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ALMA measures rapidly depleted molecular gas reservoirs in massive quiescent galaxies at z∼1.5

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近傍の最も重いQuiescent銀河（QG）はz>2で星形成を終了している
：理論でまだ説明しきれていない
⇒ 天体数
⇒ どのように星形成を止めるのか
：シミュレーションではz<2.5で合うようになってきたがパラメータチューニングして合わせている面もある
鍵は、分子ガス量。

- 星形成銀河は分子ガスがいっぱい： gas inflowがあるだろう
- QGはなぜinflowがなくなったのか？
  - SMBHフィードバック or Extreme SF ?
  - driven by rapid growth ? merger ? disk instability?
  - 逆に、バルジが発達するとこれらが止まる => quenchモデルもある。
- 近傍QGでは f_gas<0.1-1%
- z>1では単一天体の観測やstackingしかない

z~1.5 Massive QG 6天体 ALMA CO(2-1)観測

- M*>1e11.3Msun passive galaxy in COSMOS
  - UVJ color selection + UV-IR SR
  - strong balmer absorption, Dn4000 (LRIS, MOIRCS)
  - no emission line
- Low molecular gas
  - M_H2<5-10e9Msun
  - f_H2<2-6%
  - 近傍のrecently quenched galaxiesとは違う
  - 近傍とはquenching processがちがう？

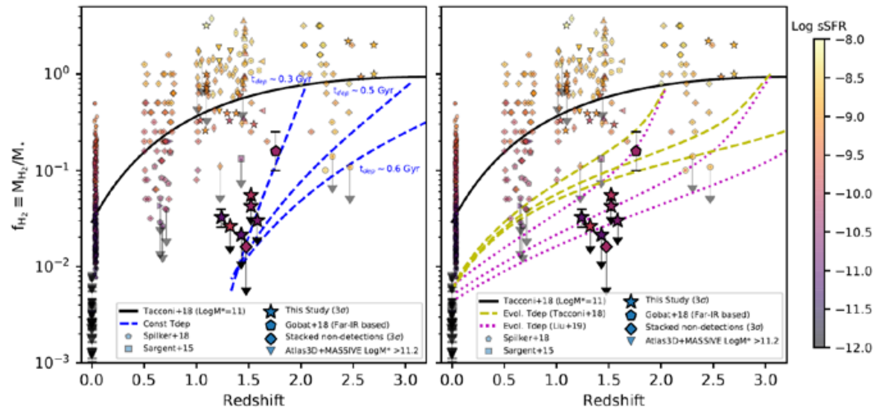

Figure 5. f_{H_2} vs redshift for galaxies in our sample (large stars) and literature measurements. All galaxies are color-coded

(1) Closed box model
- constant t_dep : 0.6gyr
- Varying t_dep : Tacconi scaling relationでは合わない：MSを離れてから早い進化(短いt_dep)が必要

(2)Bath-tab model
- M_Halo~1e14Msun(@z=0) にある銀河のモデルでよく説明できる
- critical mass(Mhalo=1e12Msun)にz~4で到達して、shock heatingが卓越するようになってgas accretionが止まる

(3) SIMBA simulation
- realistic AGN feedback (1e4km/s bipolar flow from low-Eddington BH)
- M*>11.3Msun, sSFR<0.1のサンプルを比較
- よく合う。

