

“Super spirals” at cosmic noon

Where are they headed?
(And: what have they been up to?)

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EPFL

SKACH



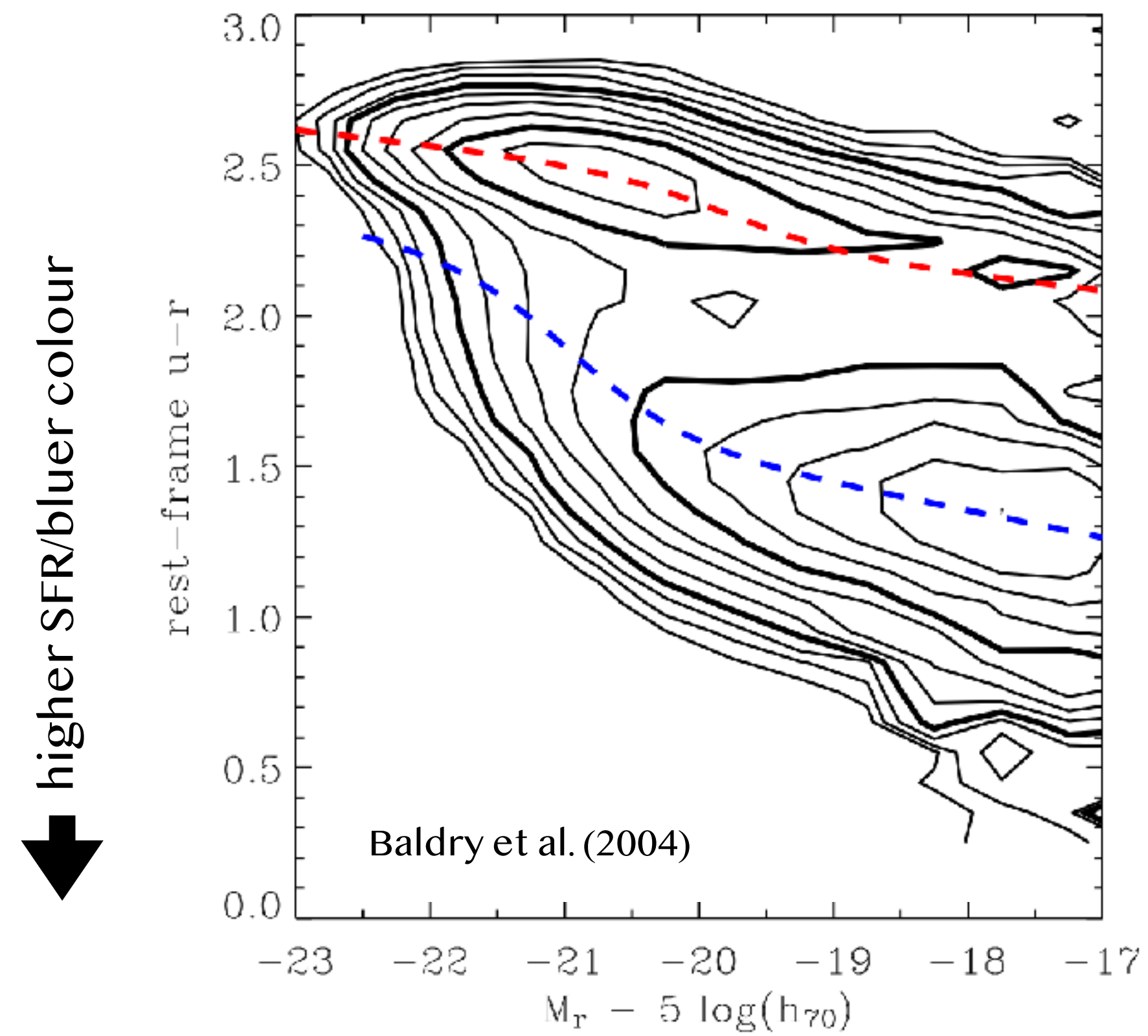
Image credit: ESO

MENU DU JOUR (du quart d'heure...)

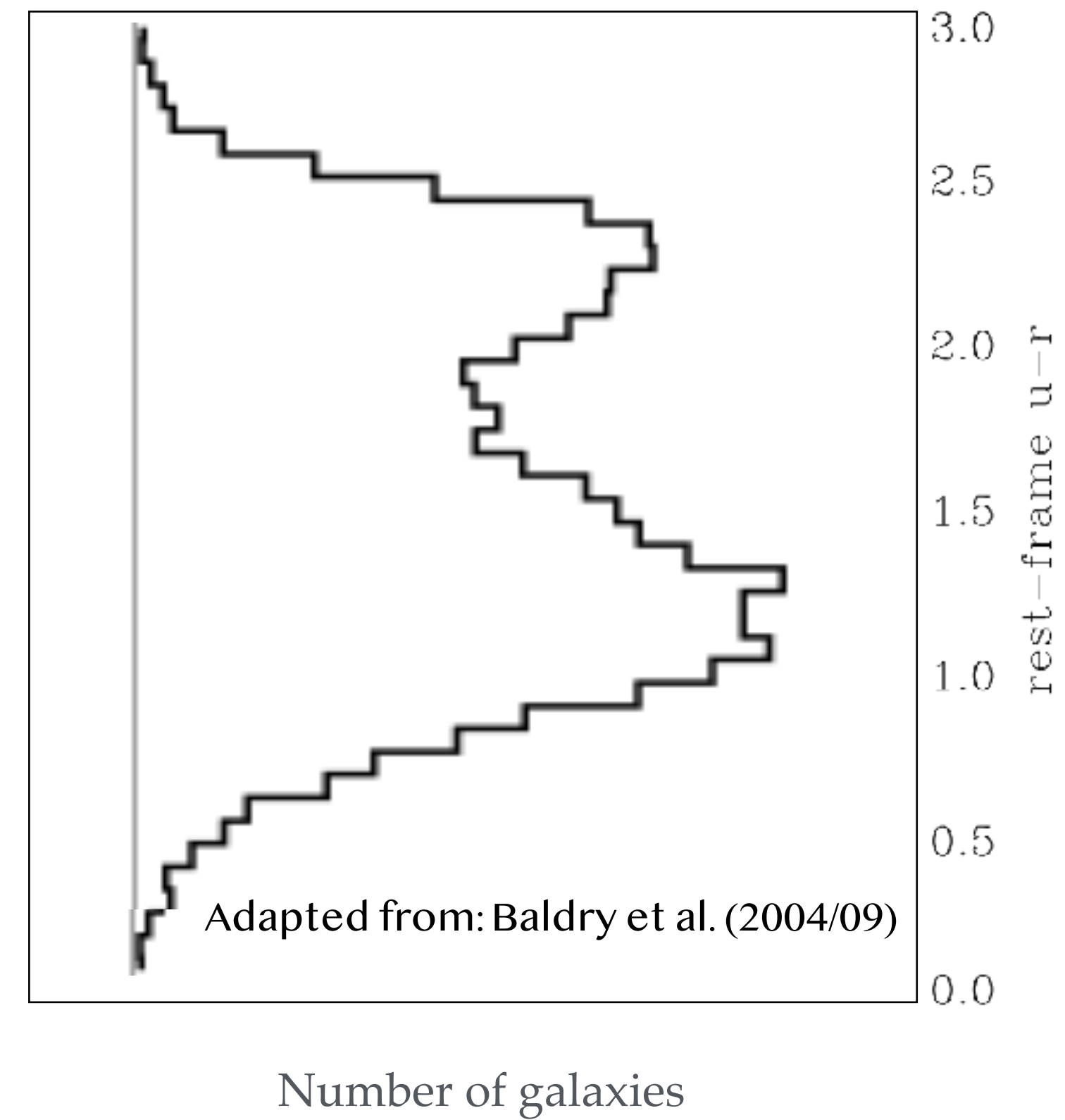
- Introduction:
 - Galaxy bimodality & quenching (mechanisms)
 - Quenched galaxies and those resisting quenching
 - Why is this radio science...?
- The sample, the telescope(s)
- Results:
 - “Where are they headed?” — Which mechanisms can bring about the inevitable quenching?
 - “What have they been up to?” — Can we identify reasons for the special status of “super spirals” among the high-mass galaxy population?

THE GALAXY BIMODALITY

In the colour-magnitude diagram ...

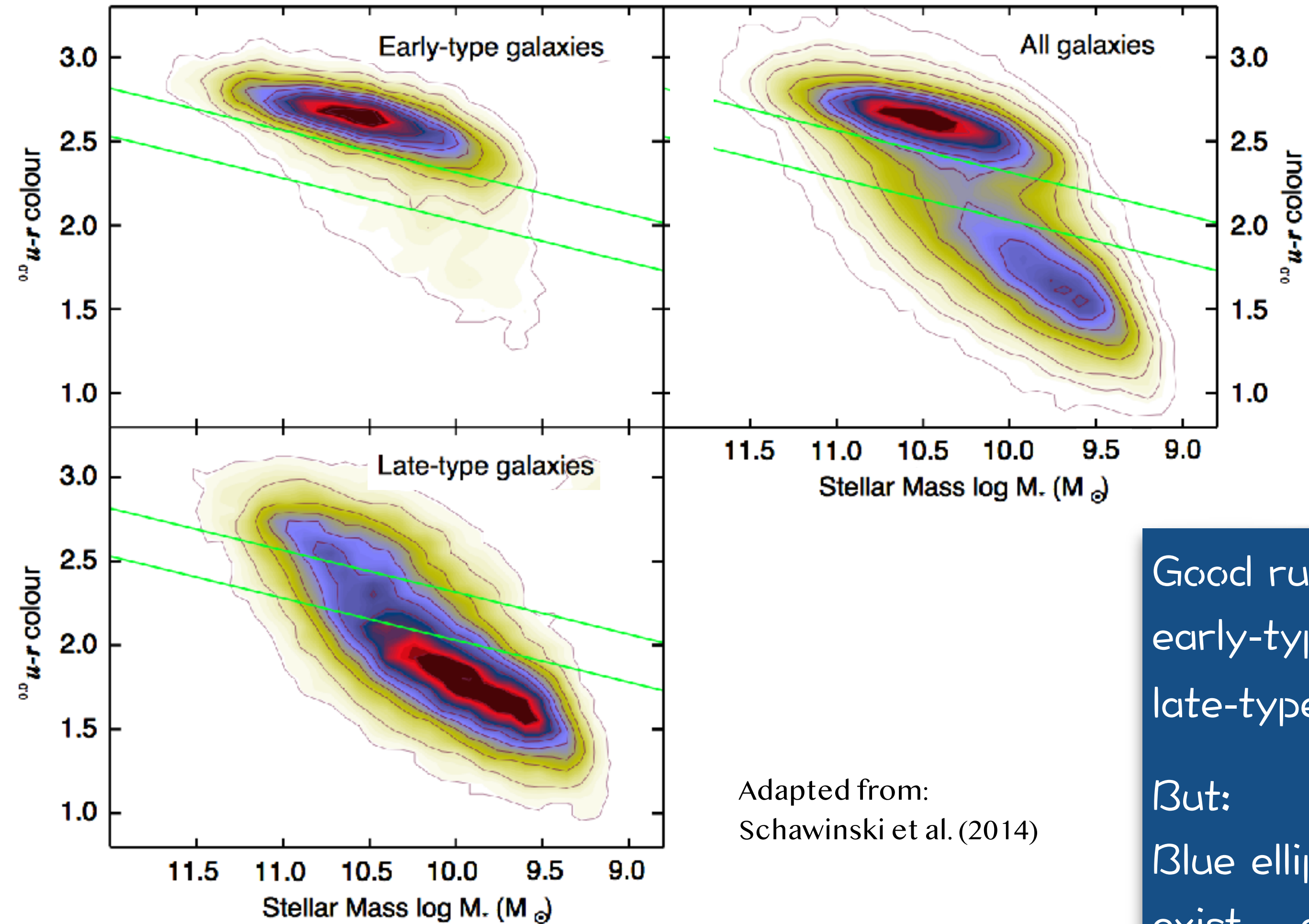


increasing luminosity (& mass)



THE GALAXY BIMODALITY

With respect to structural properties...



Adapted from:
Schawinski et al. (2014)

Good rule of thumb:

early-type galaxy $\leftrightarrow$ red colour

late-type galaxy $\leftrightarrow$ blue colour

But:

Blue ellipticals & red spirals do exist ... and provide insight into galaxy quenching mechanisms.



