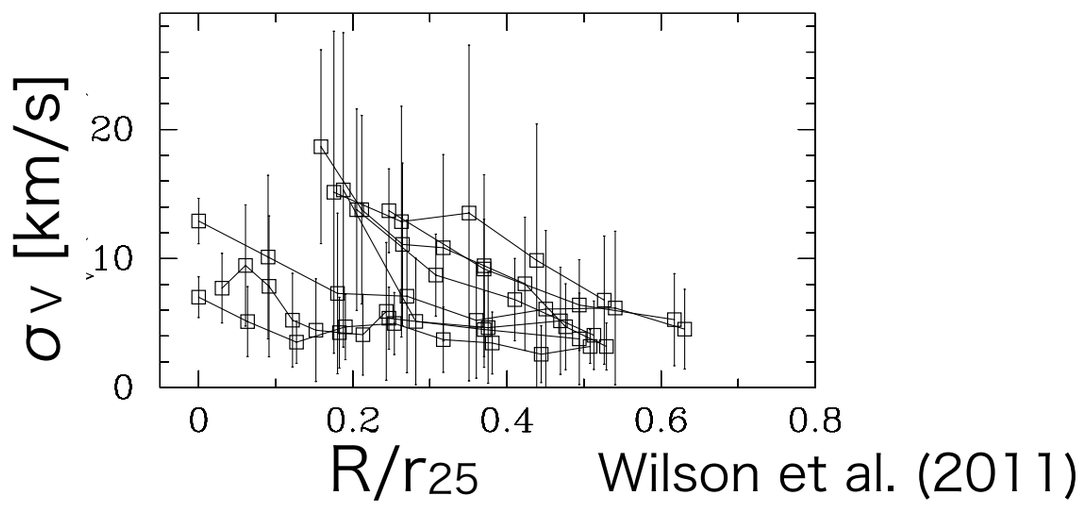
COLD GASS：Saintonge et al. (2011)

- SDSS, Arecibo(HI) survey領域
- z = 0.02-0.05
- $M_{\star} = 10^{10}$-$10^{11.5} M_{sun}$ 350天体
- IRAM 30m

- $f_{mol\text{-}gas}$ **2-16**%
  (only for detected)

J+H+K　　**velocity**

Kuno et al. (2007)



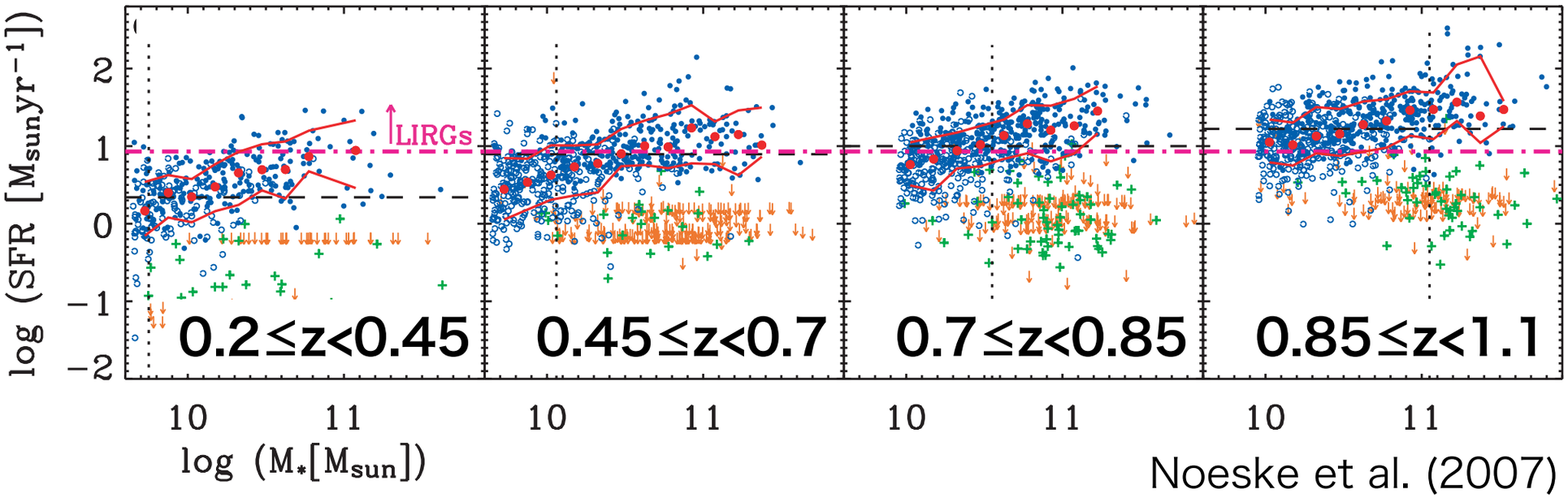
Wilson et al. (2011)

Nishiyama et al. (2001)