Table 1. Properties of ALMA targets

ID[a]	RA	Dec	z_{spec}	Mass	SFR_{UV+IR}[b]	SFR_{30Myr}[c]	Re[kpc][d]	Age[e]	Age[f]	Reference
22260	149.818229	2.561610	1.240	$11.51^{+0.04}_{-0.03}$	3.6	$5.3^{+3.41}_{-1.91}$	7.6	3.4	4.6	Bezanson+2013
20866	149.800931	2.537990	1.522	$11.46^{+0.03}_{-0.03}$	12.8	$0.7^{+2.69}_{-0.68}$	2.4	2.4	1.7	Bezanson+2013
34879	150.131380	2.523800	1.322	$11.32^{+0.04}_{-0.04}$	22.9	$1.4^{+2.30}_{-1.20}$	5.5	2.5	2.1	Belli+2015
34265	150.170160	2.481100	1.582	$11.51^{+0.03}_{-0.03}$	7.4	$0.3^{+1.61}_{-0.34}$	0.9	2.1	1.3	Belli+2015
21434	149.816230	2.549250	1.522	$11.39^{+0.03}_{-0.03}$	19.1	$0.5^{+1.79}_{-0.49}$	1.9	2.1	1.2	Bezanson+2013,2019
307881	150.648487	2.153990	1.429	$11.63^{+0.03}_{-0.03}$	5.0	$0.7^{+1.73}_{-0.66}$	2.7	2.7	3.2	Onodera+2012

Table 2. Molecular gas properties

ID	$S_\nu^{a,b}$	$S_\nu dv^b$	L'CO(2-1)[b]	M_{H_2}[c]	f_{H_2}[c]
	μJy	mJy kms^{-1}	10^8 K km s^{-1} pc^2	10^9 Msun	%
22260[d]	180 ± 38	90± 19	19 ± 4	10.5 ± 2.2	3.2 ± 0.7
20866	47.4	23.7	7.5	12.3	< 4.3
34879[d]	27.5	13.8	3.3	5.5	< 2.6
34265[d]	35.1	17.6	5.9	9.8	< 3.0
21434	69.6	34.8	8.0	13.7	< 5.5
307881	37.8	18.9	5.3	8.8	< 2.1
Stack	-	10.3[e]	2.89	4.7	<1.6

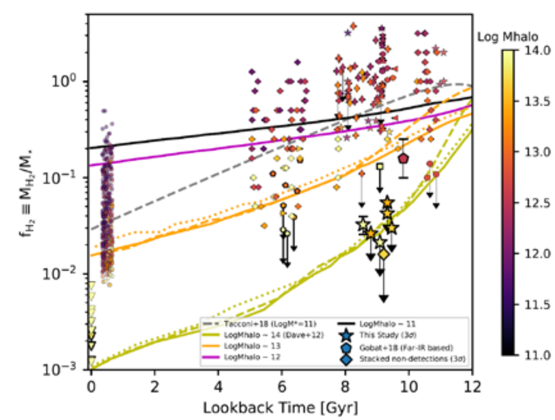

Figure 6. Same as Figure 5 but with f_{H_2} (z) predictions from analytical equilibrium "bathtub models" that balance gas

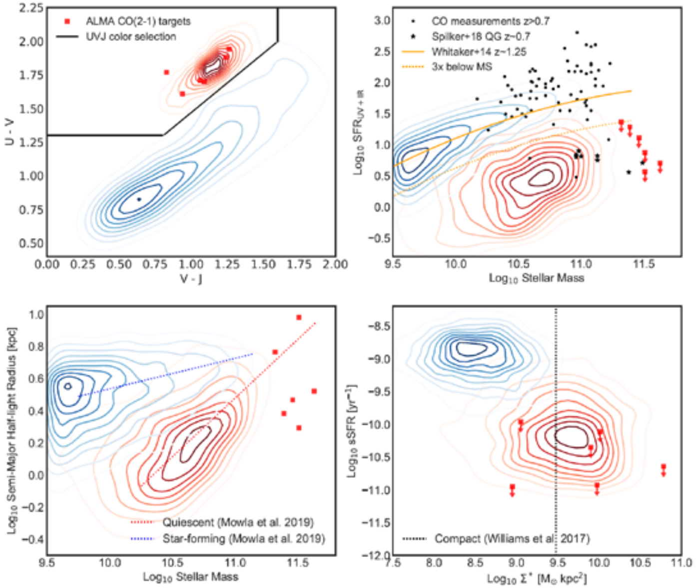

Figure 1. Our ALMA targets (red squares) compared to star-forming and quiescent galaxies from 3DHST with $\log_{10}M_*/M_{\odot}$