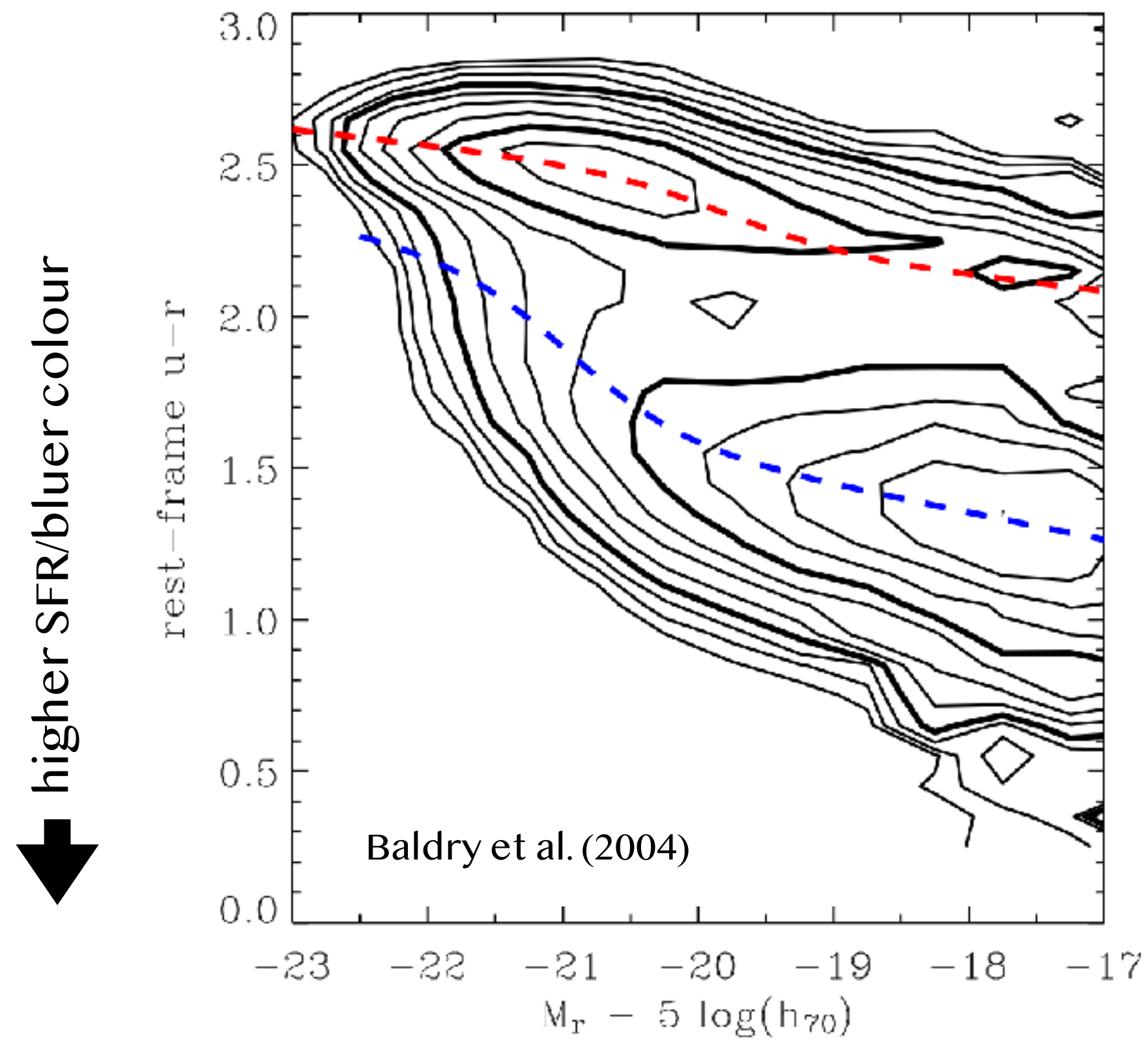
Hubble XDF

Image credit: XDF team

THE GALAXY BIMODALITY

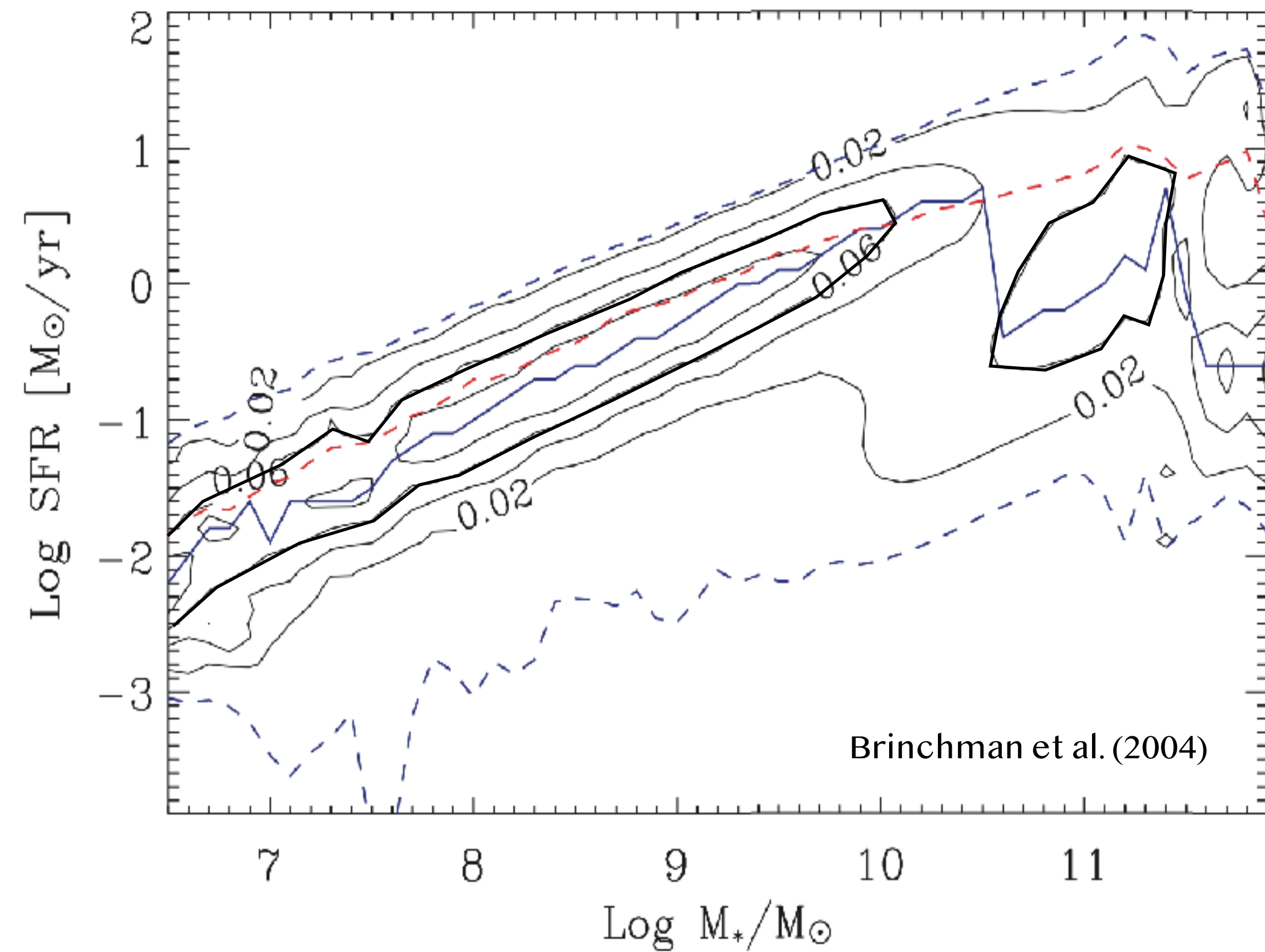
The colour-magnitude diagram vs. SFR- $M_{\star}$ space

bimodality (observables)



← increasing luminosity (& mass)

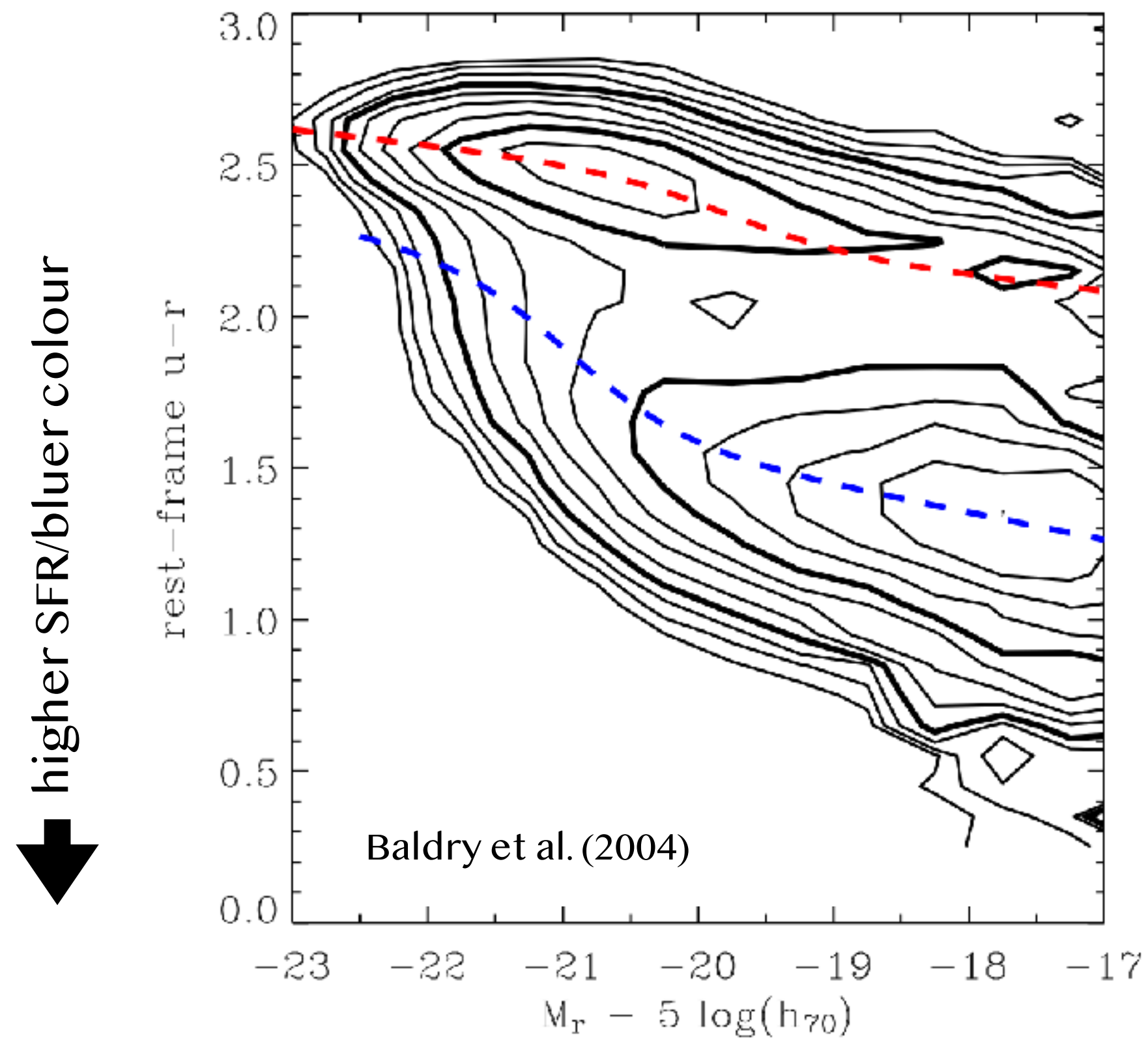
bimodality (physical properties)



THE GALAXY BIMODALITY

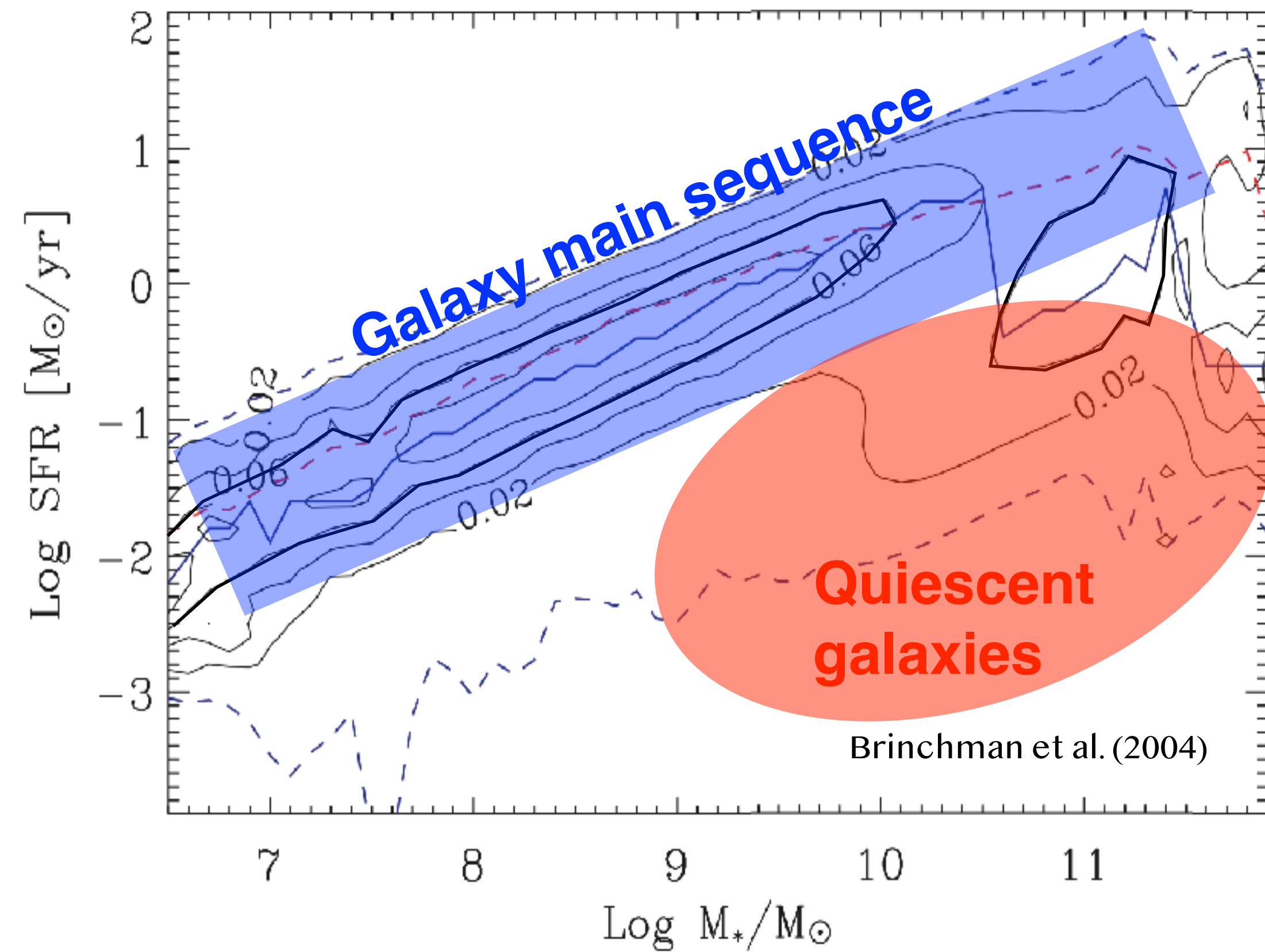
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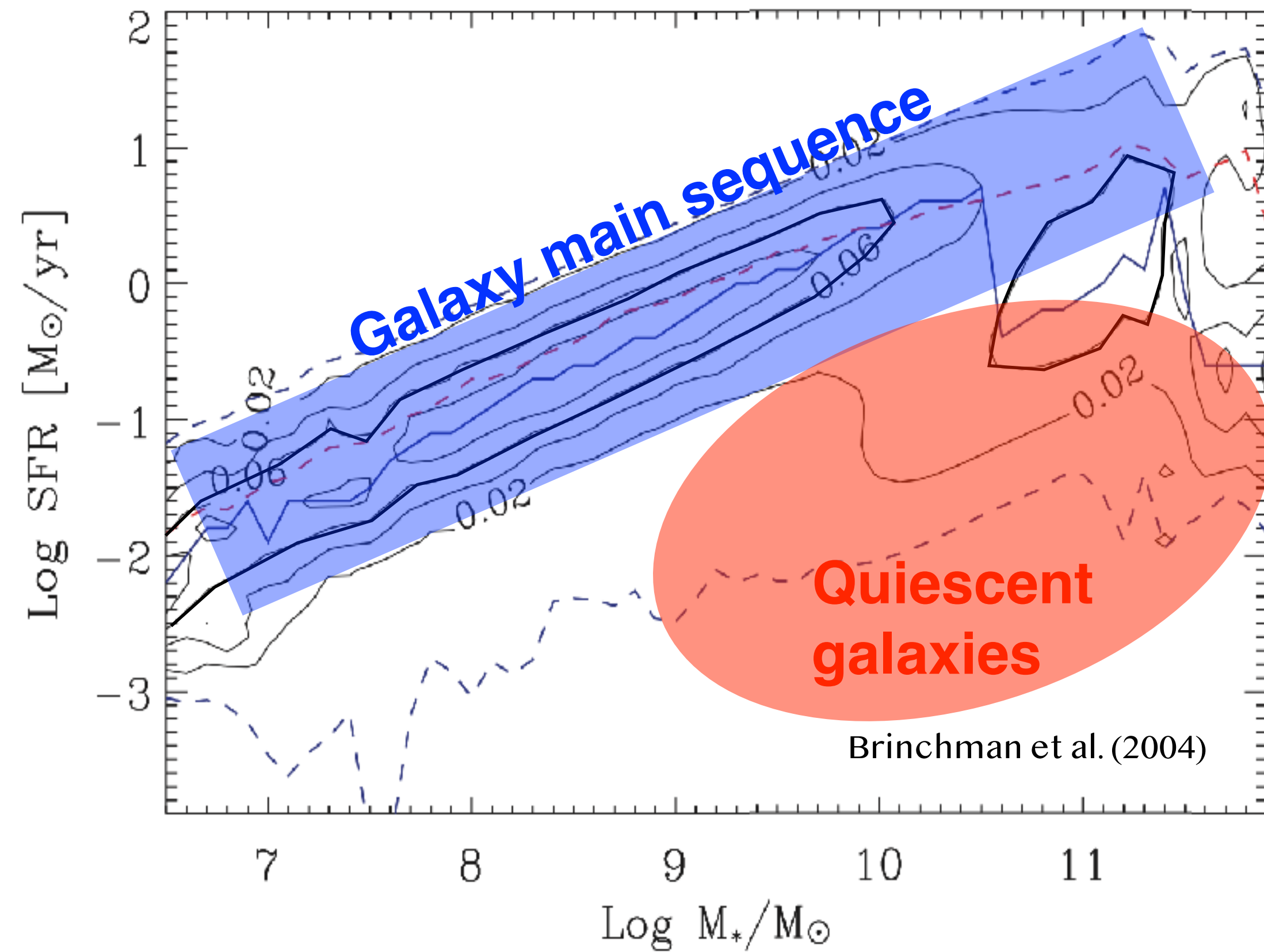
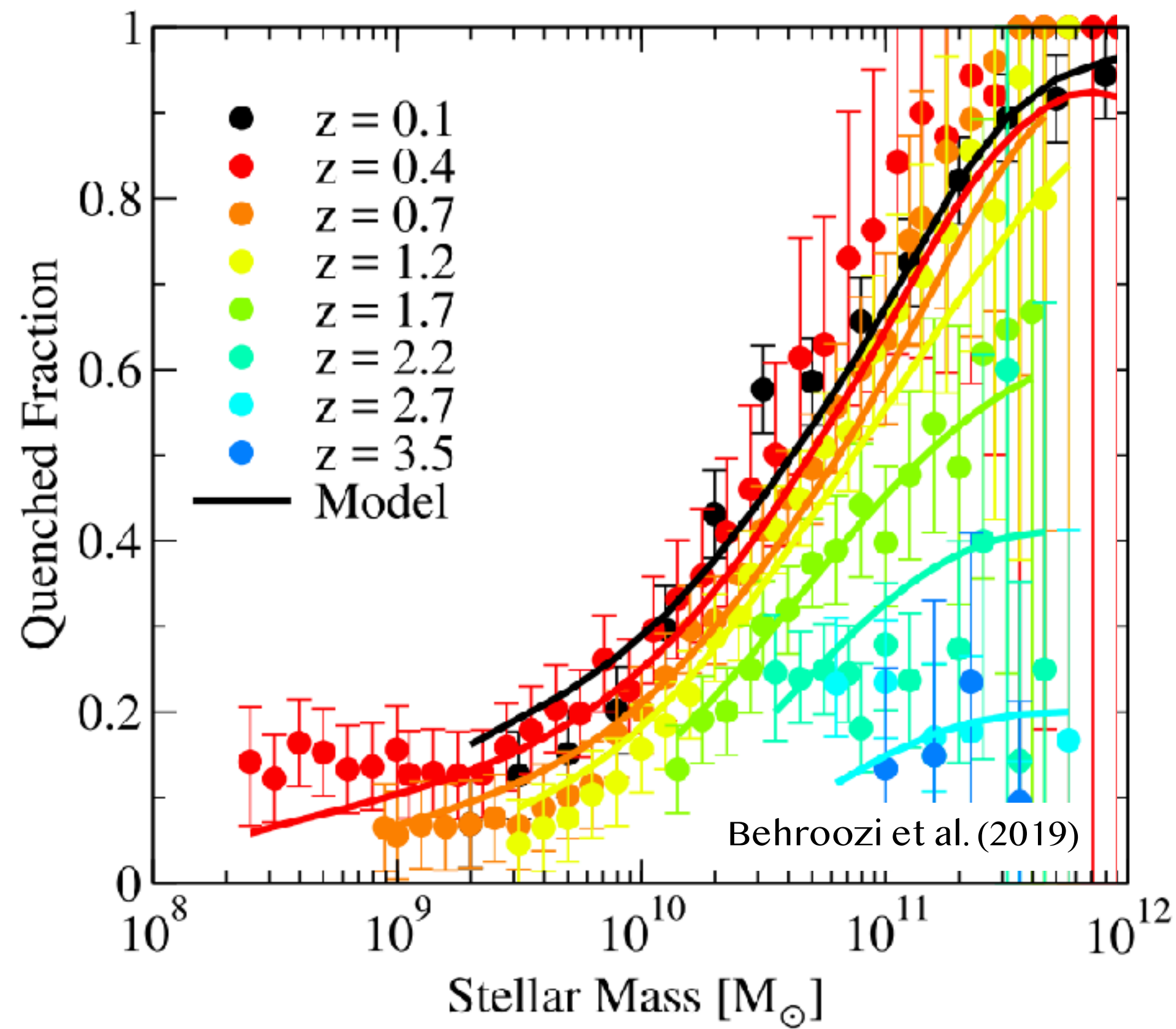
← increasing luminosity (& mass)