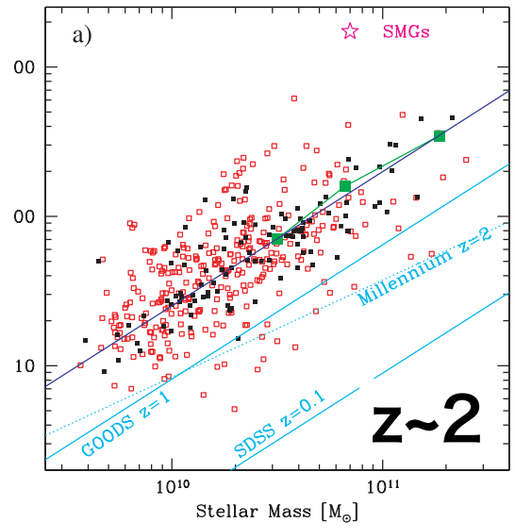
- rotation
- thin disk

z = 0.1 - 2の分子ガス観測

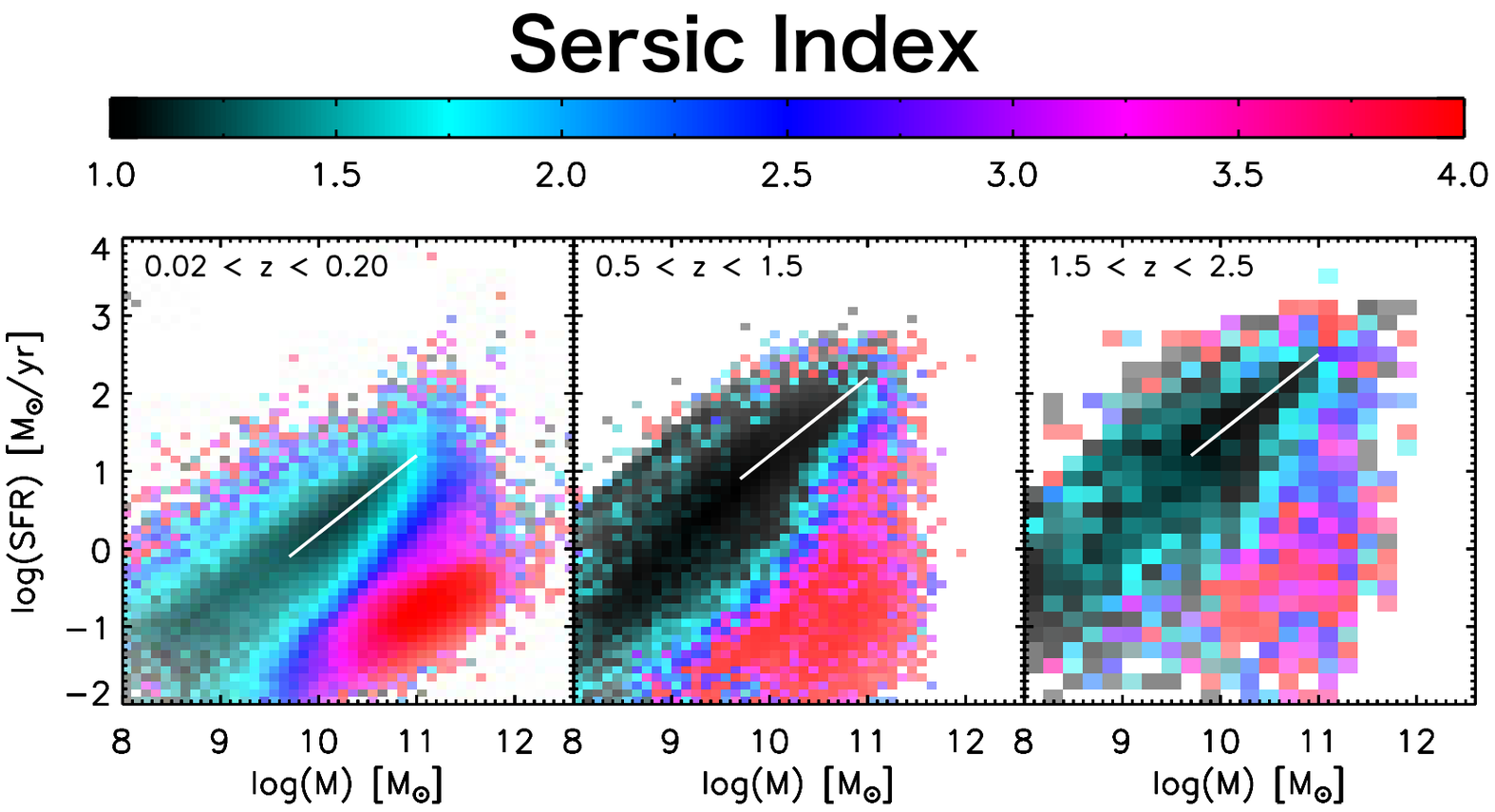
Main-Sequence Galaxies



Noeske et al. (2007)



Daddi et al. (2007)

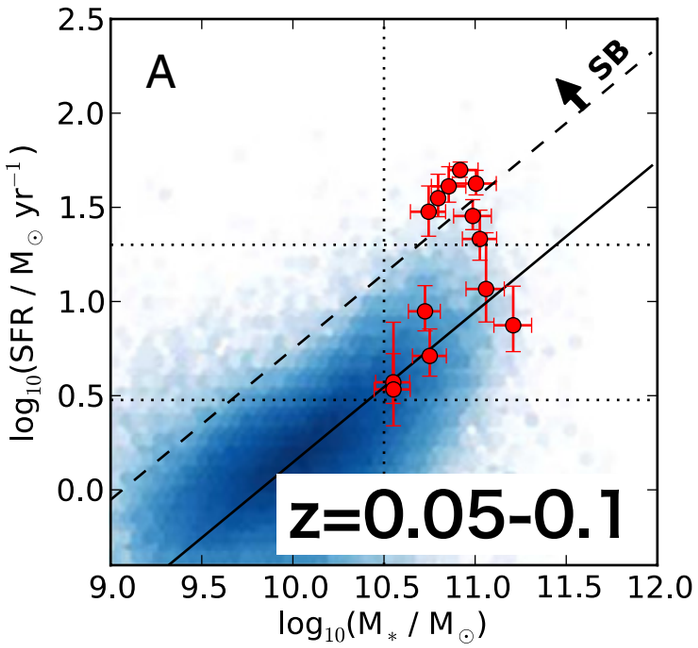


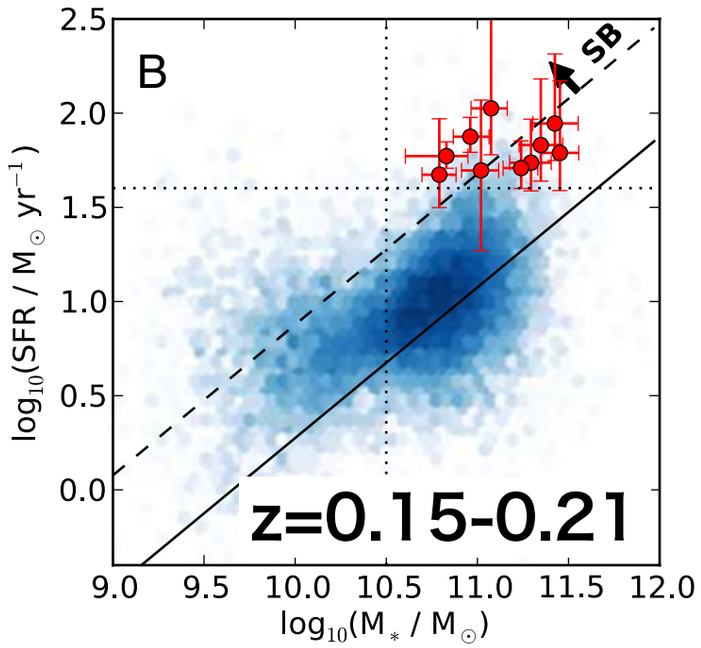
- n_{Sersic} = 1-2 (for z=0-2.5)

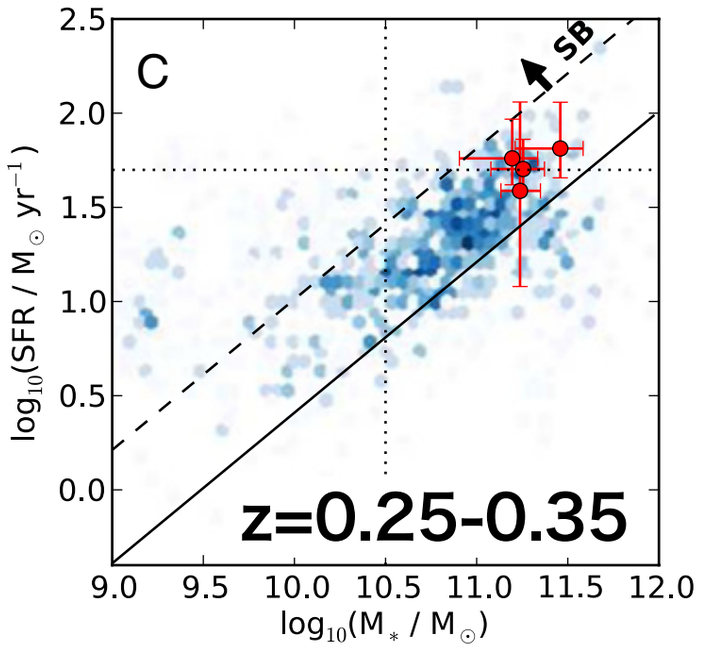
MS ≒ 円盤銀河

Wuyts et al. (2011)

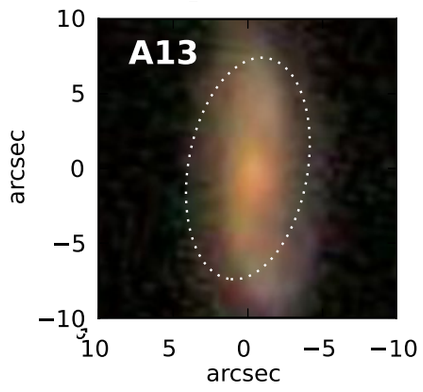
z = 0.1 - 0.3 (Bauermeister et al. 2013)

