A direct measurement of the GAS CONTENT of a MASSIVE ELLIPTICAL GALAXY in the PEAK ERA of GALAXY ASSEMBLY

(arXiv:1502.00003)

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THIS TALK

1. Introduction, or:
   Look for gas - in a high-z elliptical? Why even bother!?

2. The Target

3. CO[2-1] follow-up at IRAM/PdBI and resulting constraints on the gas fraction

4. Implications for quenching mechanisms

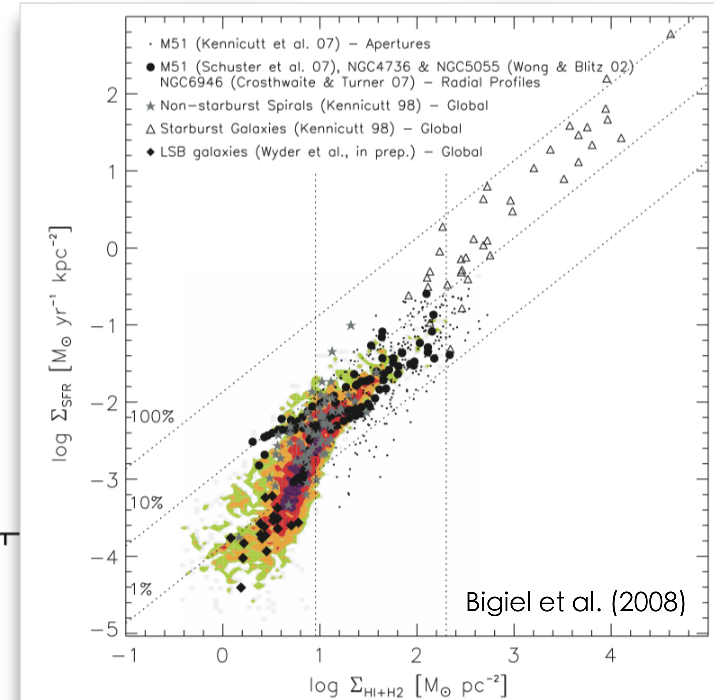
5. Summary

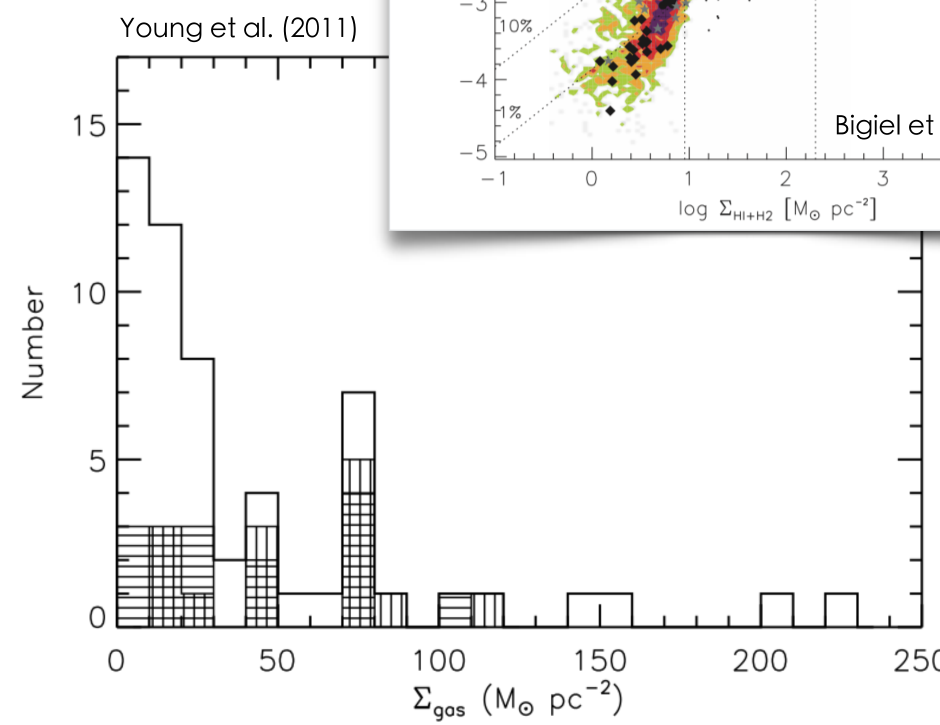
H_2 IN LOCAL EARLY TYPE GALAXIES

STRONG EVOLUTION OVER THE LAST 10 Gyr

Sample of 260 local ETGs from the ATLAS[3D] survey (Young et al. 2011):

- About 25% of ETGs are detected in CO line emission (fraction is slightly larger in the field than in the cluster environment)
- Average gas fraction of detected ATLAS[3D] ETGs is about 1%
- Gas surface mass densities are similar to those of local spiral galaxies.