bimodality (physical properties)



QUENCHED GALAXIES

The norm at high masses over a large fraction of cosmic history



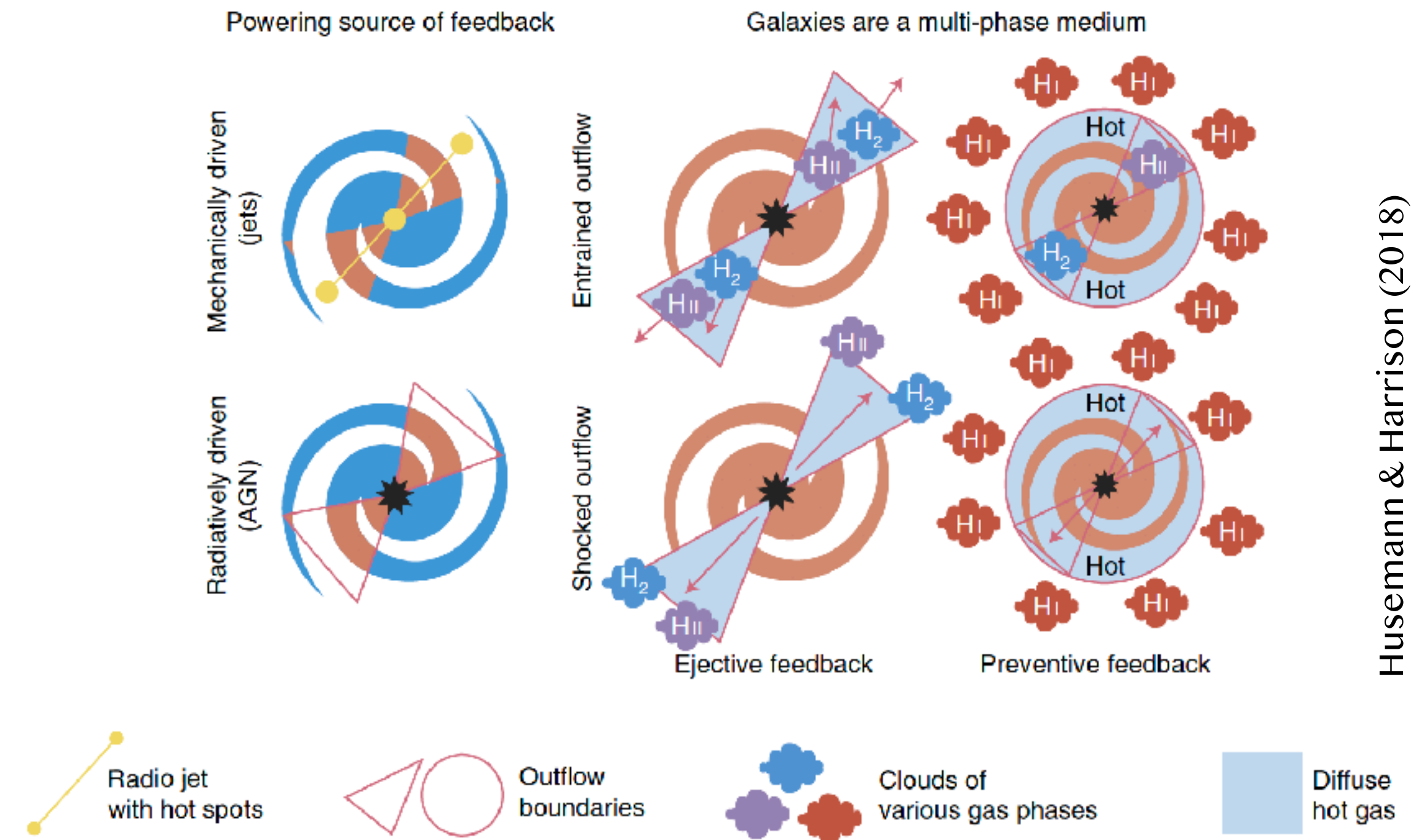
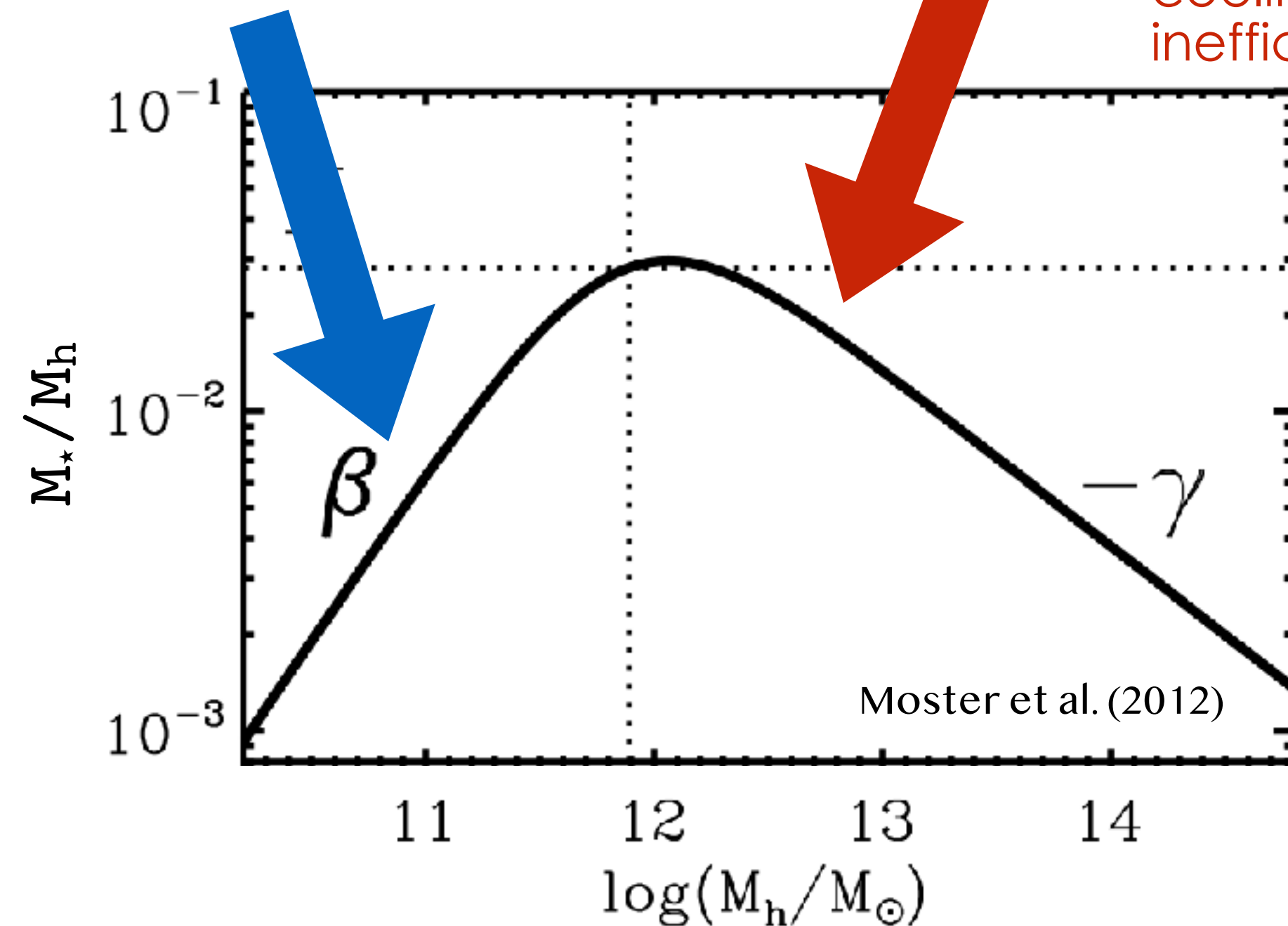
AGN FEEDBACK