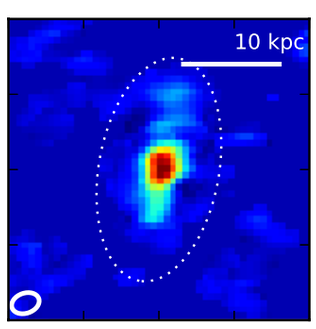


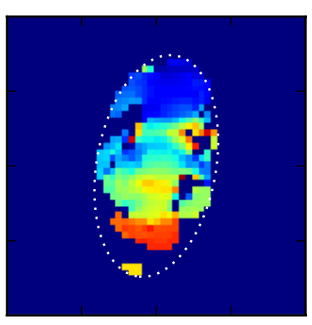




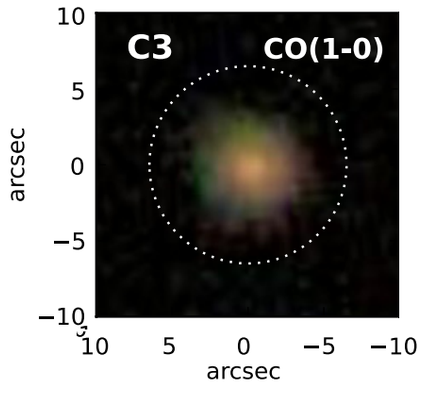
Optical　CO積分強度　速度

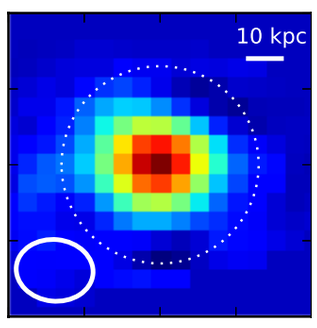


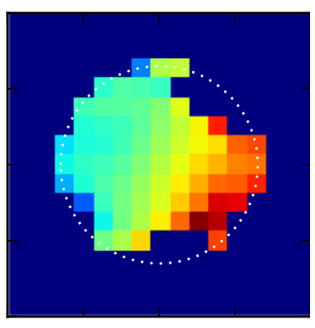




(resolution: 2.0”x1.5”)







(resolution: 4.8”x3.9”)

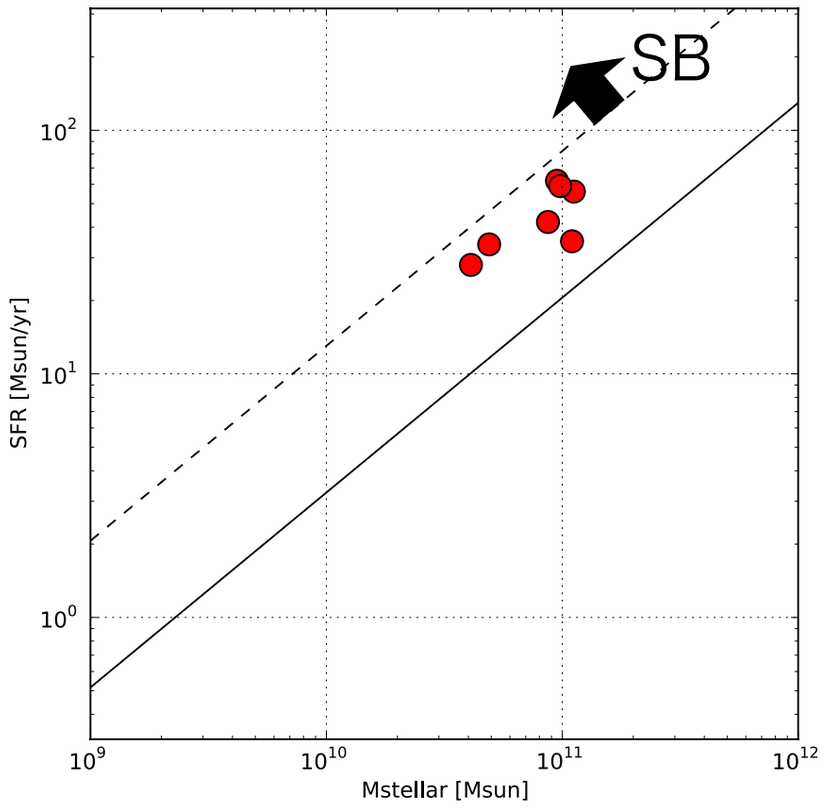
半数はStar Burst

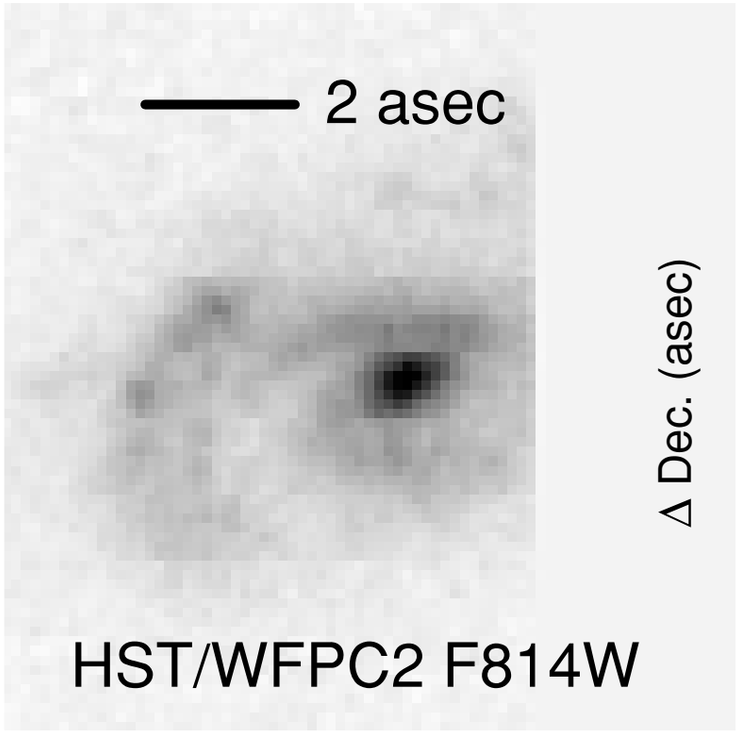
- $f_{mol\text{-}gas}$ **7-20**%
- rotating disk

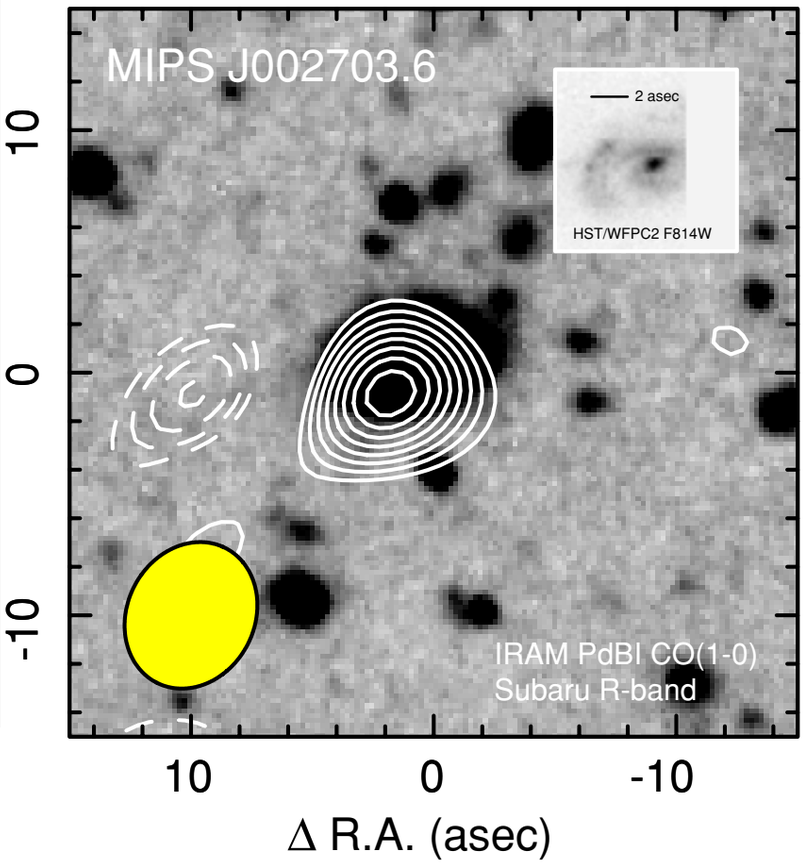
・SDSS DR7 から選択

・CARMA

z = 0.4 (Geach et al. 2011)