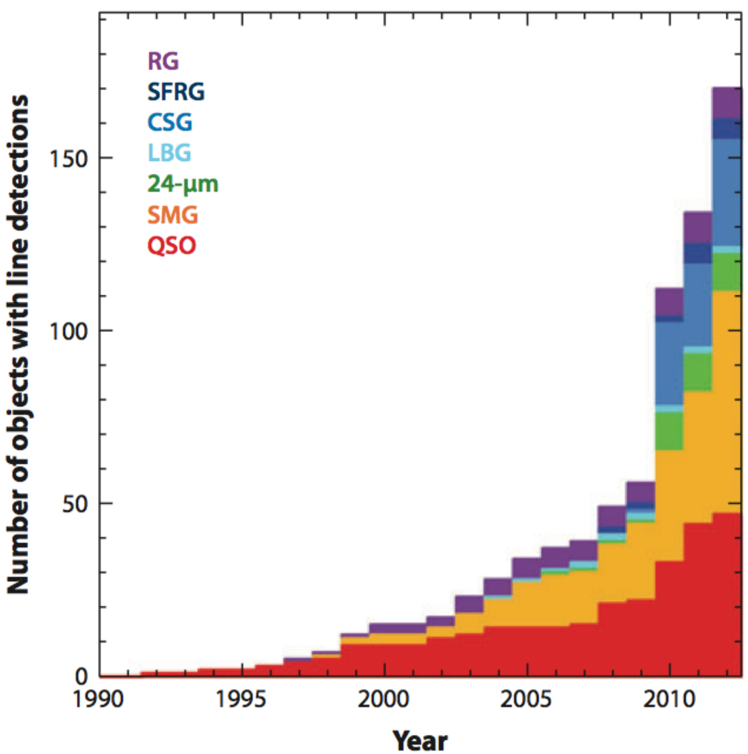




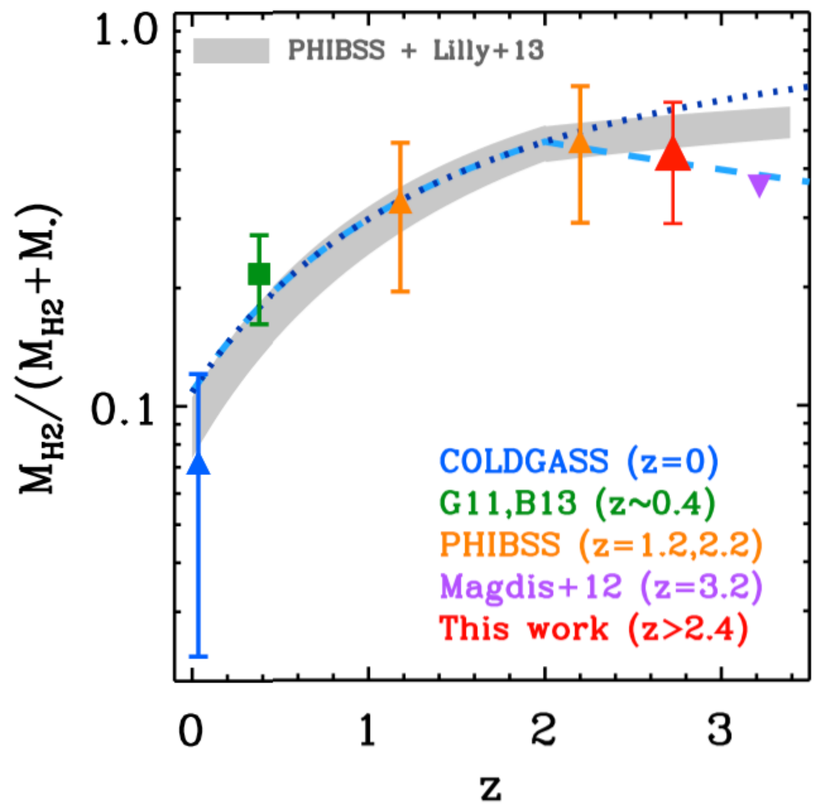
GAS IN STAR-FORMING GALAXIES

STRONG EVOLUTION OVER THE LAST 10 Gyr

Thanks to a rapidly increasing number of molecular line detections we have solid evidence that high-redshift galaxies in general are much more gas rich than local galaxies. For massive ($M_{\star}>10^{10}M_{\odot}$) main-sequence galaxies, which contribute most to the stellar mass growth, gas fraction evolution is closely linked to the evolution of the sSFR and amounts to a 5-10 fold increase out to z~2.



Carilli & Walter (2013)

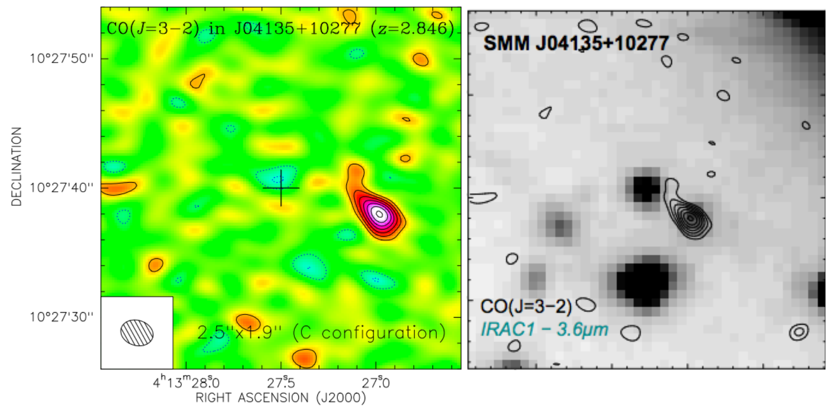


Saintonge et al. (2013)

EVOLUTION OF GAS CONTENT OF ETGs

VERY POORLY CONSTRAINED COMPARED TO STAR-FORMING POPULATION

- Is there a universal/synchronized evolution of the gas content of <u>all</u> galaxies with cosmic time? (How much gas do high-z ETGs acquire through mergers with more gas rich galaxies?)



"A candidate early-stage wet-dry merger of two massive galaxies at z=2.8"

Riechers (2013)

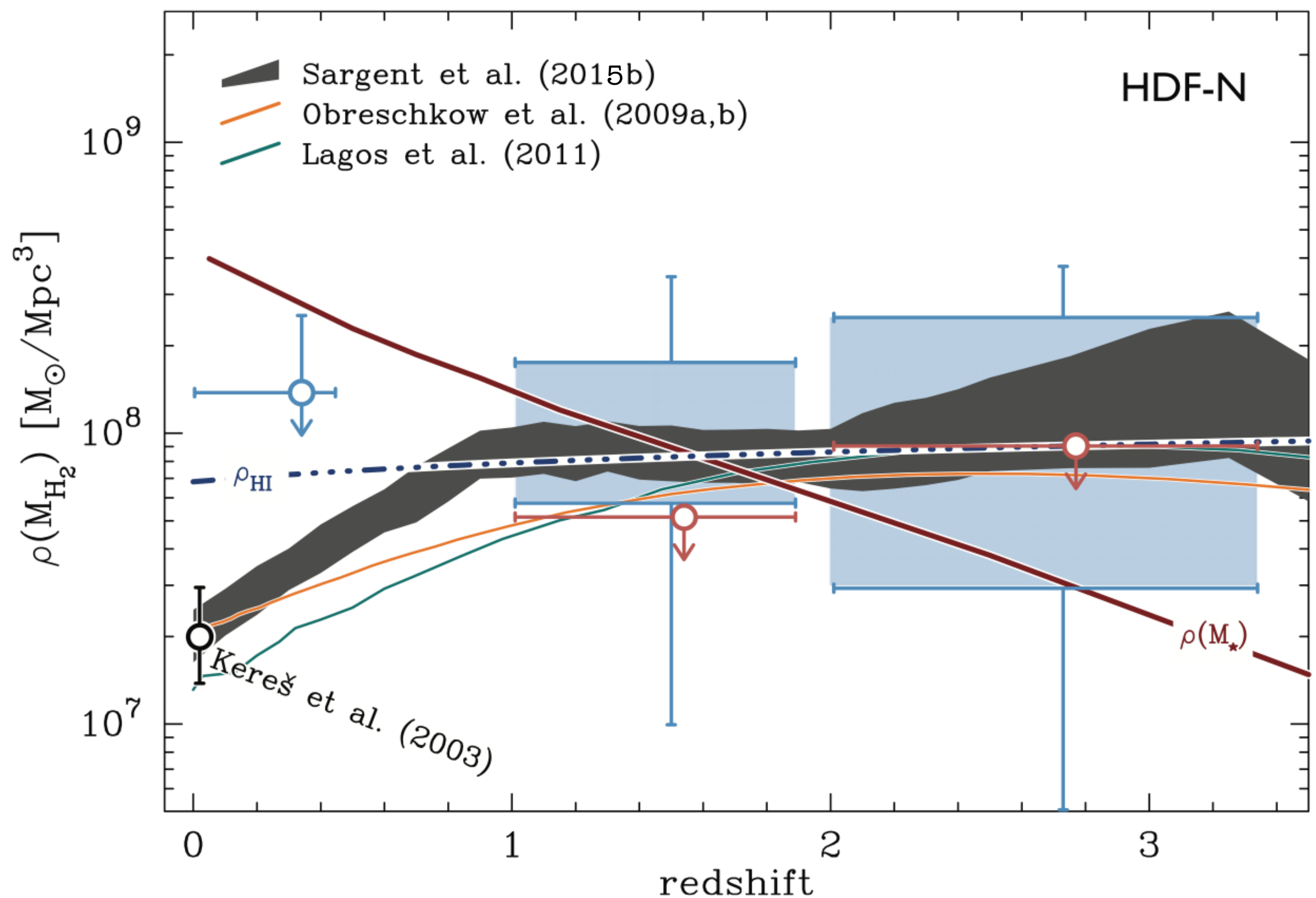
- How does the quenching process work for ETGs which are the offspring of gas-rich, starbursting sub-mm galaxies?
- Are high-redshift quiescent galaxies inactive due to a lack of gas or a low star formation efficiency?