A key factor impacting the ability of galaxies at high mass to incorporate and retain baryons

feedback from
star formation

suppression by AGN-
driven feedback

radiative
cooling
inefficient

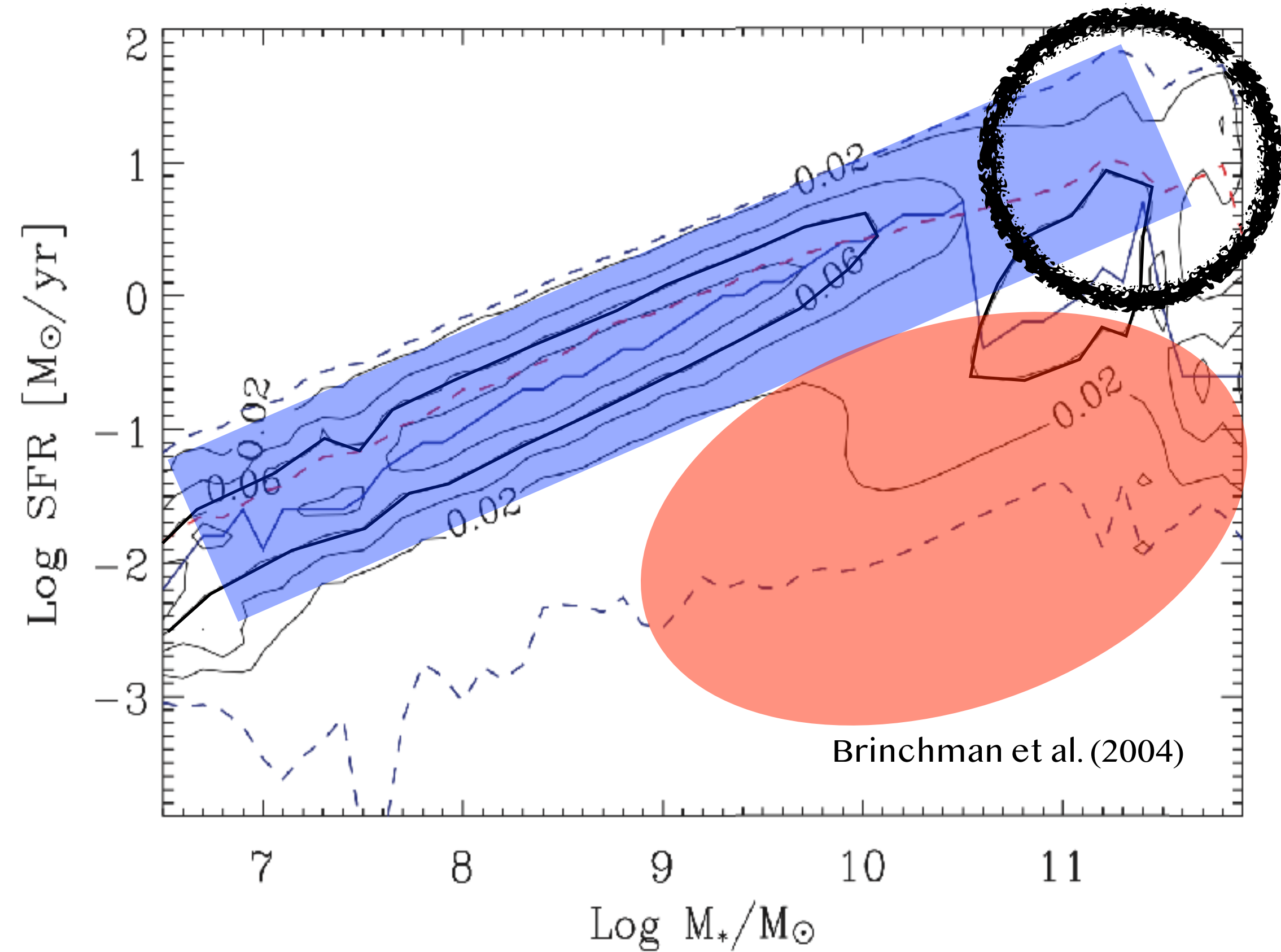
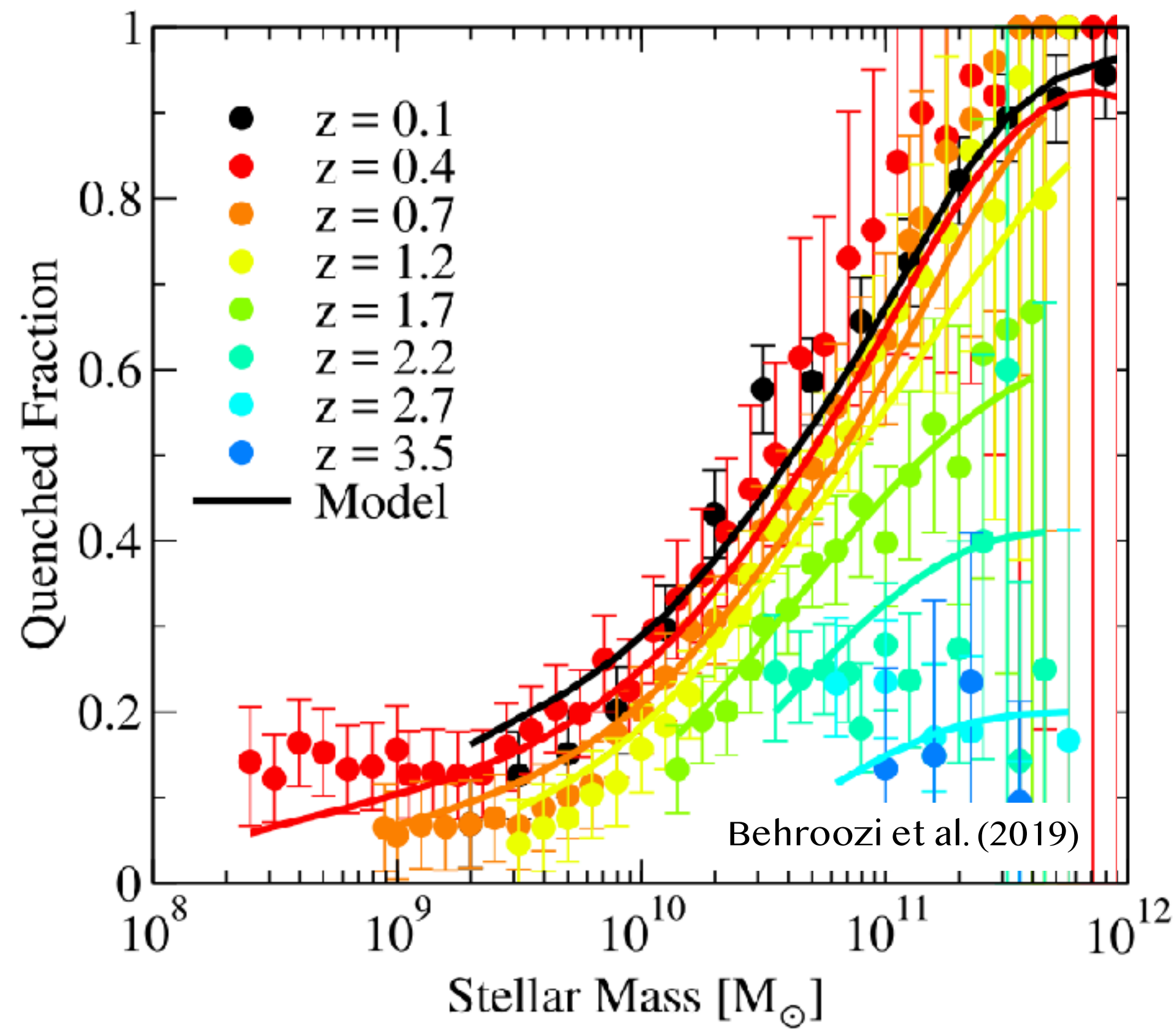


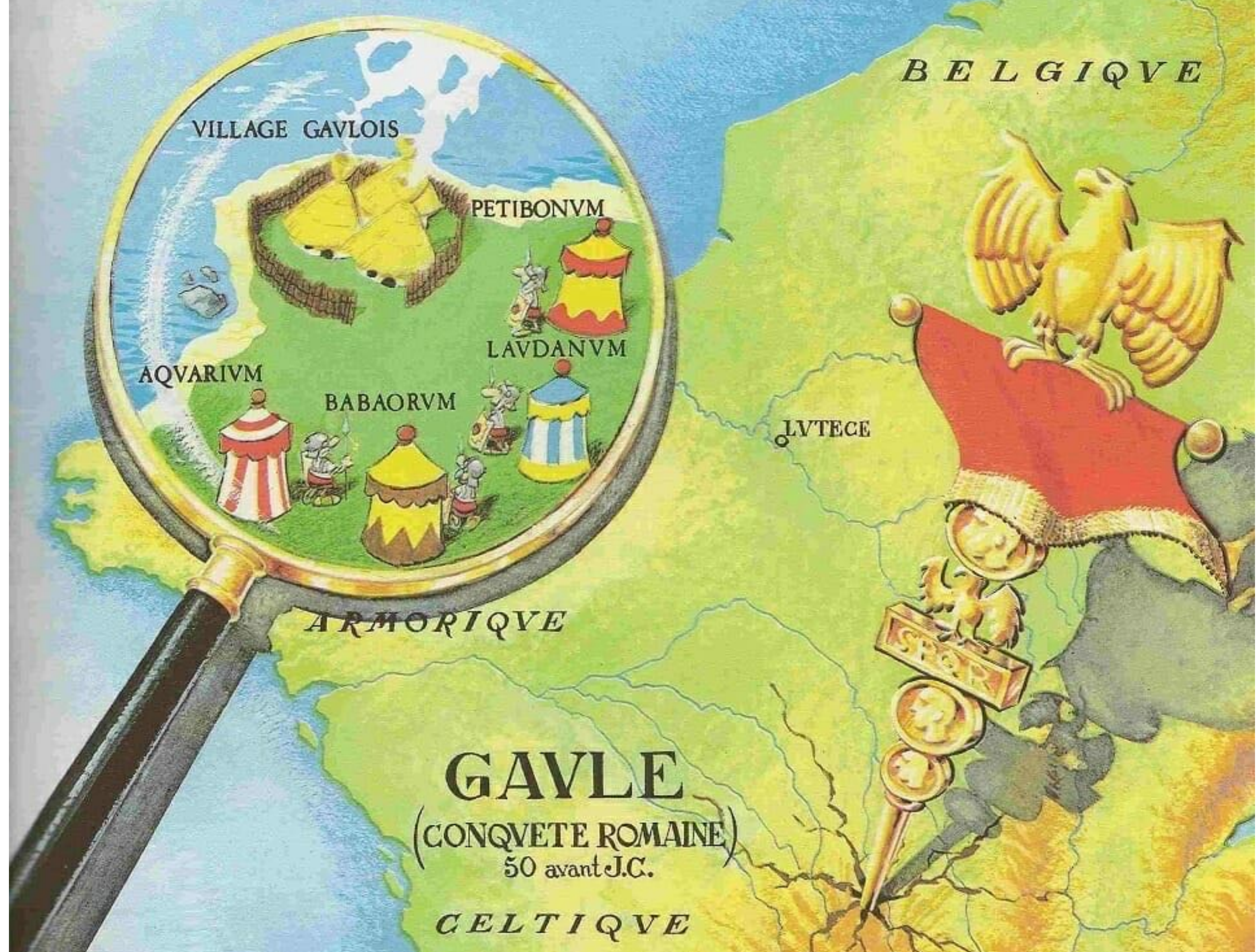
Milky Way-sized haloes ($\sim 10^{12} M_{\odot}$) are the most favourable location for star-formation.

(Even in these only about 10-20% of the baryons are incorporated into stars.)

QUENCHED GALAXIES

The norm at high masses over a large fraction of cosmic history





BELGIQVE

VILLAGE GAVLOIS

PETIBONVM

LAVDANVM

AQVARIVM

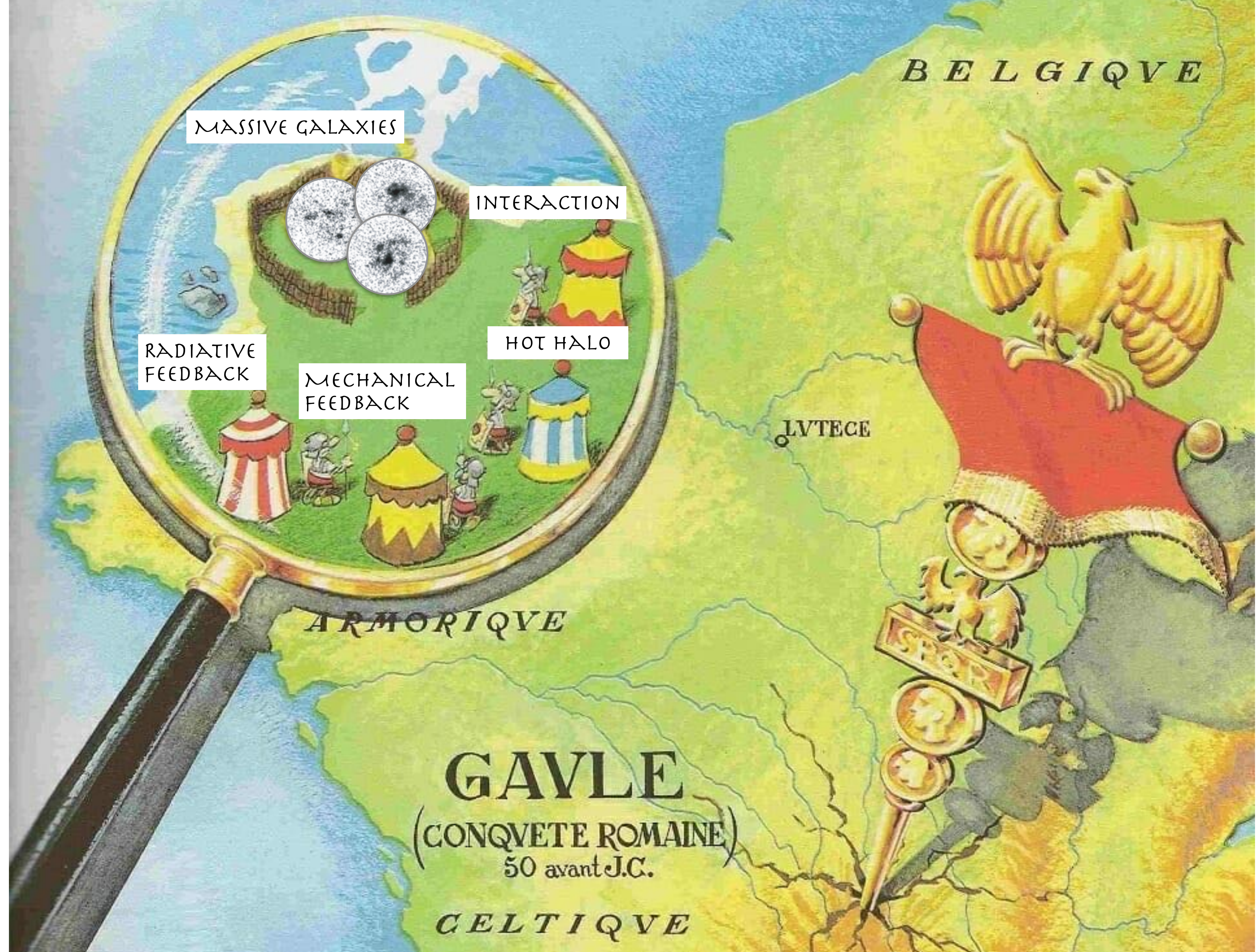
BABAORVM

LVTECE

ARMORIQVE

GAVLE
(CONQVETE ROMAINE)
50 avant J.C.

CELTIQVE



MASSIVE GALAXIES

INTERACTION

RADIATIVE
FEEDBACK

MECHANICAL
FEEDBACK

HOT HALO

ARMORIQUE

GAVLE
(CONQVETE ROMAINE)
50 avant J.C.