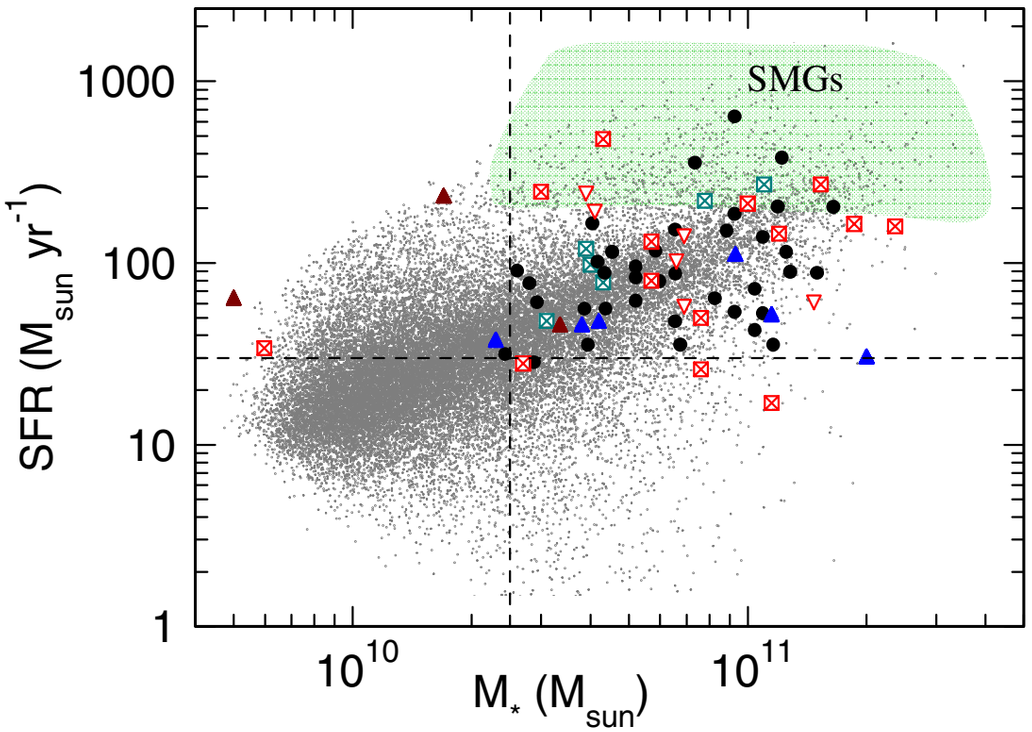


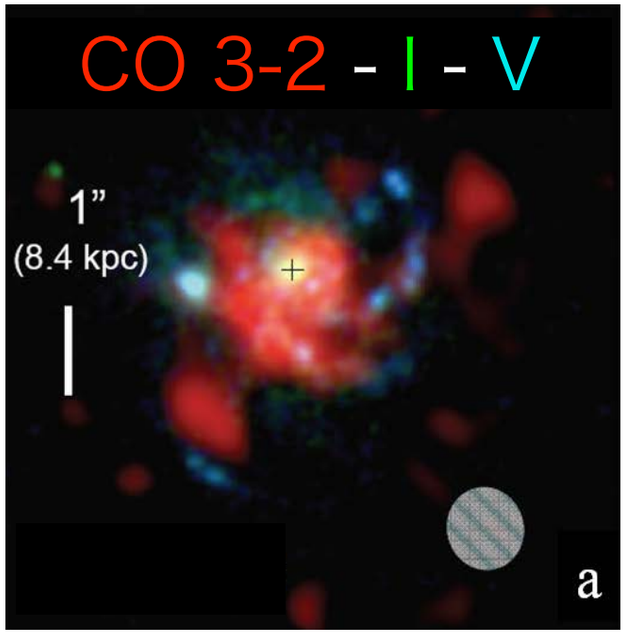
- outskirt of rich cluster (C1 0024+16 @z=0.395)
- LIRG-class

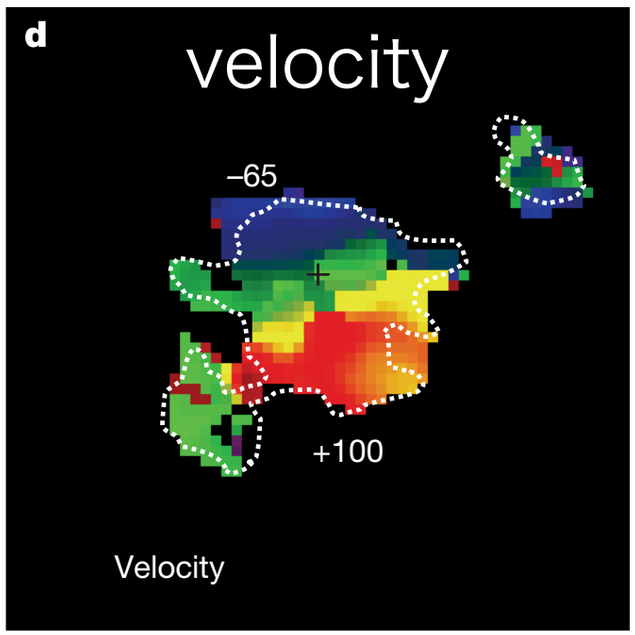
- IRAM PdBI

- $f_{mol\text{-}gas}$ **20** %
- 内部構造は まだ...

z = 1 - 2 (Tacconi et al. 2013)







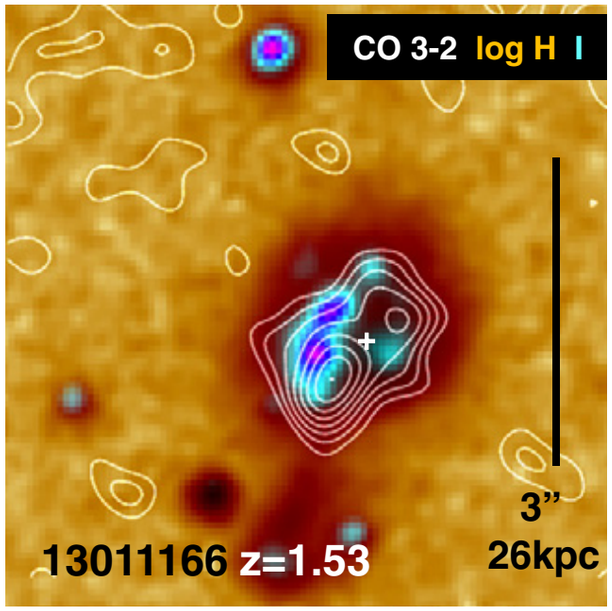
<z=1-1.5>
- EGS survey field
- 分光観測(DEEP2)

<z=2-2.5>
- BX/MD criteria
- 近赤外の分光観測

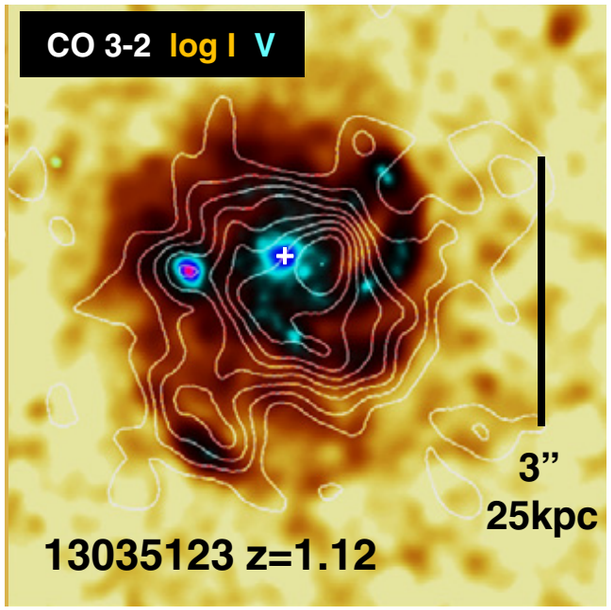
- IRAM PdBI

- $f_{mol\text{-}gas}$ **33** % @z=<1.2>
- $f_{mol\text{-}gas}$ **47** % @z=<2.2>
- $R_{1/2(CO)} = R_{1/2(rest\text{-}B)}$
- rotating disk