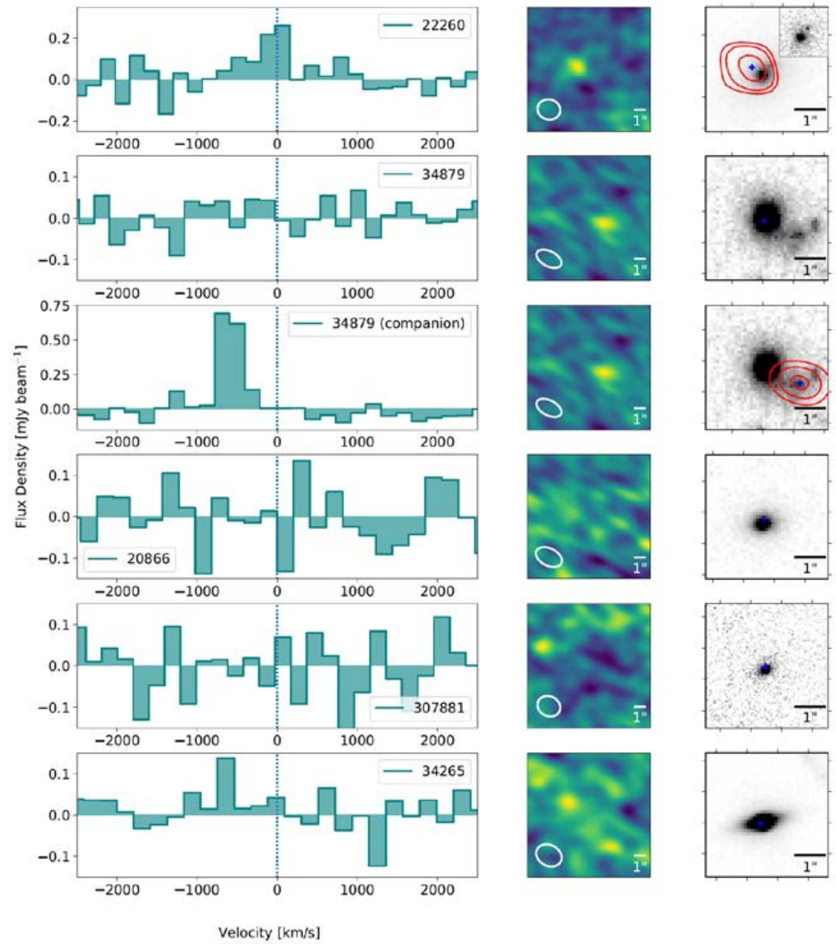

Figure 2. Left panel: ALMA CO(2–1) spectra in 200 km/s channels for each of our galaxies. Spectra are extracted from the

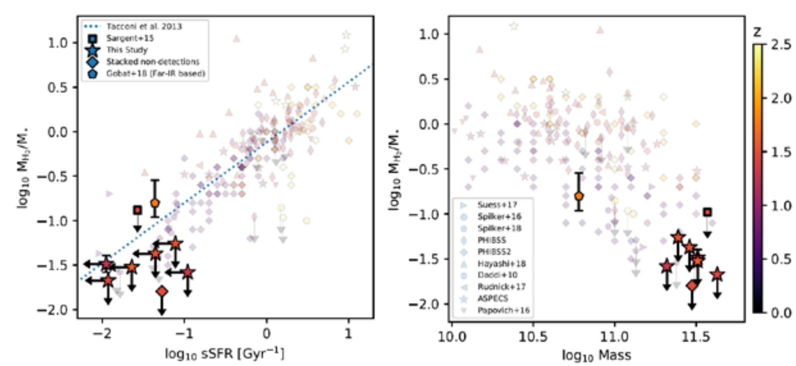

Figure 4. Comparison of our measurements to measurements based on CO in literature at $z > 0.5$. Large symbols indicate