CELTIQUE

BELGIQVE

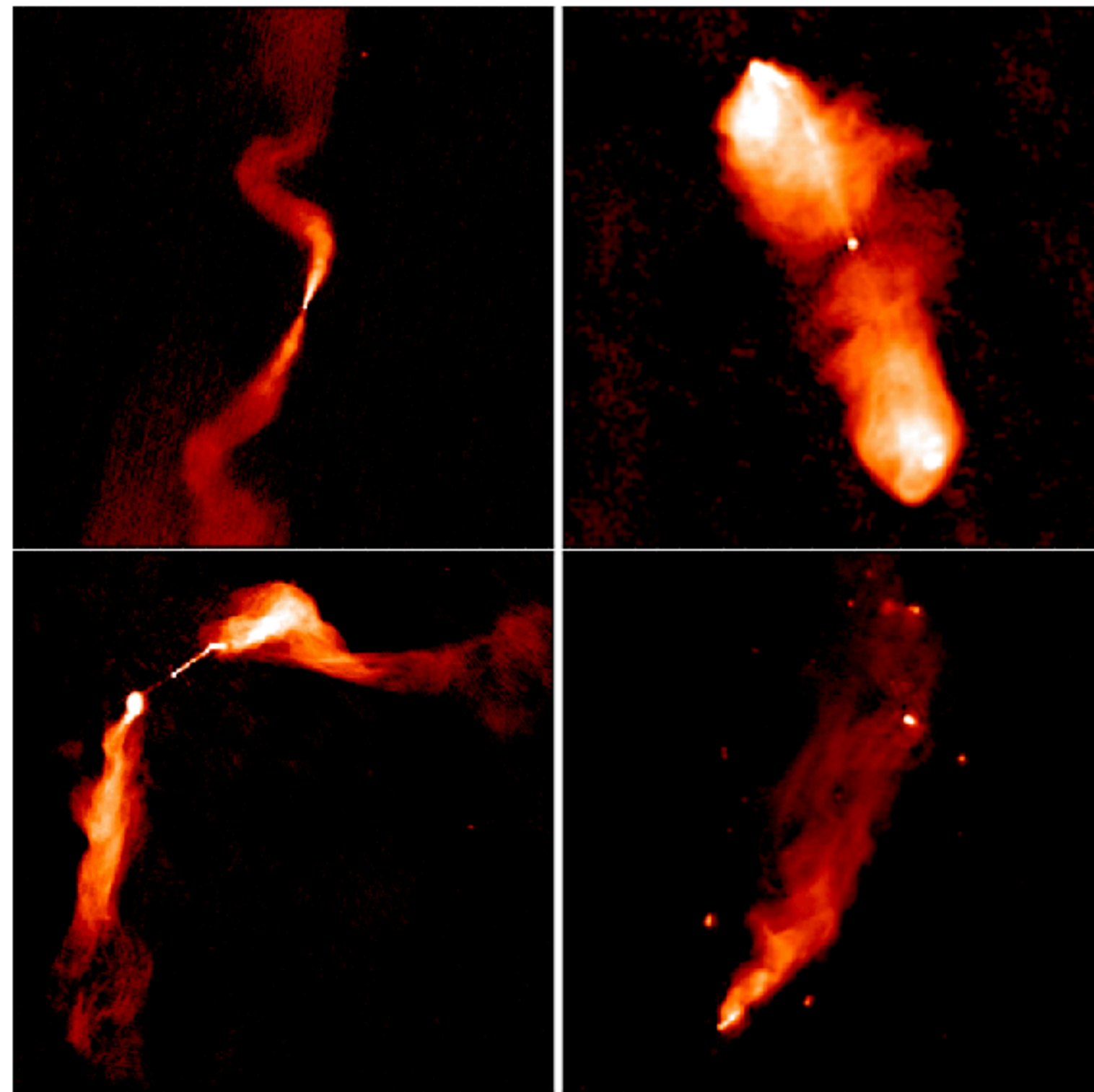
LVTECE

SPQR

THE HIGHEST-MASS STAR-FORMING GALAXIES

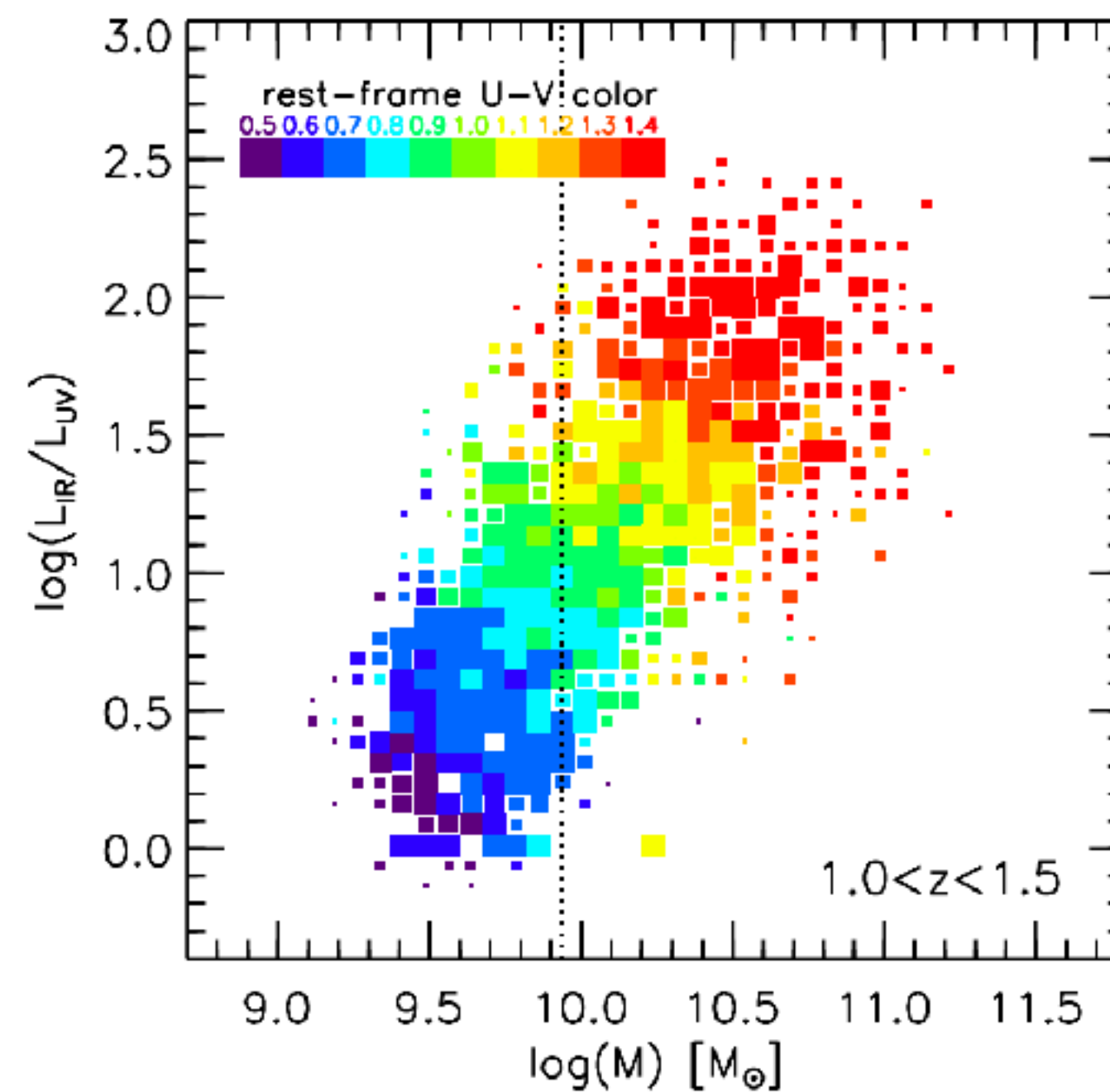
Three reasons to study them with radio telescopes

Radio-mode AGN feedback



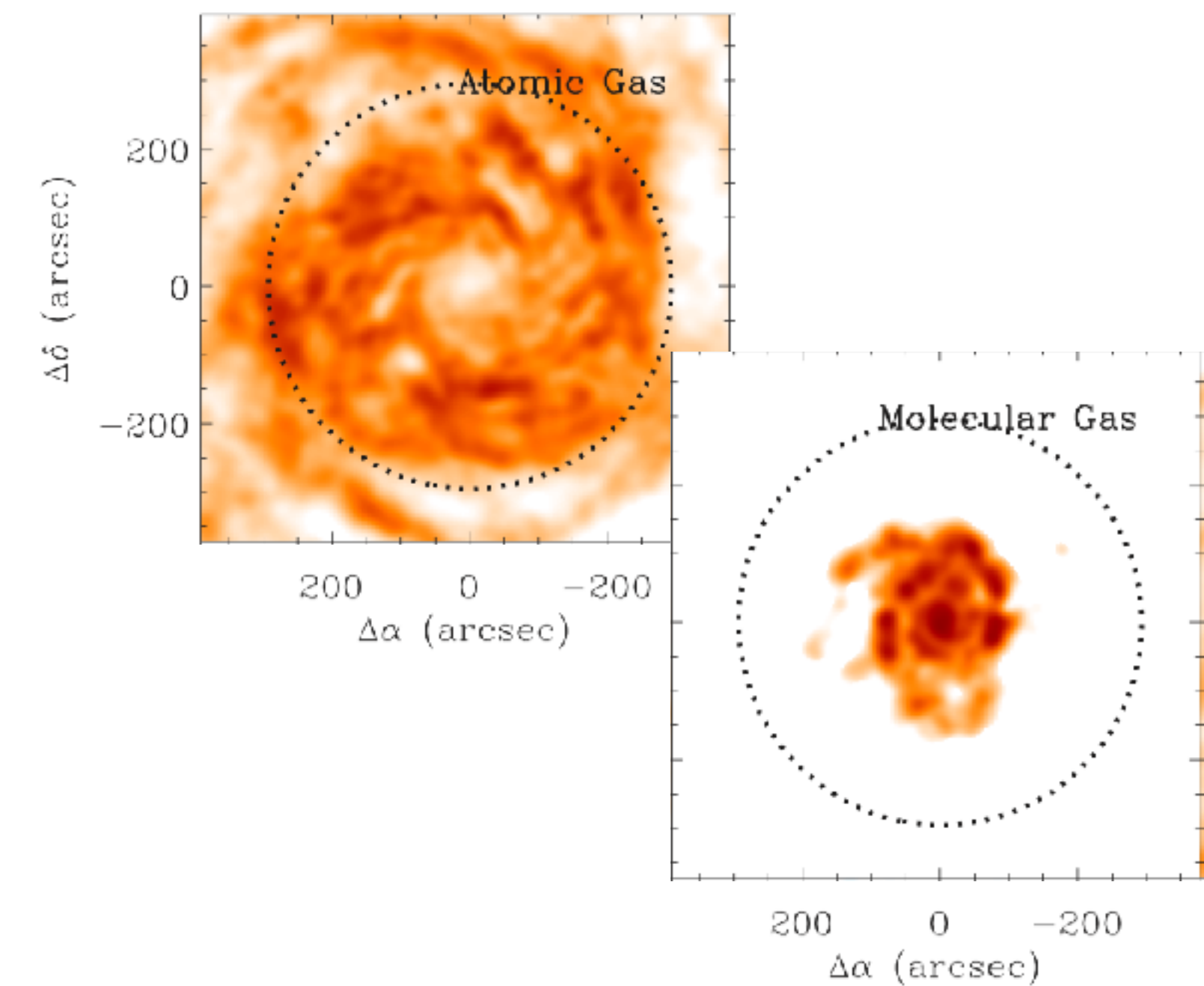
Hardcastle & Croston (2020)

Massive galaxies are esp. dusty.
(Radio emission is not affected!)



Whitaker et al. (2012)

Radio line emission from the
atomic & molecular gas.



Leroy et al. (2008)



IRAM/NOEMA

Gas mass measurements for a sample of high-mass main-sequence galaxies at cosmic noon to:

- Study potential for continued growth
- Look for evidence of quenching processes in action