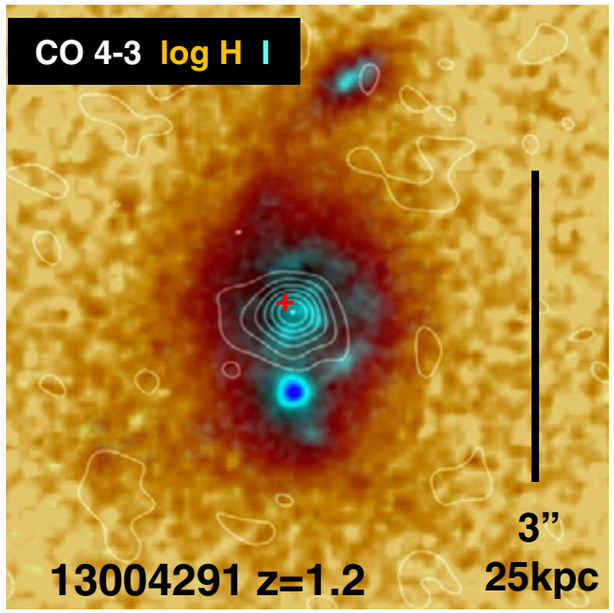
z = 1 - 2 | CO分布(contour)



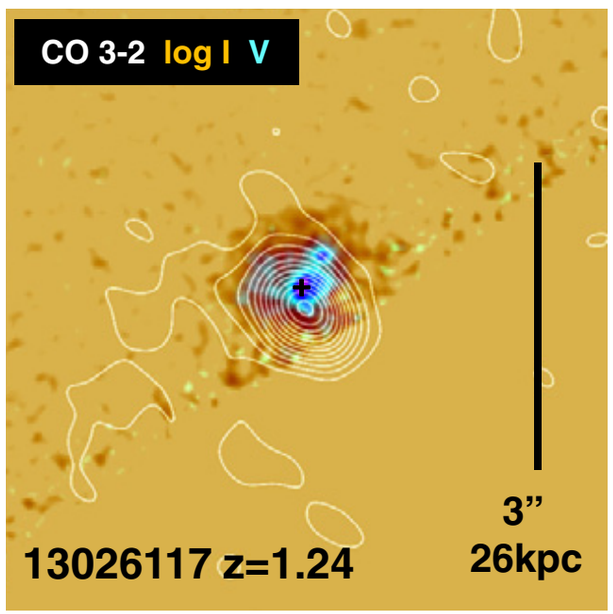
0.6”×0.7”(~6kpc)



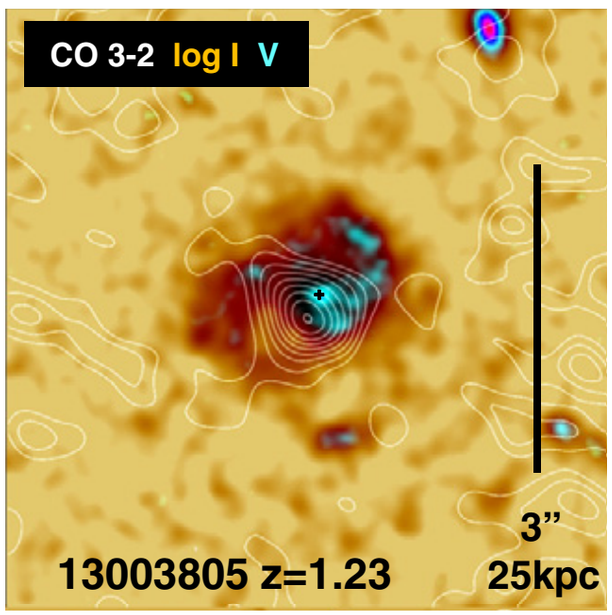
0.8”×0.6”



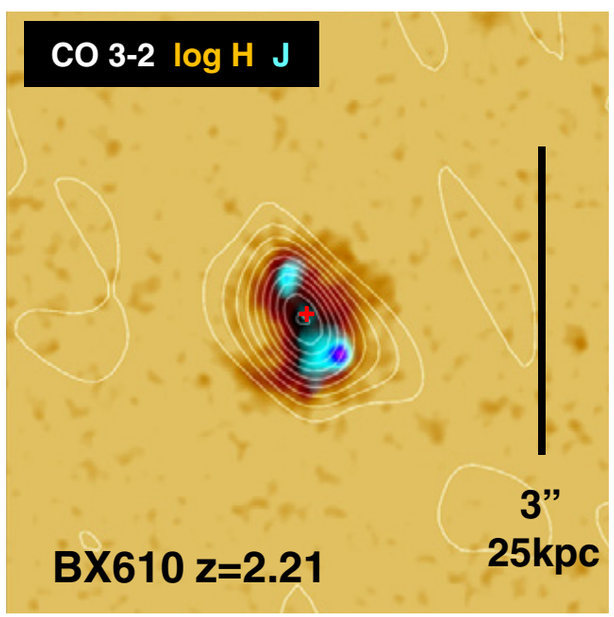
0.7”×0.6”



0.8”×0.5”



0.8”×0.6”

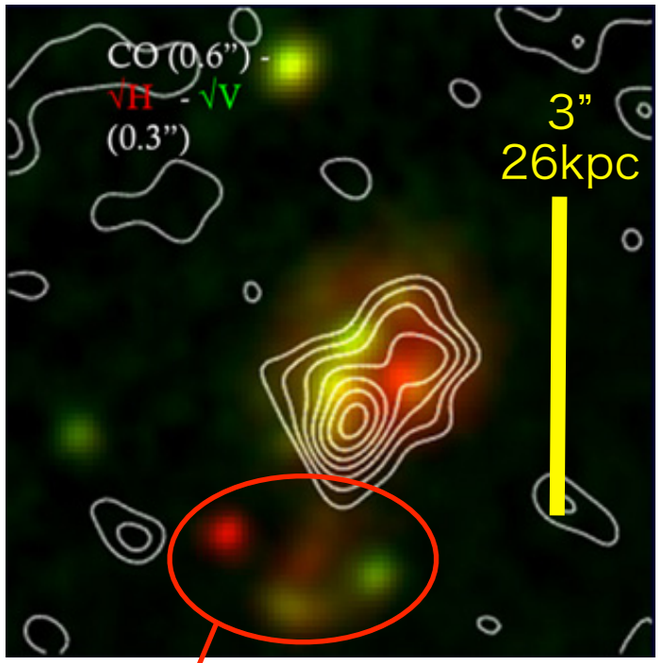


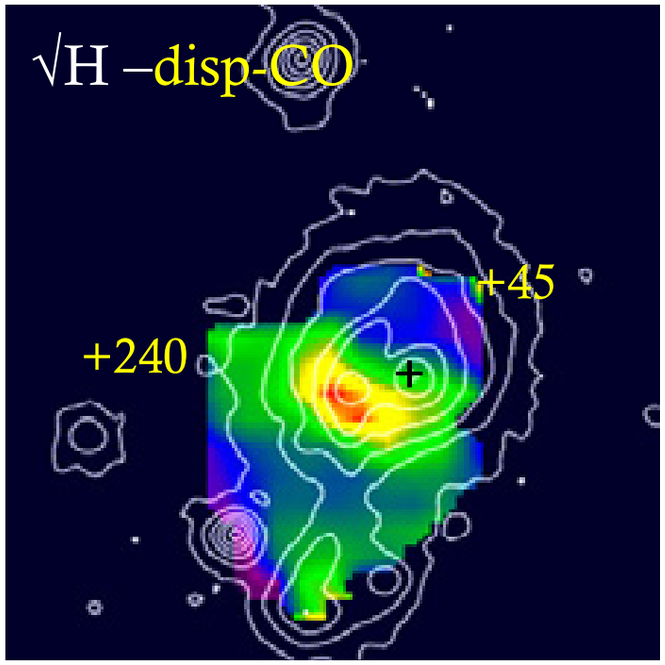
1.5”×0.7”