THE COLD GAS HISTORY OF THE UNIVERSE

ARE WE IN FOR SURPRISES?

First evidence from molecular deep field studies suggests that cosmic cold gas density is dominated by the gas that resides in normal main sequence galaxies. Once we refine this measurement, will surprises come from gas-rich star-forming galaxies with unusually low SFE or from sizeable gas reservoirs hidden away in quiescent objects? Or both/neither?

First blind CO survey for molecular gas in HDF-N (110 hr w/ PdBI):

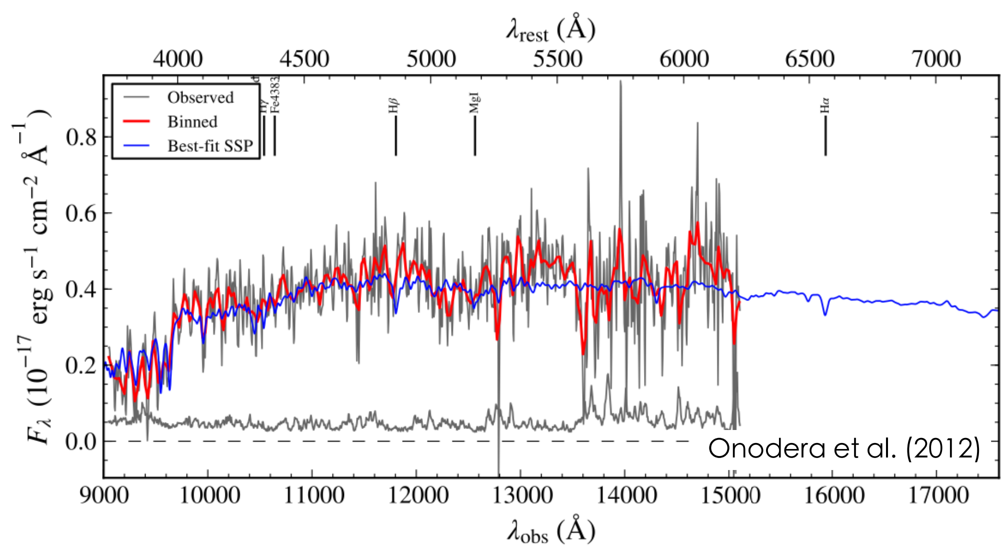


Walter et al. (2014)