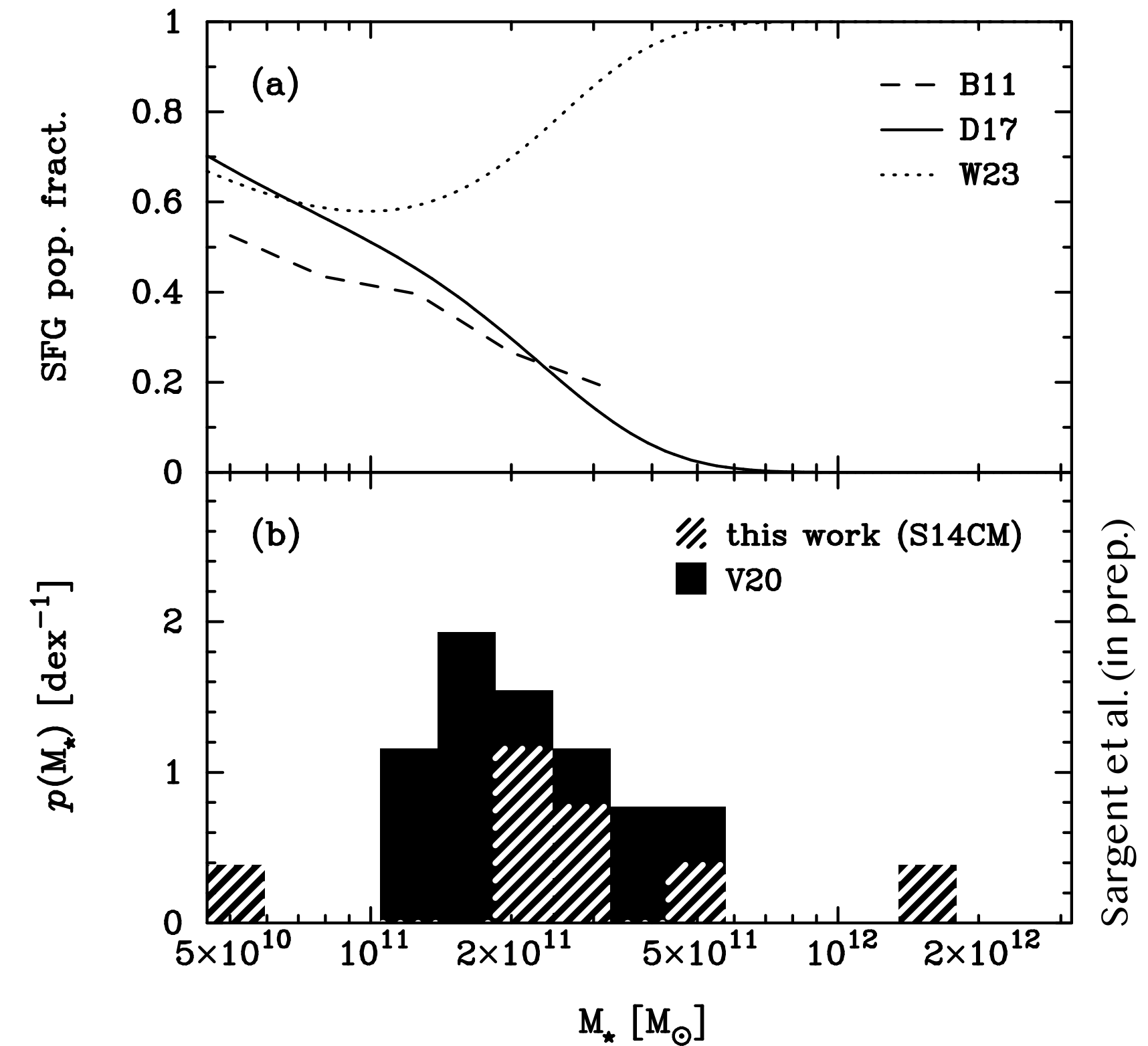
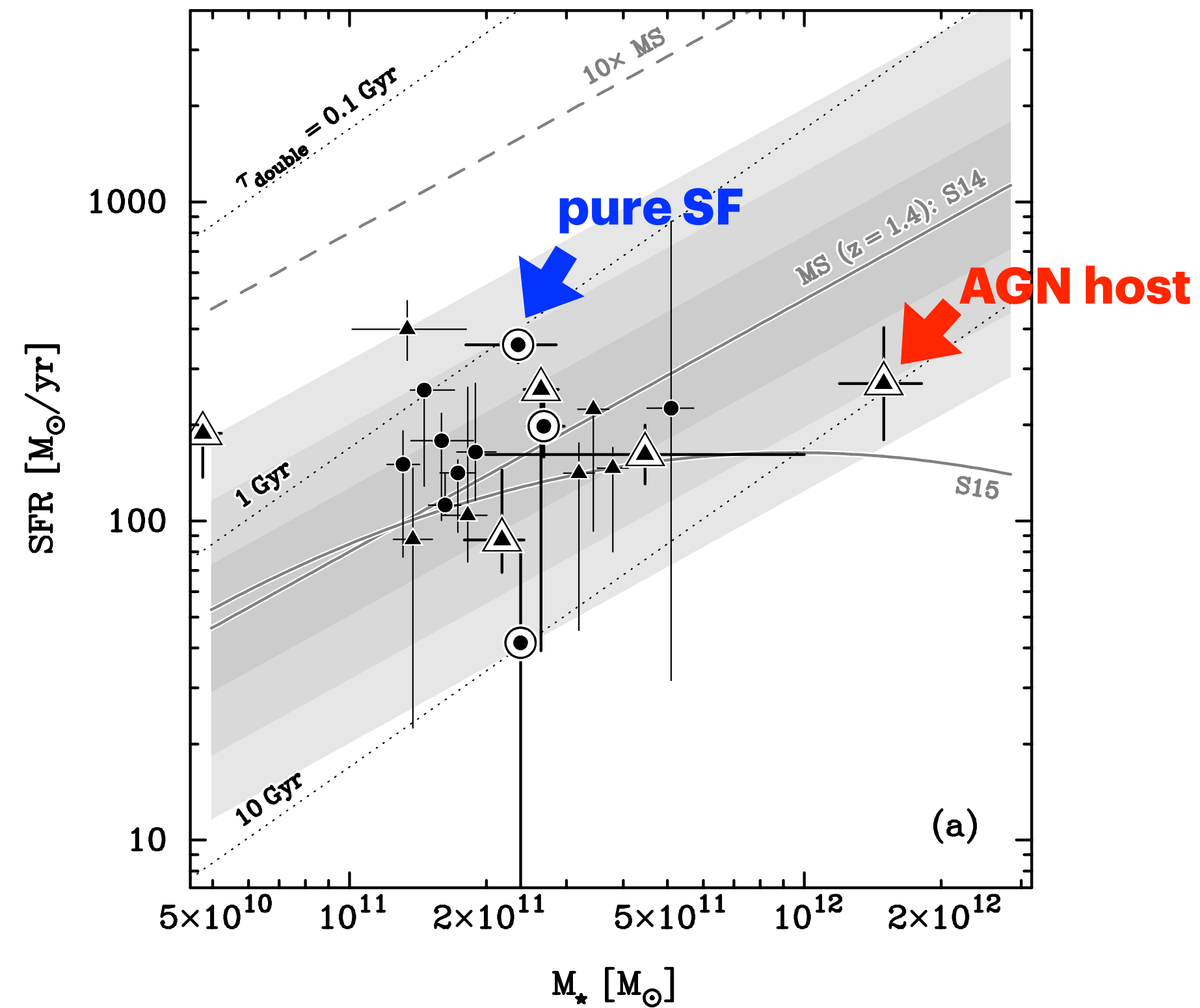


ALMA

THE SAMPLE I

High-mass main-sequence galaxies at cosmic noon

- 20 main-sequence galaxies with stellar mass $>10^{11} M_{\odot}$ and median redshift $z \sim 1.4$
- Roughly 50% of sample with AGN signatures (either X-ray, mid-IR or radio excess)

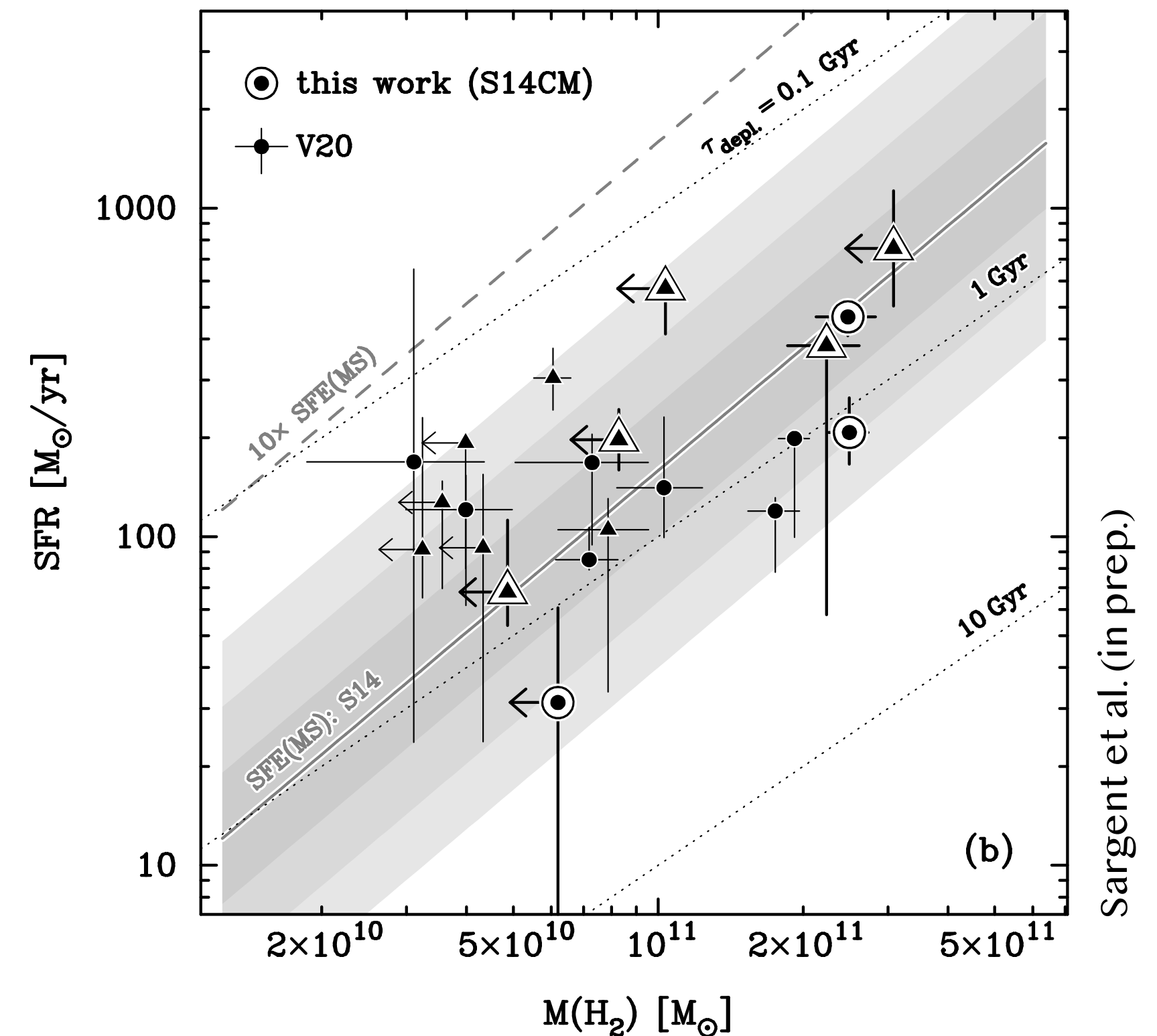
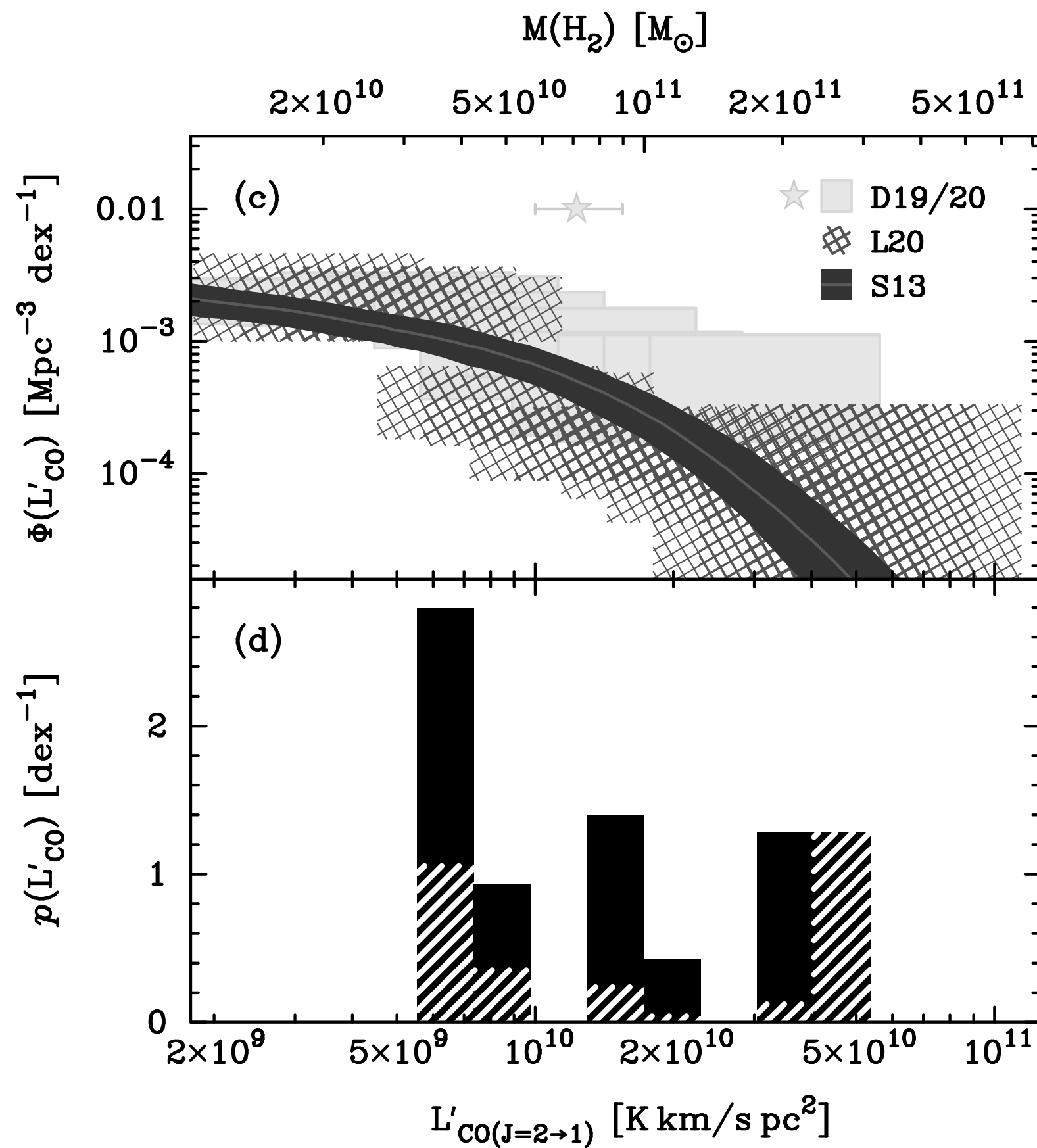


Sargent et al. (in prep.)

THE SAMPLE II

Galaxies with large gas reservoirs of molecular gas

- CO[2-1] molecular line detections for 55% of the sample
- Baryon budget of some galaxies gas-dominated, others with gas fractions as low as $\sim 10\%$