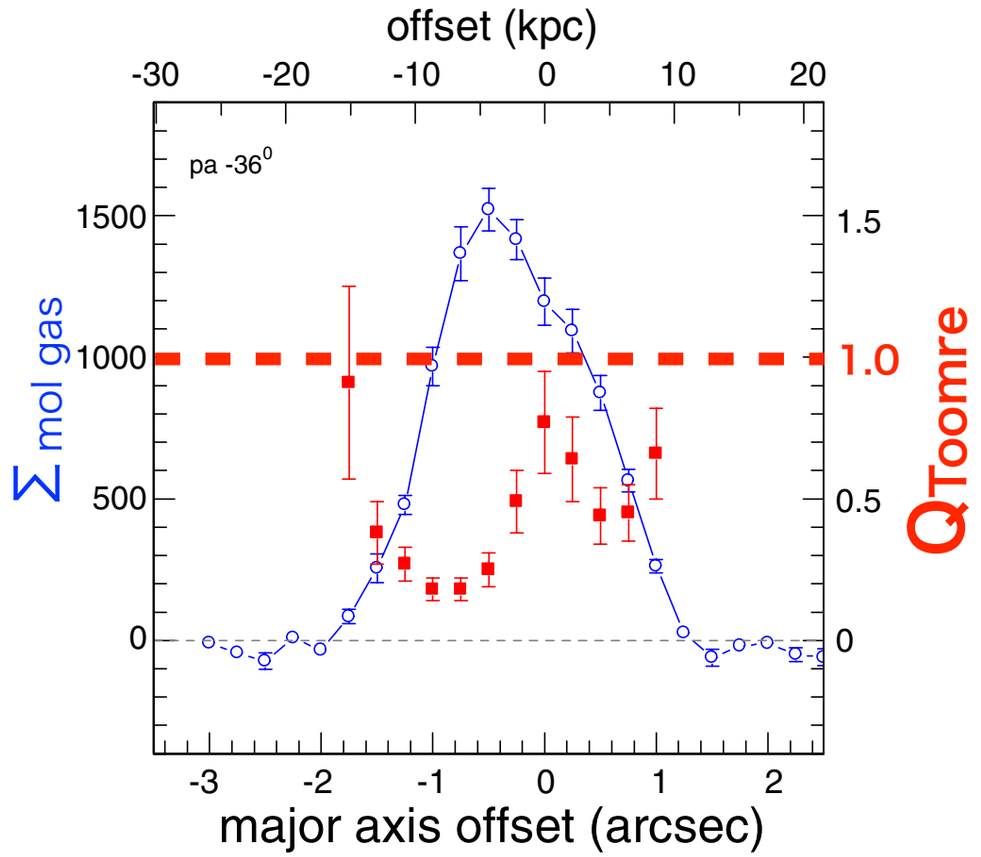
Tacconi et al. (2013)

z = 1 - 2 | 力学状態 (Genzel et al. 2013)

CO resolution: 0.6”x0.7”(~6kpc)







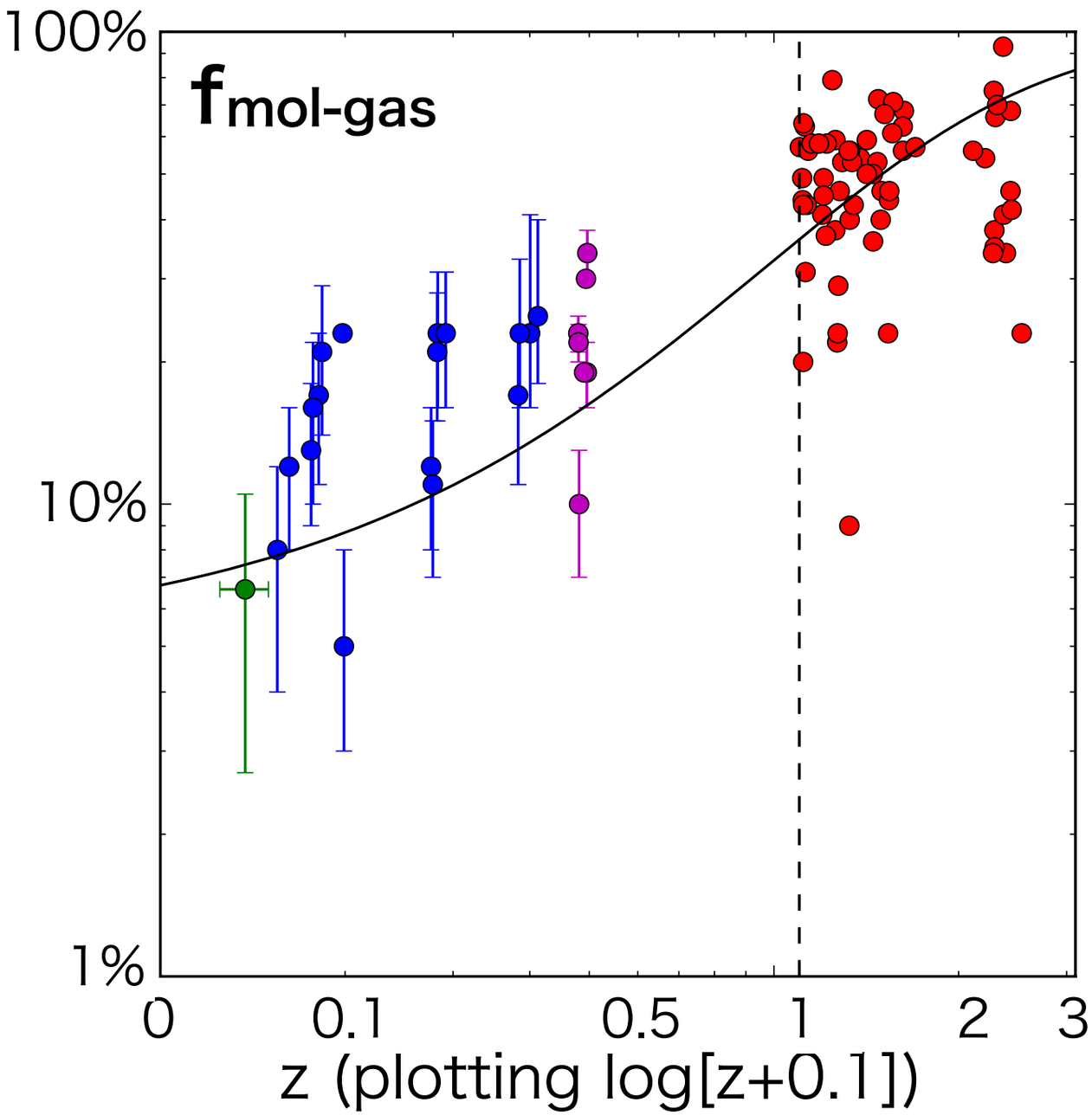
clumpy **large σv** **unstable**

minor merger!?