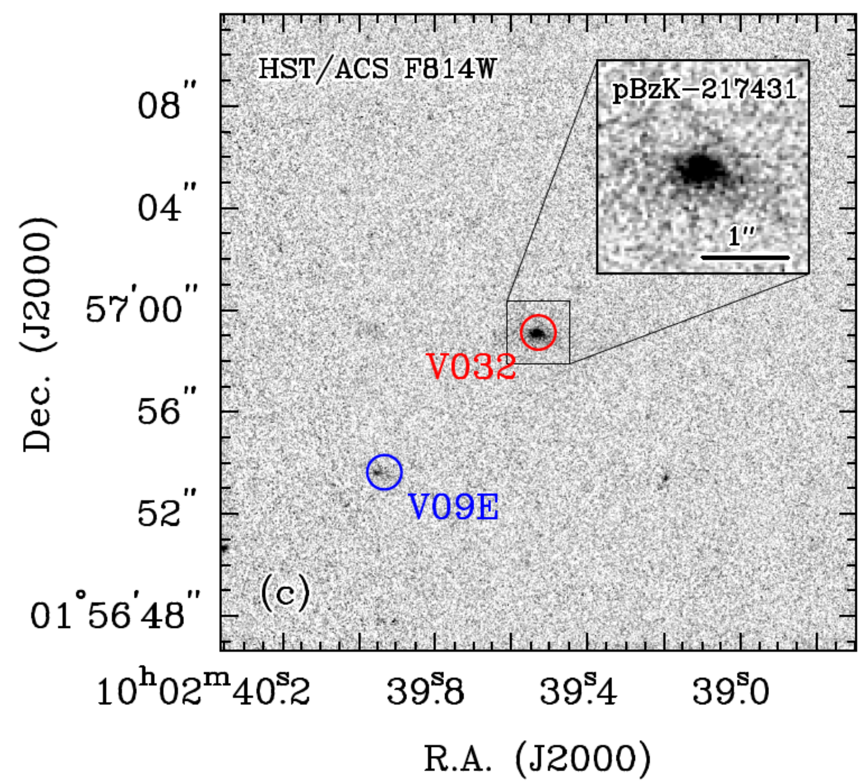
THE TARGET

pBZK-217431 - A MASSIVE ELLIPTICAL IN THE COSMOS FIELD AT z~1.43

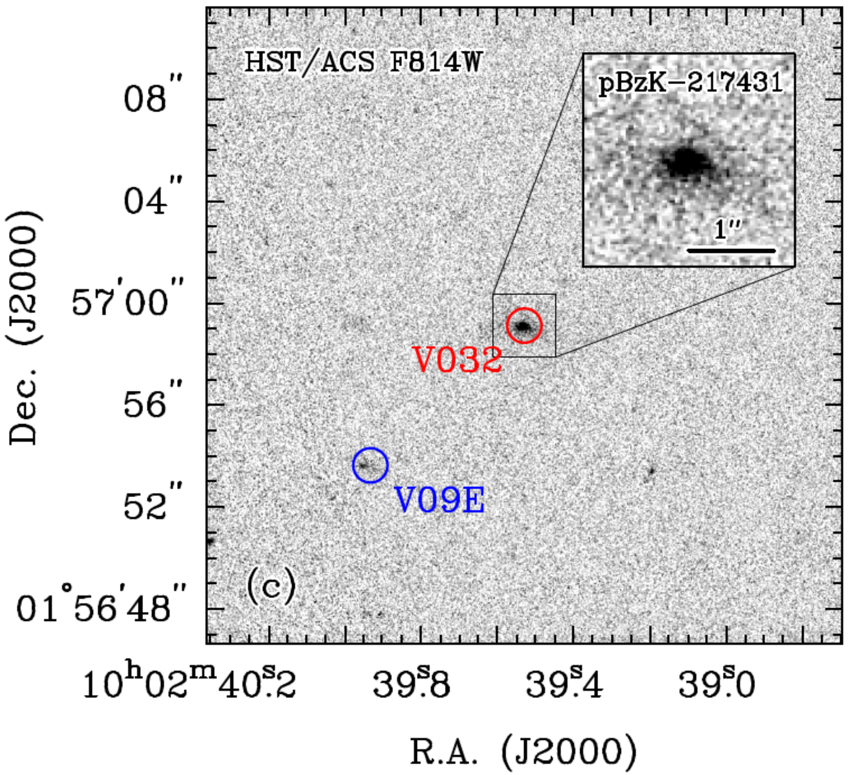
Most promising approach to measuring a gas fraction for a distant elliptical galaxy?
➨ pick one that is particularly massive & spectroscopically confirmed.



quantity/observable	value
R.A. [J2000]	$10^h02^m39.527^s$
Dec. [J2000]	$+01^d56^m59.12^s$
$z_{\rm spec}$	1.4277 ± 0.0015
$M_\star$ [$M_\odot$]	$6.6^{+0.5}_{-1.9}\times10^{11}$
r_e [kpc]	7.19 ± 1.95
Sérsic index n	3.8 ± 0.6



PdBI 3mm FOLLOW-UP OF CO[2-1]
1ST ATTEMPT



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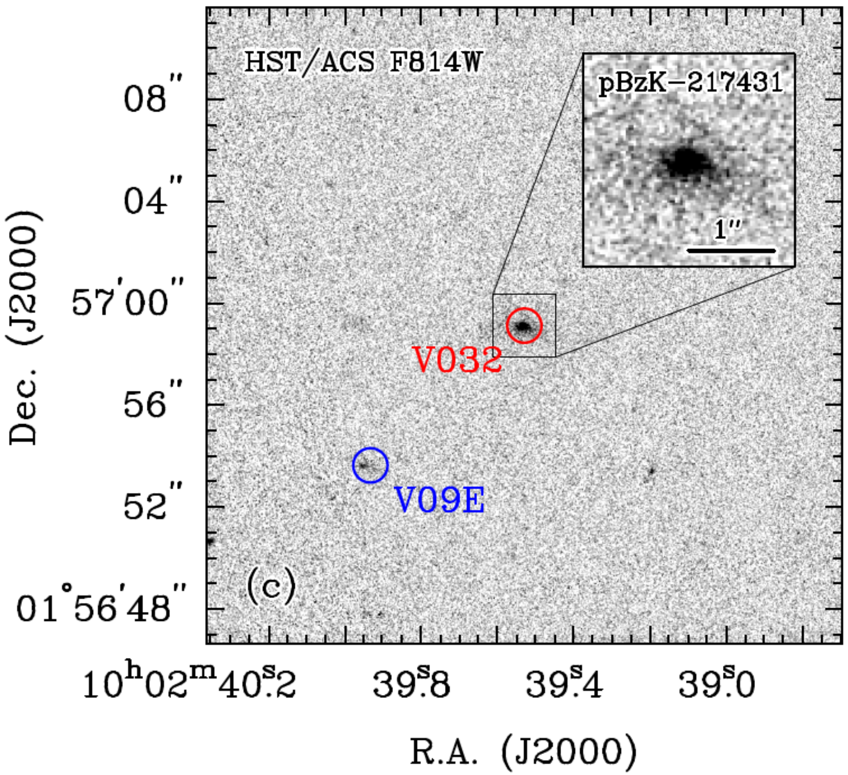
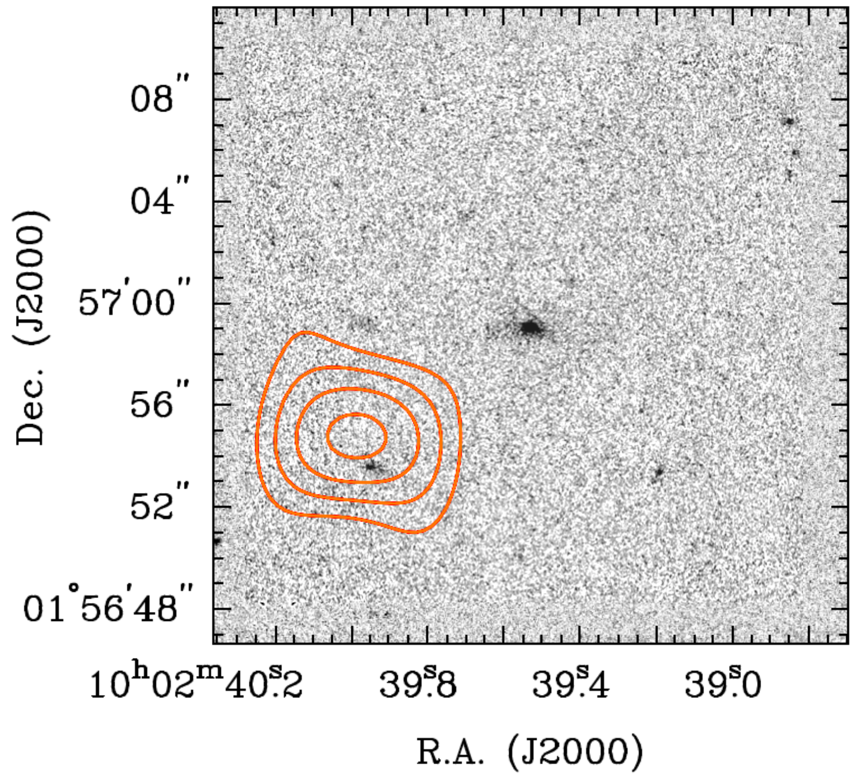