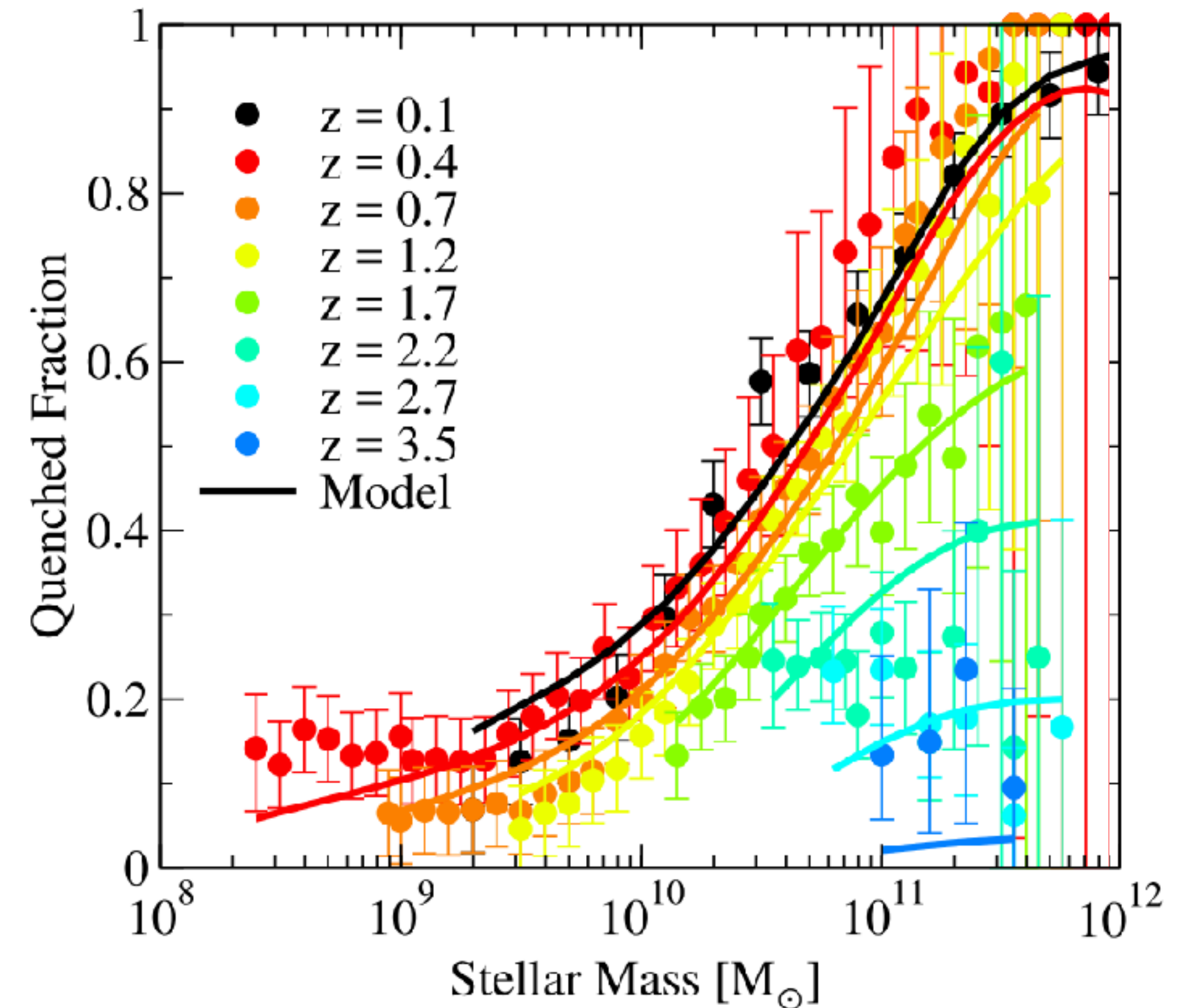
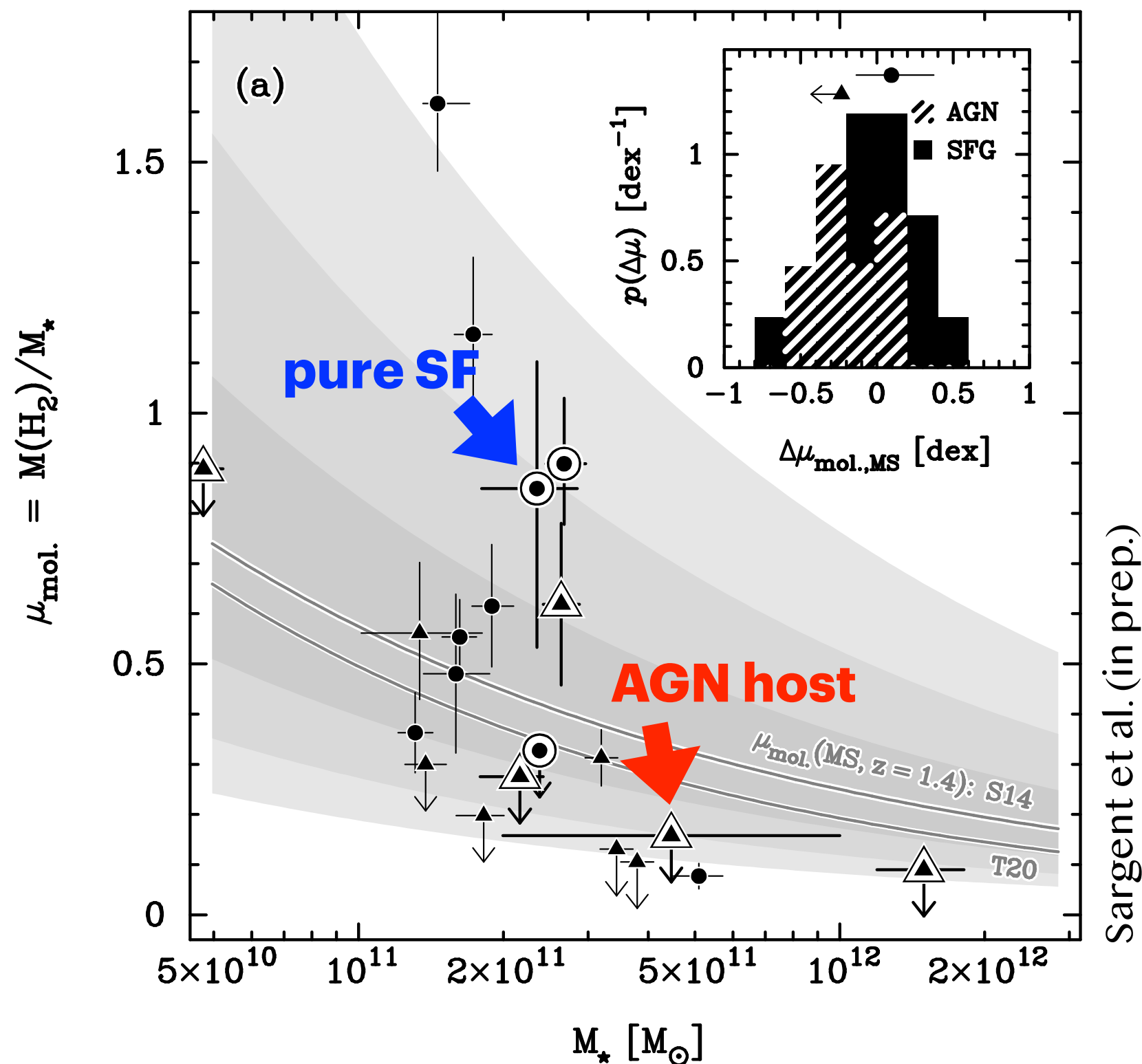


Sargent et al. (in prep.)

WHERE ARE THESE GALAXIES HEADED?

Strong link between gas reservoir depletion and AGN activity

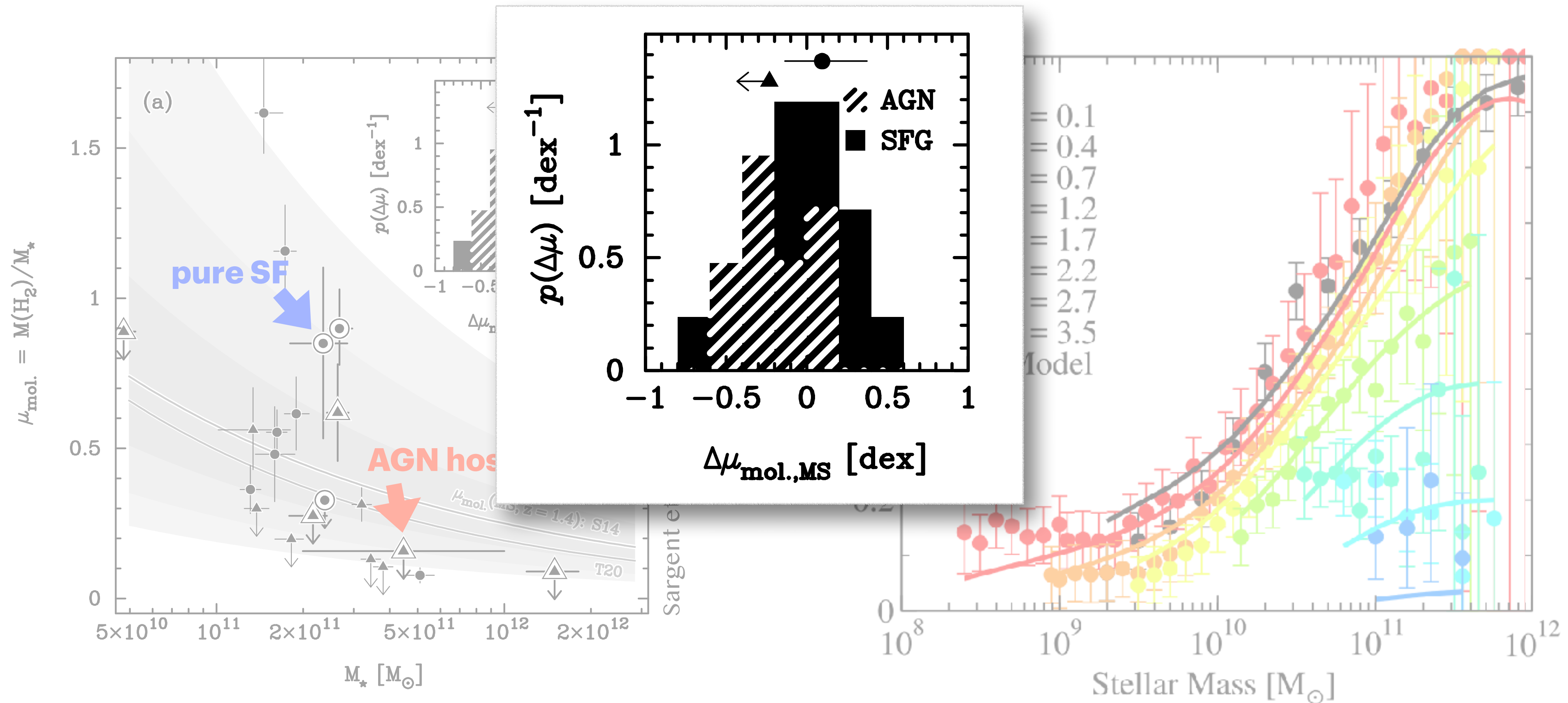
- Depletion of current reservoir may be sufficient to bring about quenching; in absence of further gas accretion, and for a const. SFR, star-formation would cease by $z \sim 1.2$ ($t_{\text{depl.}} \sim 0.6$ Gyr).
- The AGN host galaxies have the lowest gas fractions in the sample.



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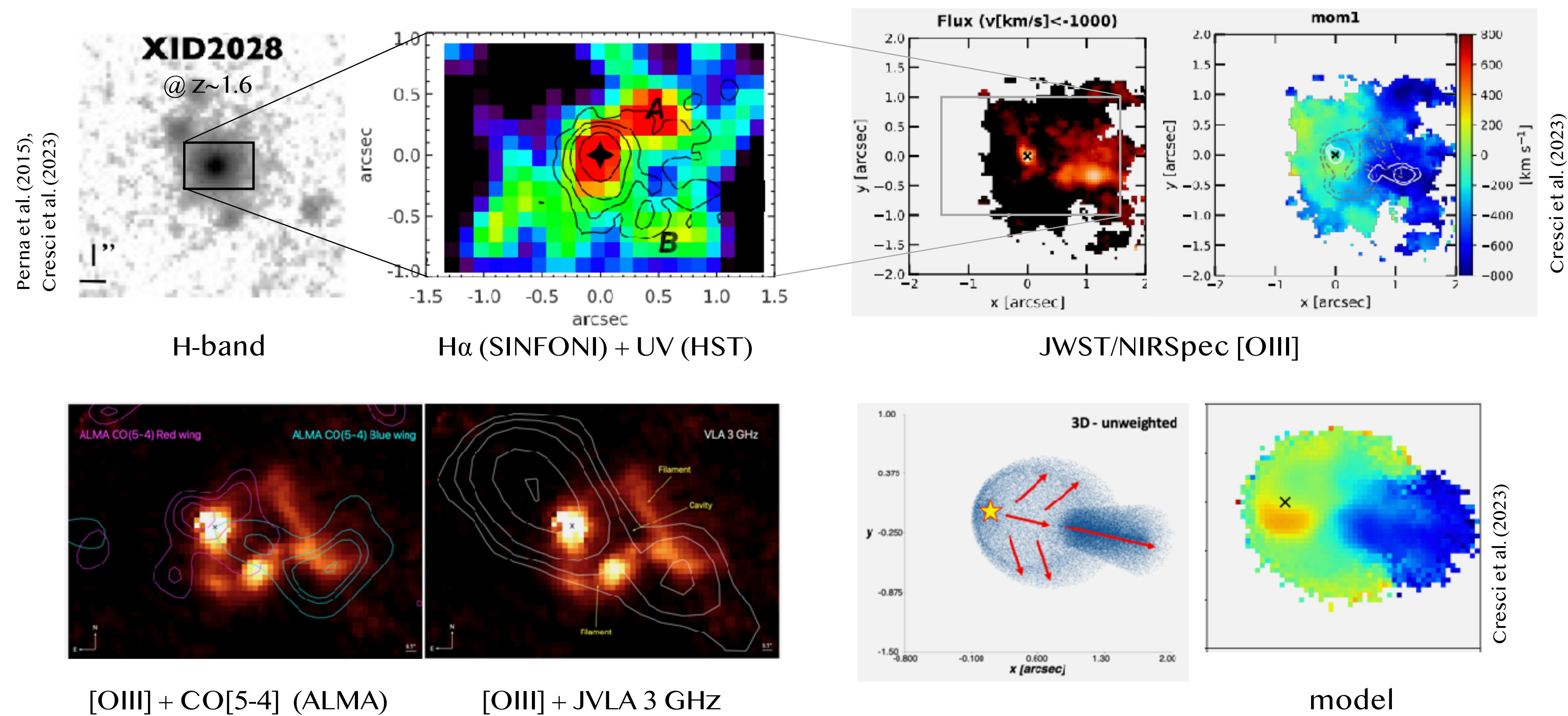
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CASE STUDY FOR SMBH-GALAXY CO-EVOLUTION: XID2028

Superposition of negative and positive feedback triggered by AGN activity

Positive and negative feedback (via bubble & outflows) in an obscured quasar at cosmic noon:

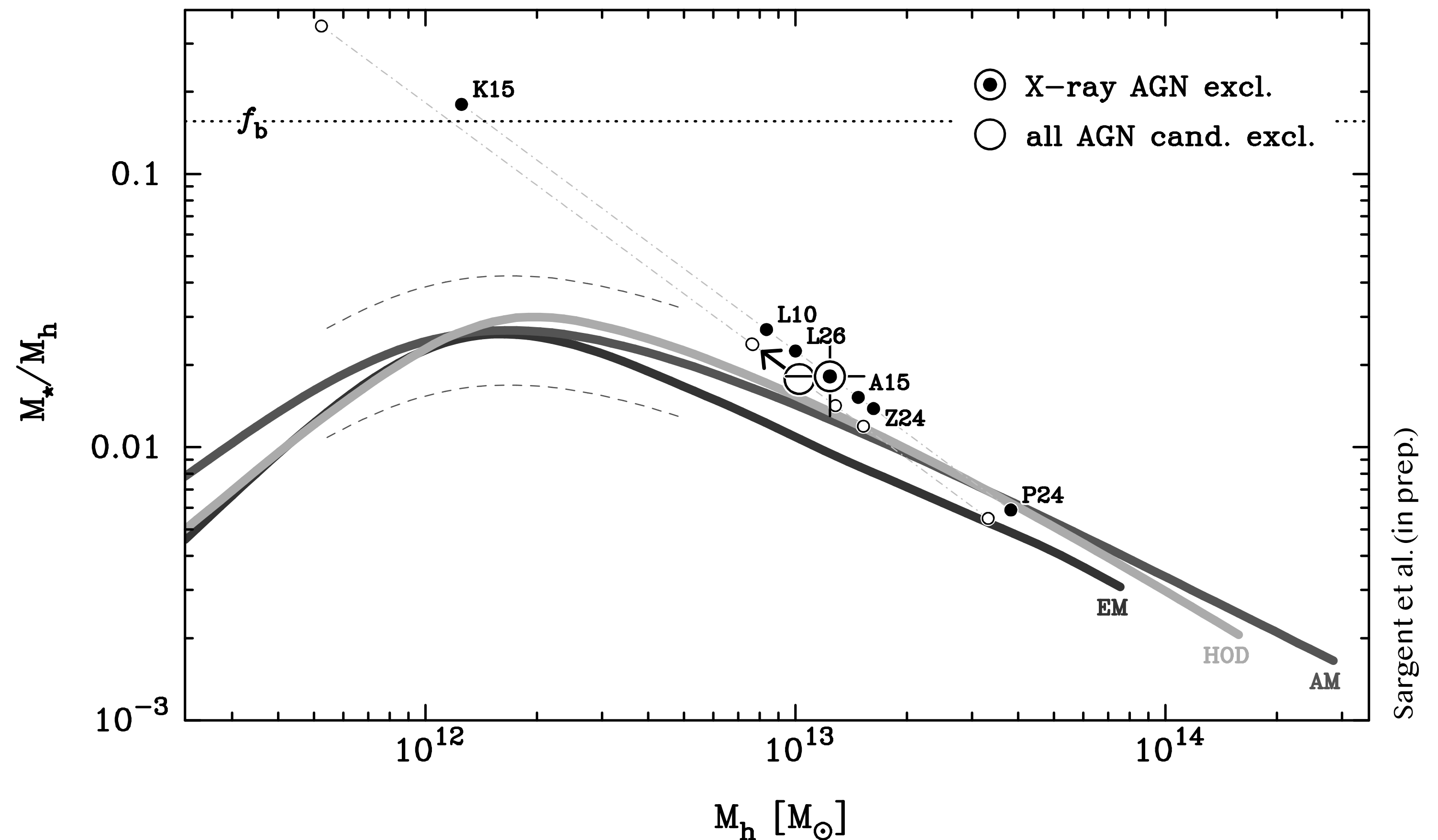
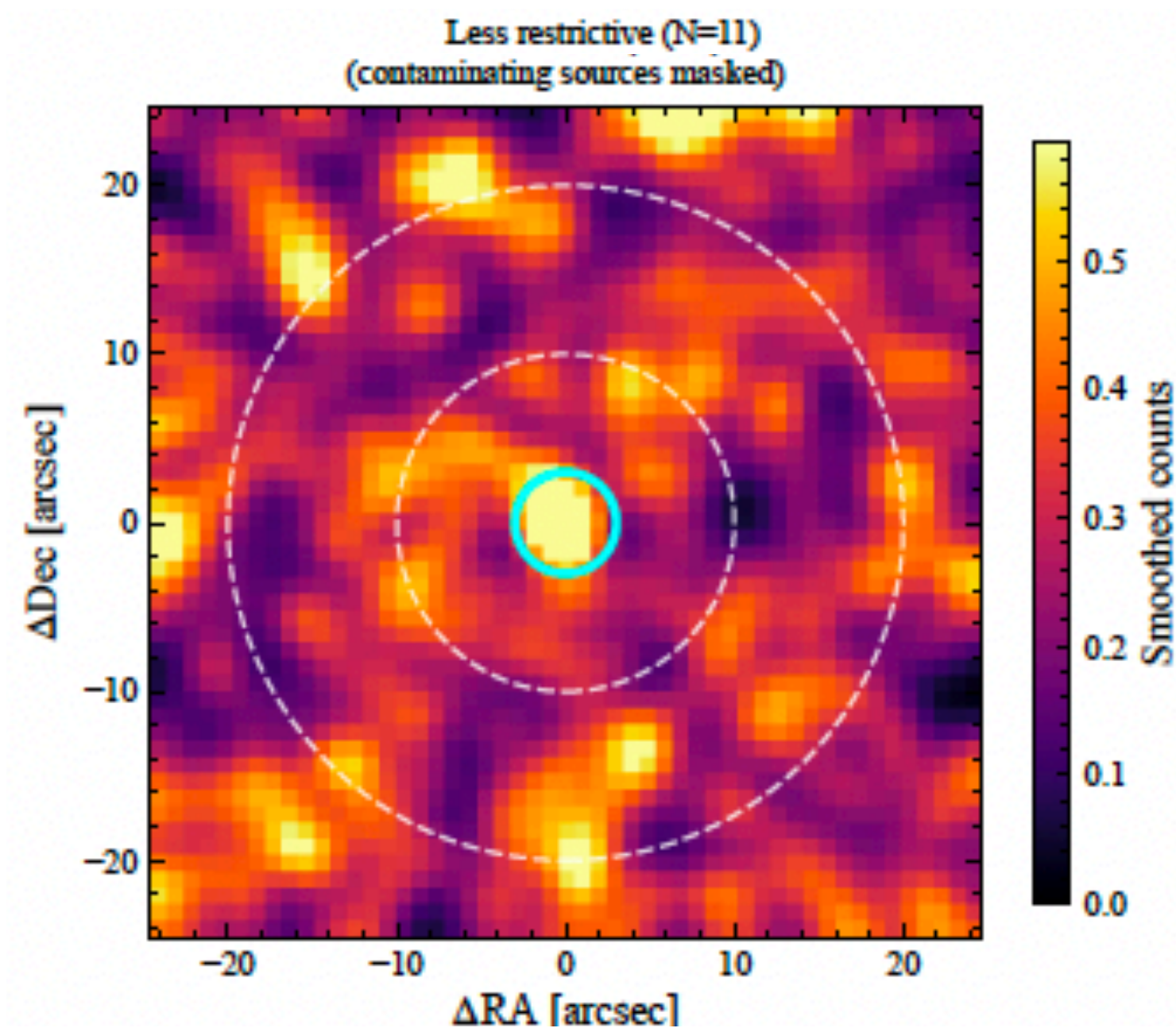


High-res and multi-tracer observations are essential for a detailed understanding of the feedback process (here: multi-phase outflow with $\sim 150 M_{\odot}/\text{yr}$, depletion time of $\sim 30 \text{ Myr}$).

WHAT HAVE THESE GALAXIES BEEN UP TO SO FAR?

Why are they among the few at the high-mass tail of the galaxy population that manage to keep forming stars?

Use X-ray (Chandra) stack of emission from hot halo gas to constrain the average dark matter halo mass of the pure SF galaxies via the L_X - M_h relation.

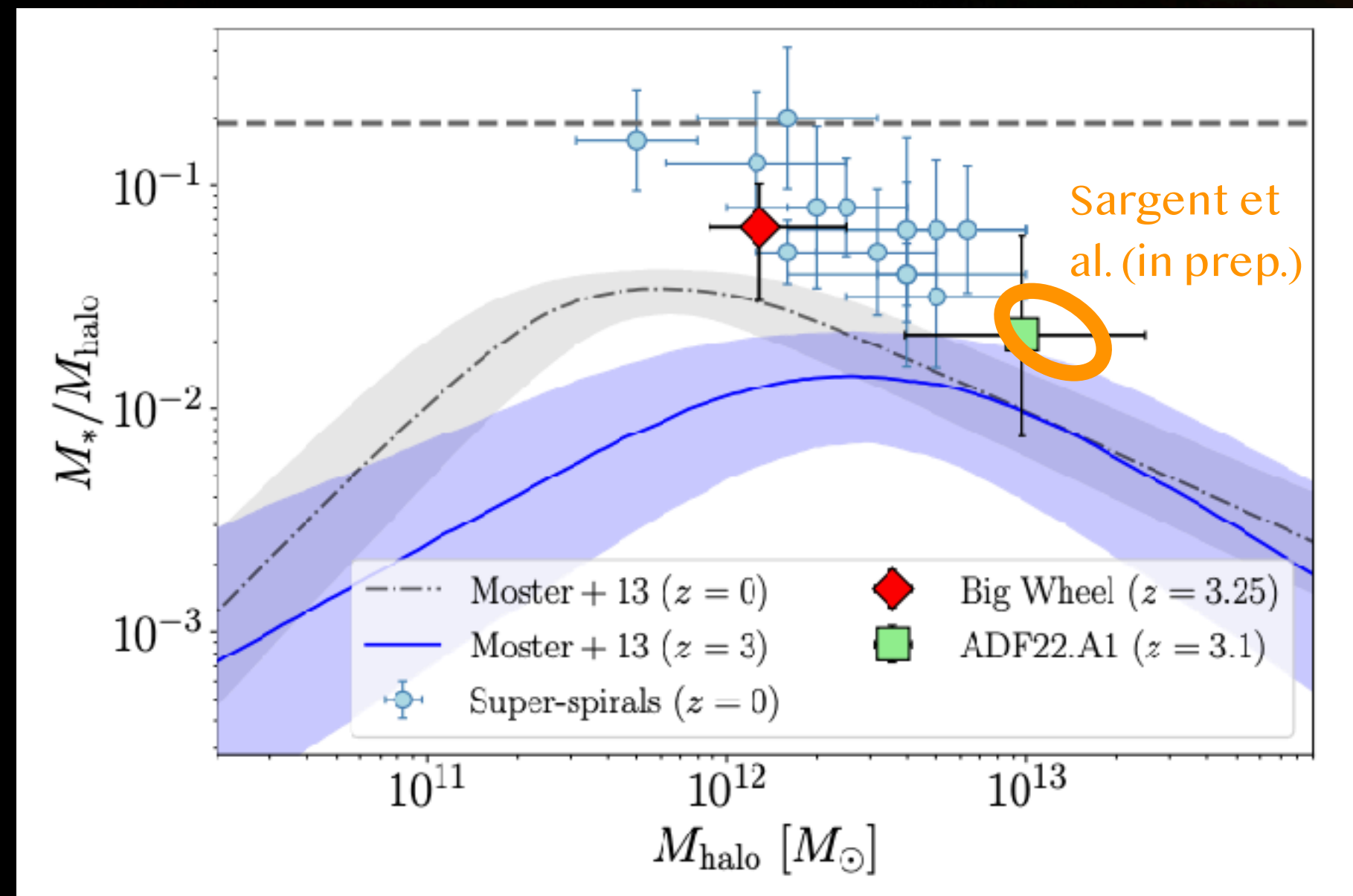


Tentative evidence that many of these galaxies may lie in “under-massive” dark matter haloes.

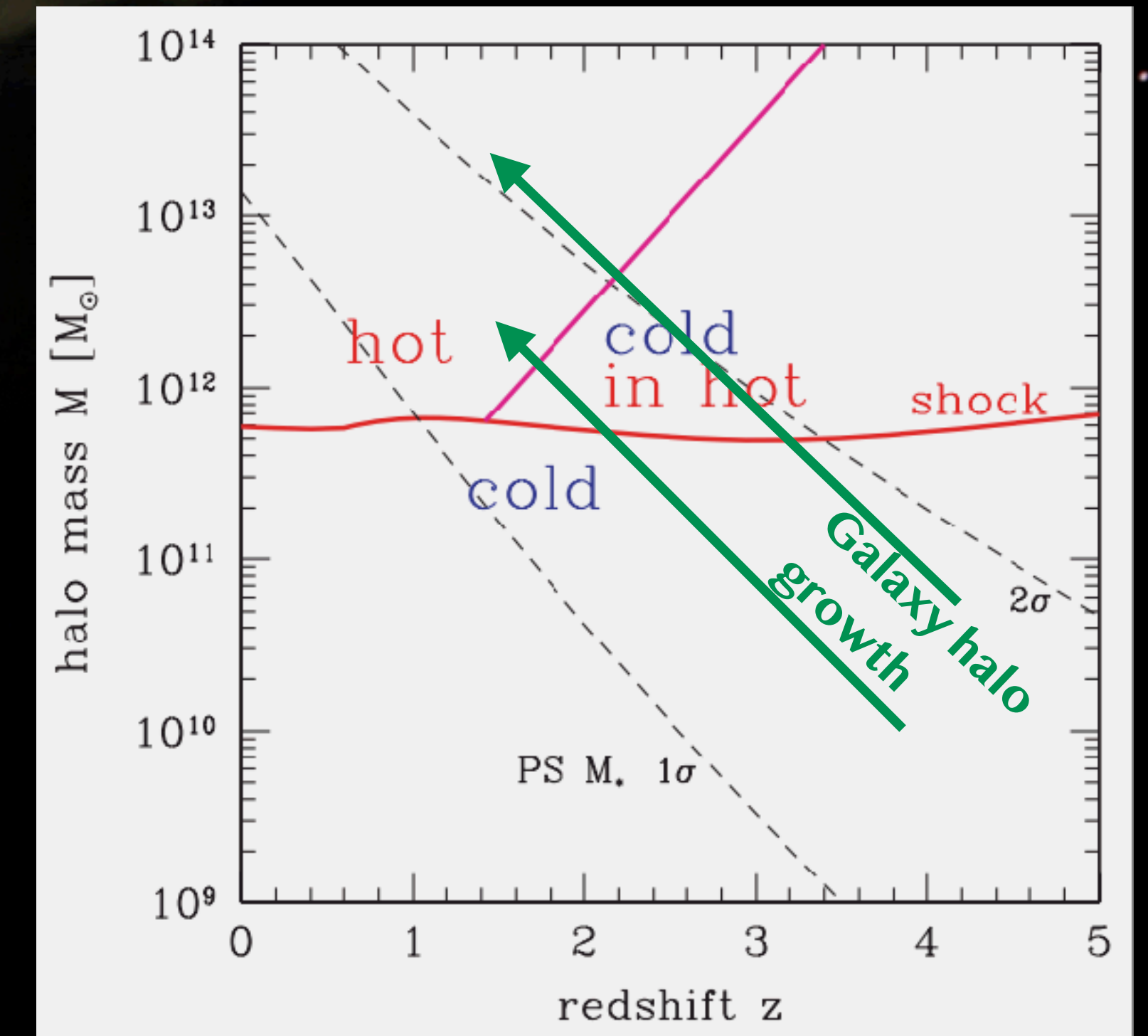
WHAT HAVE THESE GALAXIES BEEN UP TO SO FAR?

Evidence for an unusually long history of efficient accretion of IGM gas?

Our results are reminiscent of low- and high- z “super spirals”:



Quadri et al. (2026)



Dekel & Birnboim (2006)

SUMMARY

- (Very) high-mass spiral galaxies can be found across much of cosmic history. They start representing an anomaly in the “cosmic noon” epoch.
- Information re. both (i) the potential of these systems to continue growing, and (ii) how their growth path likely ends can be gleaned from measurements of their gas content.
- We found that:
 - Gradual gas consumption through the star formation may in some cases be sufficient to explain the cosmic rate at which such high-mass star-forming galaxies become rarer.
 - In our sample there is a conspicuous link between gas reservoir depletion and AGN activity.
 - Similar to literature low- and high- z “super spirals”, the dark matter haloes of ours are measured to be less massive than expected.
- We speculate that they have benefitted from an unusually long history of efficient accretion of IGM gas, to be able to grow to such high masses and remain active.