- ISMはturbulent
  &
  thick

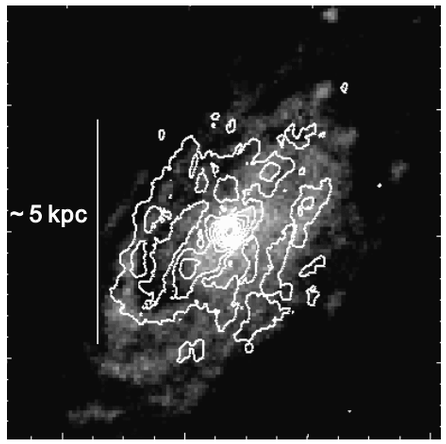
z = 0.1 - 2 の分子ガス観測｜まとめ

統計的性質



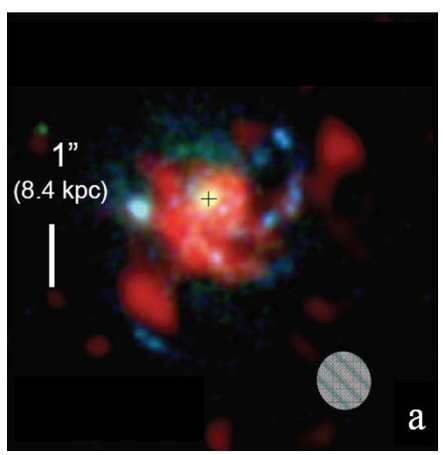
内部構造

z=0



thin disk
stable

z=1.5



clumpy
thick disk
turbulent

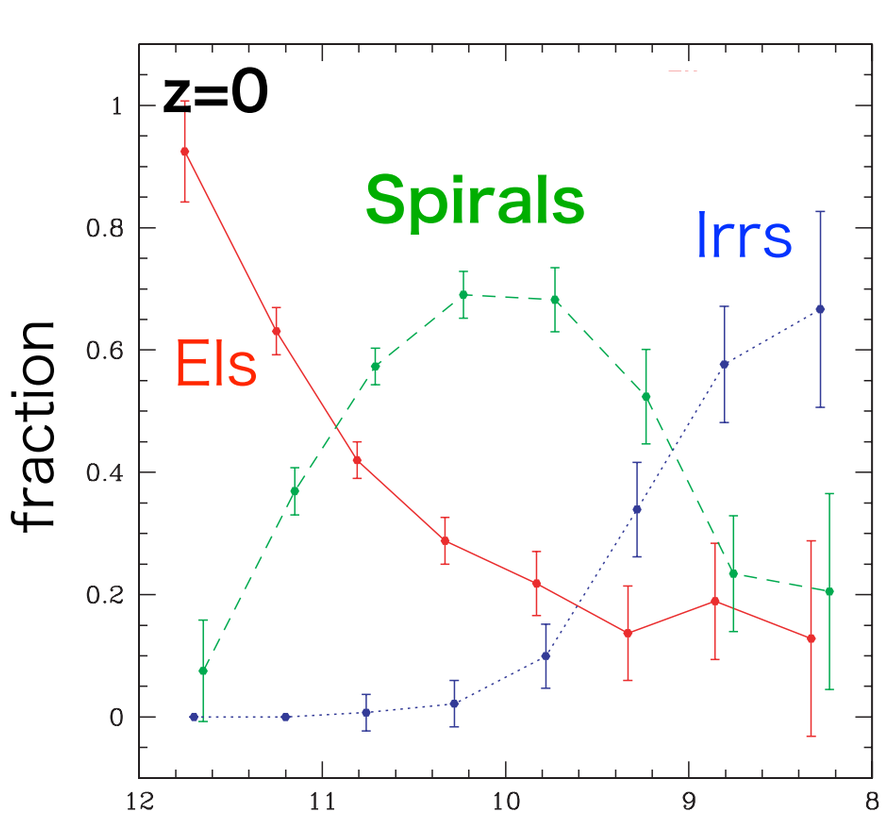
まとめと問題点

	$M_{\bigstar}$ [Msun]	観測天体数
z~0	$>10^{10}$	>350
z=0.1	$>3\times10^{10}$	8
z=0.2	$>10^{11}$	5
z=0.3	$>10^{11}$	4
z=0.4	$>5\times10^{10}$	6
z=1-1.5	$>2.5\times10^{10}$	51
z=2-2.5	$>2.5\times10^{10}$	15

・z = 0.4-1.0での観測が欠けている

・high-massのものに限られている

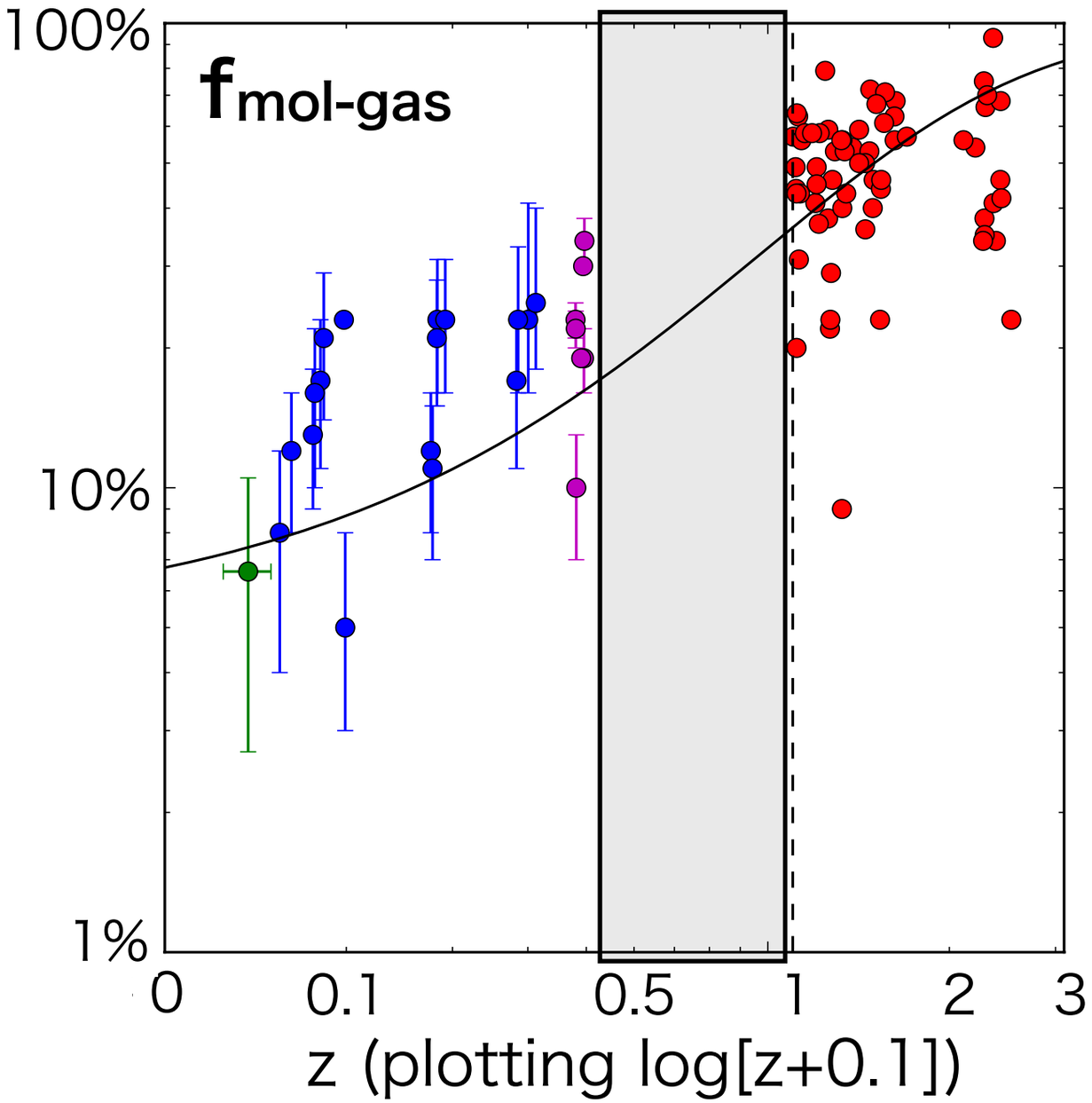
・z=0での円盤銀河の多くは$10^{9\text{-}11}M_{sun}$



ALMAに向けて

ALMA｜統計的性質

- $f_{mol\text{-}gas}(z, M_{\star})$



① 中間redshift

② low-mass側

③ high-mass側

cycle 2では...

high-mass: CO line

low-mass: ダスト連続波

(ガス・ダスト比を仮定してM_{H2})

ALMA | 内部構造

z = 0

?