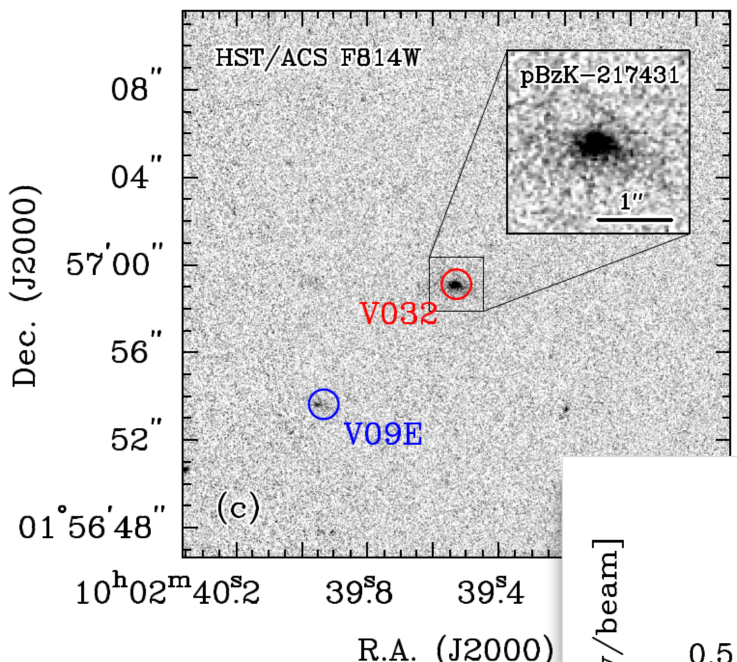
After one 8-hour track...: a S/N>4 detection (albeit offset from pBzK-217431 at phase centre)

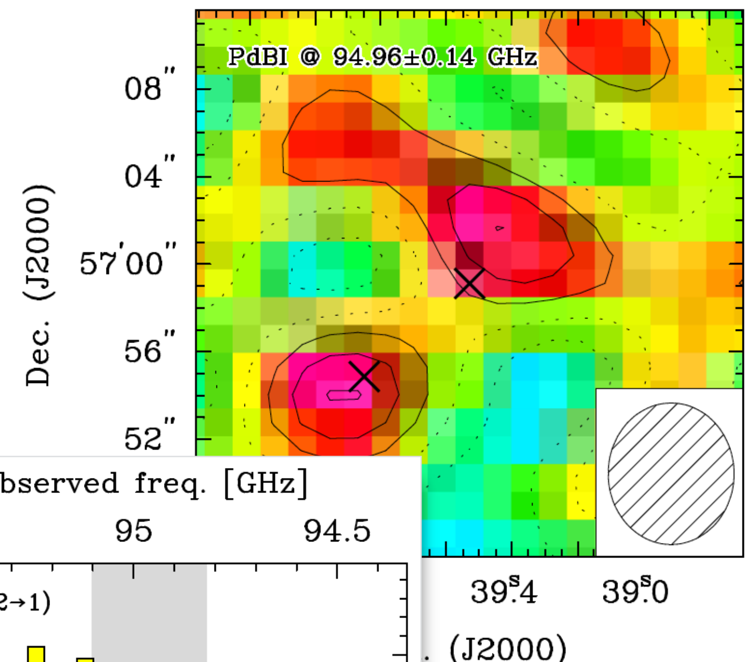


PdBI 3mm FOLLOW-UP OF CO[2-1]

FINAL DATA

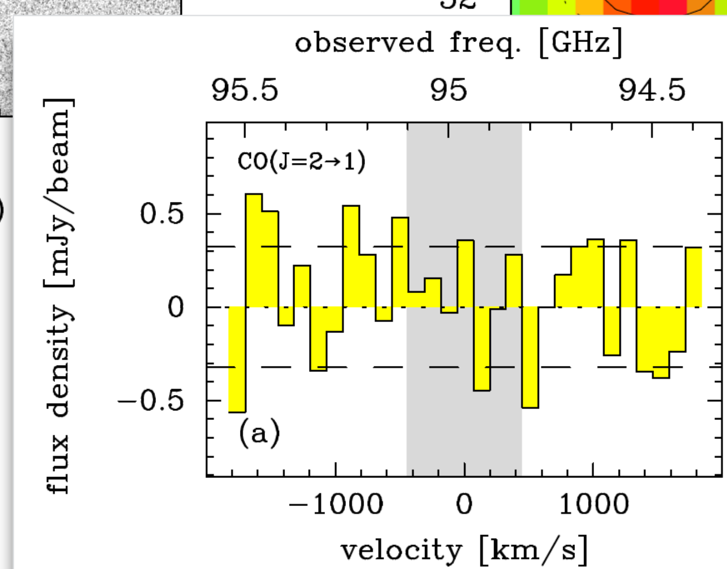
2 full IRAM/PdBI tracks:
- rms noise level of 0.3 mJy/bm per 125 km/s channel
- no significant detection (anywhere...)





(contours plotted in steps of 1σ)

3mm spectrum extracted at elliptical galaxy position:



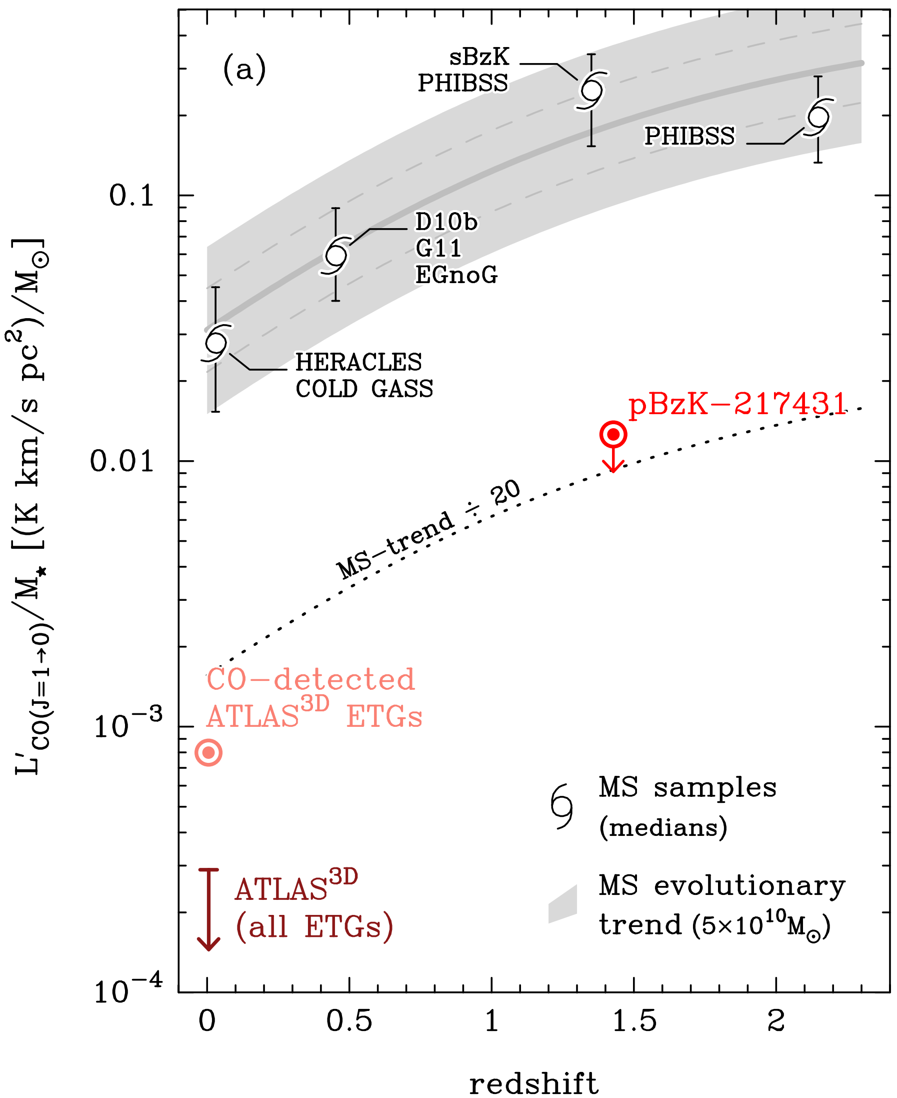
CO UPPER LIMIT: PHYSICAL INTERPRETATION

CONSTRAINTS ON CO LINE LUMINOSITY

First order hypotheses:

- CO line width is commensurate with stellar velocity dispersion obtained from spectroscopy (Onodera et al. 2012)
- ISM conditions in low-z ETGs resemble those of local spiral galaxies (dense gas fractions, gas mass density, SFE, dust temperatures; Krips et al. 2010, Young et al. 2011, Crocker et al. 2012, Martig et al. 2013). Assume this applies also to pBzK-217431 (in accordance with high-res. simulations; Bournaud et al. 2014).

This z=1.43 elliptical has a similar CO-deficit w.r.t. high-z disks as CO-detected ATLAS3D ETGs have w.r.t. local spirals.



CO UPPER LIMIT: PHYSICAL INTERPRETATION

CONSTRAINTS ON H_2 MASS & GAS FRACTION

quantity/observable	value
R.A. [J2000]	$10^h02^m39.527^s$
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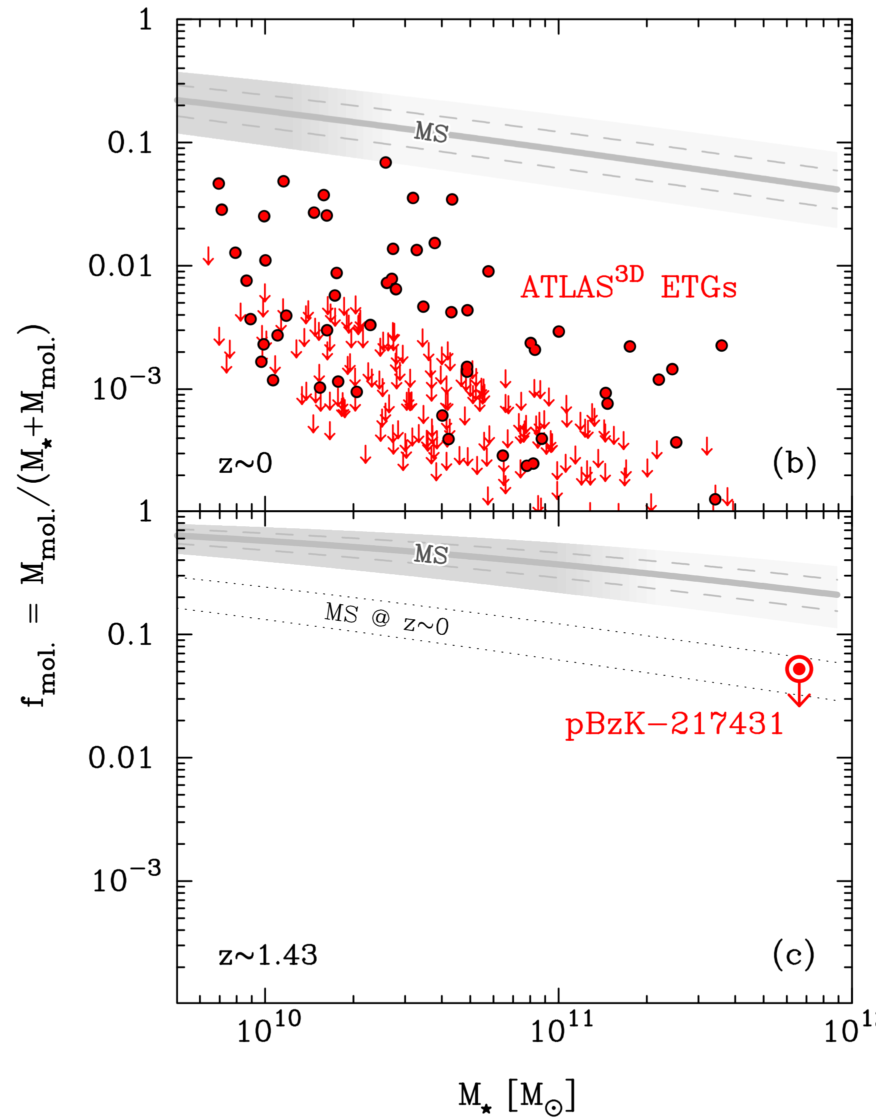
z_{spec}	1.4277 ± 0.0015
$M_\star$ [$M_\odot$]	$6.6^{+0.5}_{-1.9}\times10^{11}$
r_e [kpc]	7.19 ± 1.95
Sérsic index n	3.8 ± 0.6
rms/40 MHz [mJy]	0.33
$I_{CO(J=2\rightarrow1)}$ [Jy km/s]	$<0.30\sqrt{\left(\frac{\Delta v}{777\,\mathrm{km/s}}\right)}$
$L'_{CO(J=2\rightarrow1)}$ [K km/s pc^2]	$<8.3\times10^9$
$M_{mol.}$ [$M_\odot$]	$<3.6\times10^{10}\left(\frac{\alpha_{CO}}{4.4}\right)$
f_{gas}	$<5.1\%$