z = 0.1-1

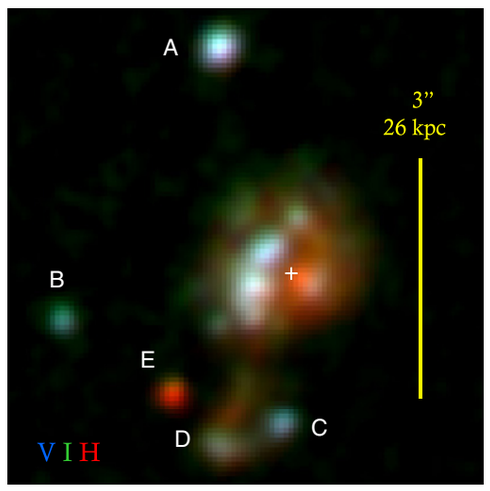
low mass
$<10^{10.5}$

high mass
$>10^{10.5}$

more
sample

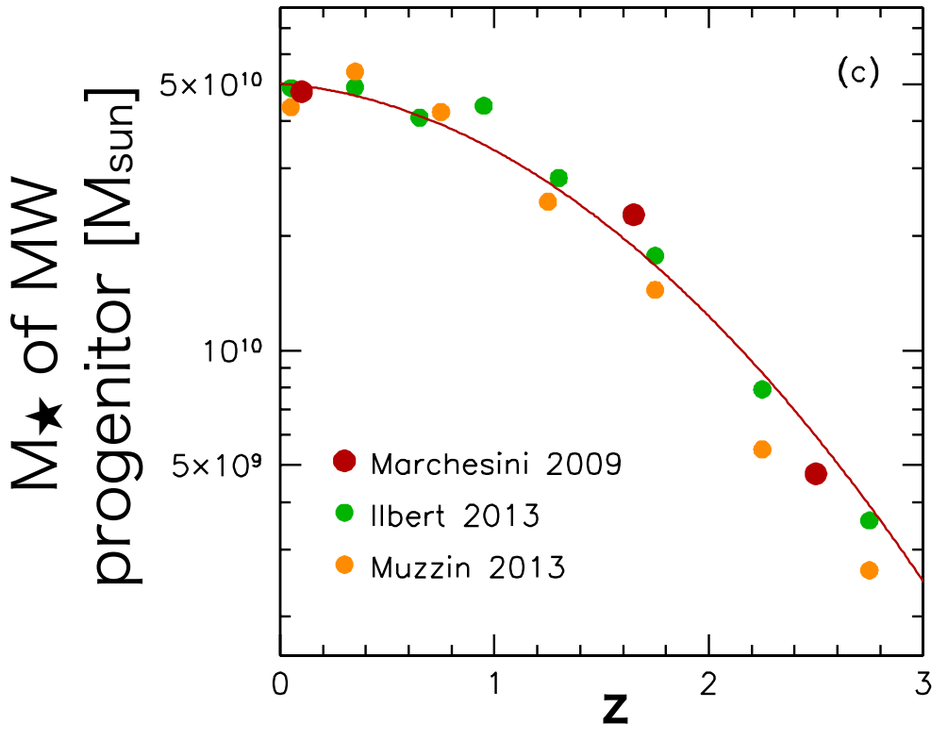
?

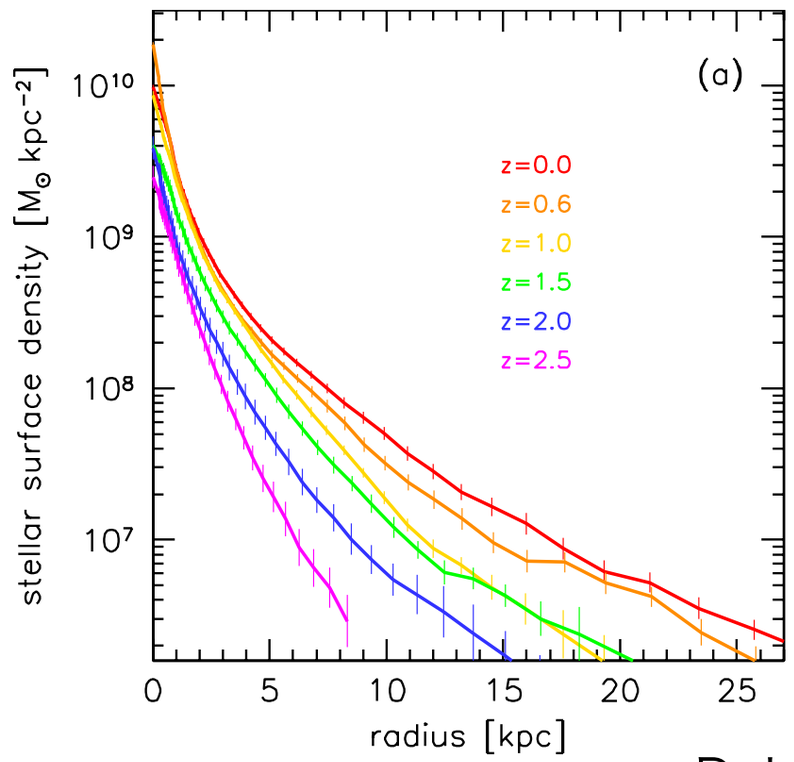
z = 1.5-2.5



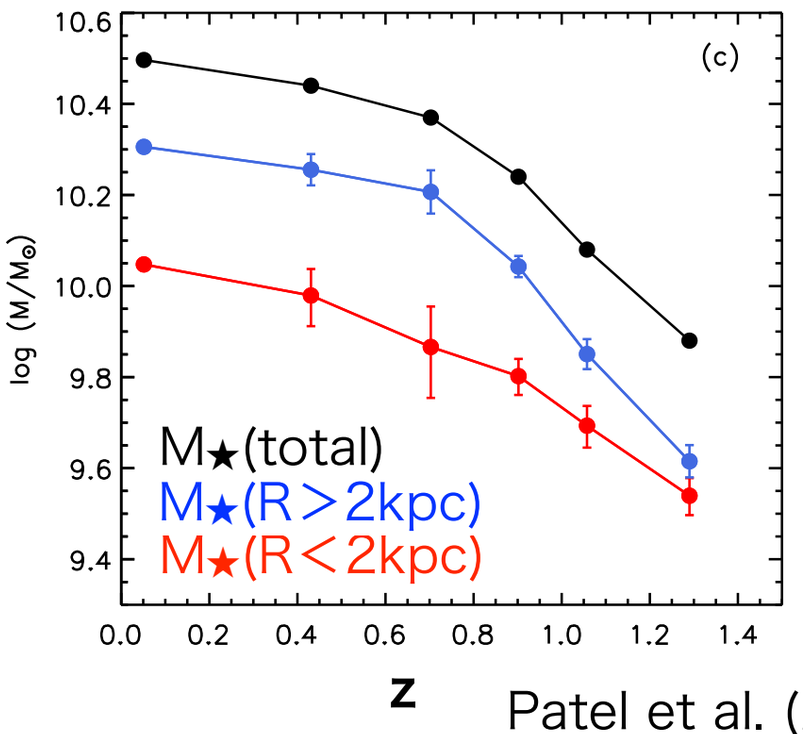
high-z

MW progenitor





van Dokkum et al. (2013)



Patel et al. (2013)

- z>1ではbulge, disk共に成長
- z<1ではdiskの方が大きく成長

  ΛCDM simulationからも示唆

  (Okamoto 2013)
- z~0.7付近でdiskの成長に変化

ALMA cycle2 (pre-announce)

- 12mアンテナ：34台
- Receiver

Band	周波数 [GHz]	分解能 (1kmで評価)	CO(1-0)	CO(2-1)	CO(3-2)	
3	84-116	0.74”	z=0-0.4	z=1.0-1.7	z=2.0-3.1	
4	125-163	0.52”	-	z=0.4-0.8	z=1.1-1.8	cycle2から!
6	211-275	0.31”	-	-	z=0.2-0.6	
7	275-373	0.23”	-	-	-	
8	385-500	0.17”	-	-	-	cycle2から!
9	602-720	0.11”	-	-	-	

ALMAに向けて｜まとめ

- **$f_{mol\text{-}gas}(z,M_\star)$**
  - 中間redshift (z=0.1-1.0)
  - low-mass側 for various redshift

- **MW progenitor**

  $M_\star \sim 5\times10^{10} M_{sun}$ @z=0
  - disk成分はz＜1でも成長
  - z~0.7でdiskのM★進化に変化

  $M_{progenitor} \sim 3\times10^{10} M_{sun}$ @z=0.7; Band-4