This z=1.43 elliptical has a ~10× lower gas fraction than CO-detected BzK- or BM/BX-selected galaxies (e.g. from the PHIBSS project; Tacconi et al. 2013) at the same redshift.

pBzK-217413 is truly gas poor (f_{gas}~5% vs. ~50%).

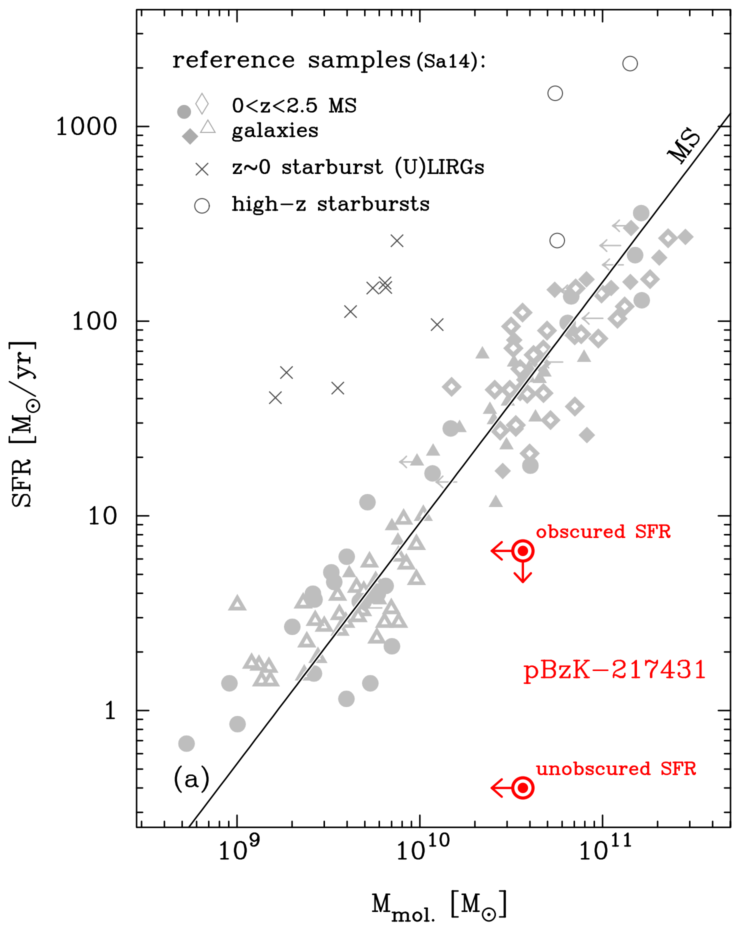


INSIGHTS INTO SFE & QUENCHING

CONSTRAINTS ON THE STAR-FORMATION EFFICIENCY

Integrated Schmidt-Kennicutt relation

(pBzK-217431 SFR values are based on COSMOS ETG sample averages in Man et al. 2015):



Our current upper limit on the gas fraction does not permit a meaningful comparison of the SFE of this z=1.43 elliptical with that of local ETGs.

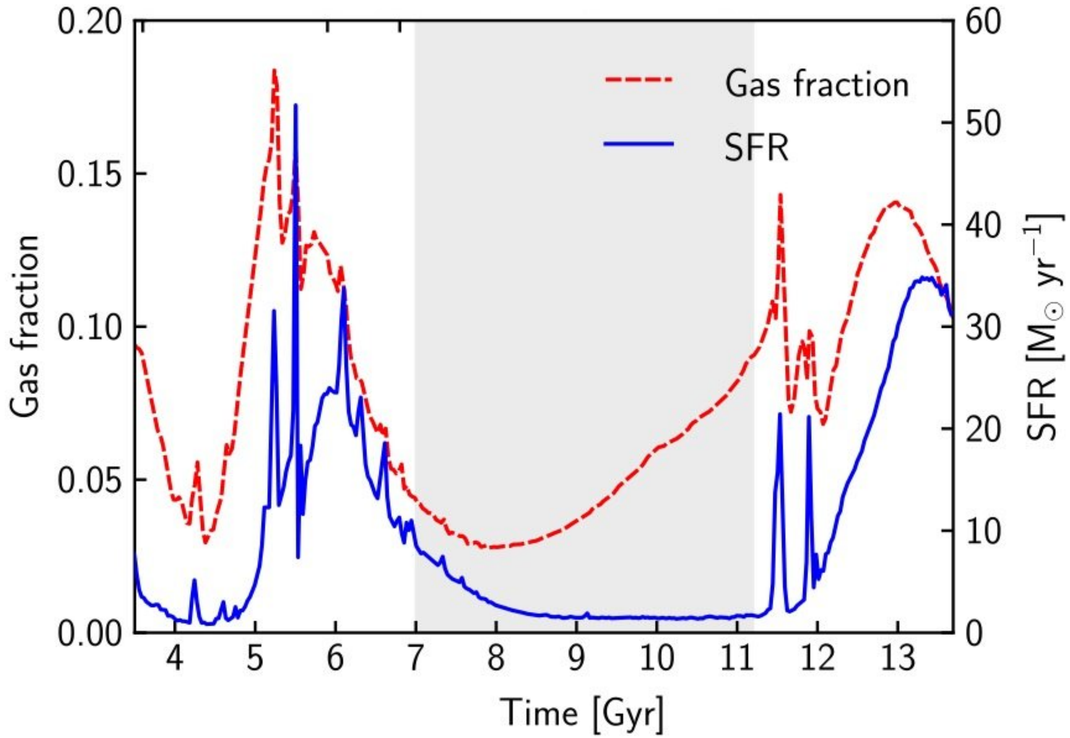
If pBzK-217431 had the same SFE/gas depletion time scale as local ATLAS^{3D} ellipticals its gas fraction would be <1%, implying that ALMA is indispensable for such a detection experiment.

MORPHOLOGICAL QUENCHING

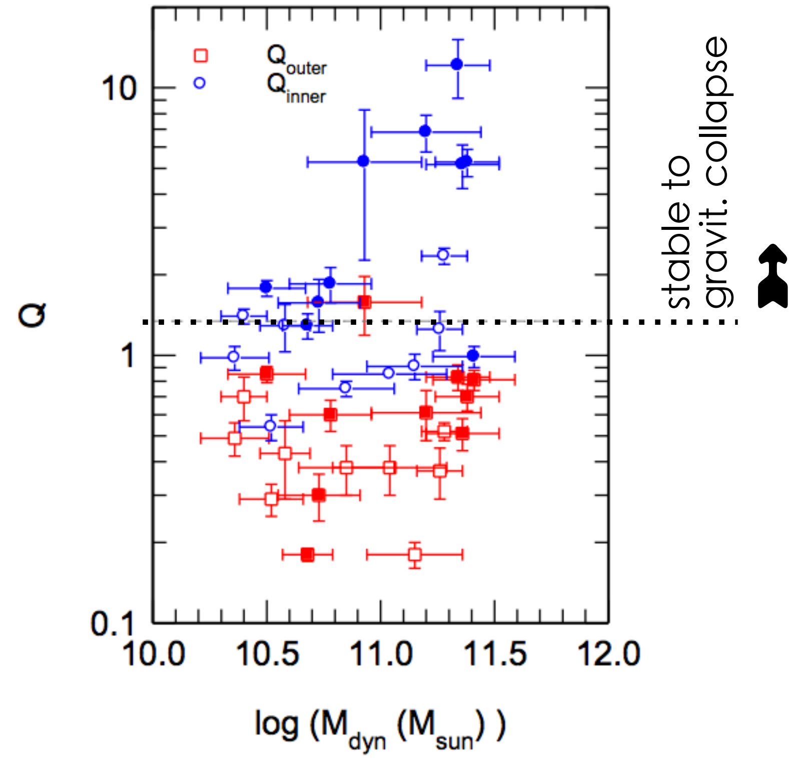
HOW TO KEEP A LOW PROFILE EVEN IN THE PRESENCE OF GAS

Was the scenario of finding significant amount of gas in a quenched elliptical at all plausible? Both simulations and observations suggest that morphological/gravitational quenching could achieve such a configuration.

Simulations (Martig et al. 2009): Early type galaxies can maintain a gas fraction of 5-10% over a significant fraction of their lifetime while the SFR is virtually zero due to stabilization of the gas in the potential of the stellar spheroid.



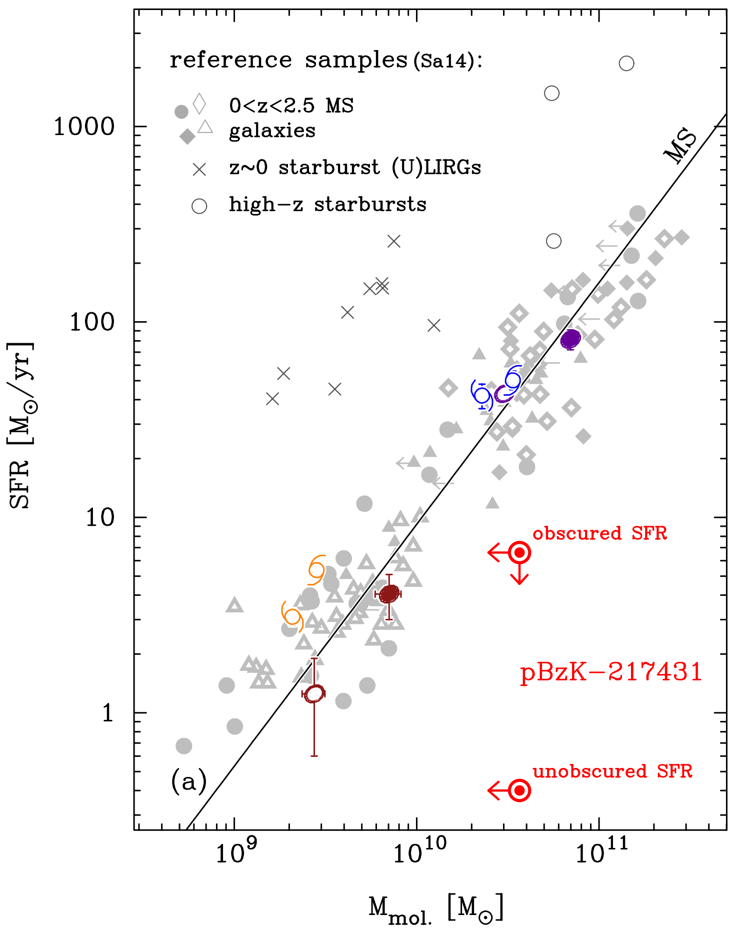
Observations (Genzel et al. 2014): The inner parts of high-z disks with bulges are Toomre-stable.



INSIGHTS INTO SFE & QUENCHING

CONSTRAINTS ON THE STAR-FORMATION EFFICIENCY

Integrated Schmidt-Kennicutt plane: position of simulated ellipticals and disks with both high and low gas fractions. (Bournaud et al. 2014)



Simulations suggest: morphological quenching is ineffective for very high-gas-fraction objects. It can, however, make a low-gas-fraction galaxy become truly passive.

For high-z quiescent galaxies to be as passive as observed, morphological quenching is presumably not the preferred explanation. Gas removal/exhaustion is more plausible.

SUMMARY

1. Measurements of the gas fraction and SFE of high-z quiescent galaxies are a crucial missing piece of information to understand their formation.

2. Our first attempt to detect CO in an elliptical at the peak epoch of galaxy assembly produced an upper limit of ~5% on the gas fraction. This is ~10× lower than the majority of the star-forming galaxies with H_2 mass measurements at these redshifts.

3. Morphological quenching alone cannot shut down high-z ETGs as thoroughly as necessary. These objects are presumably truly gas poor due to feedback/gas exhaustion.