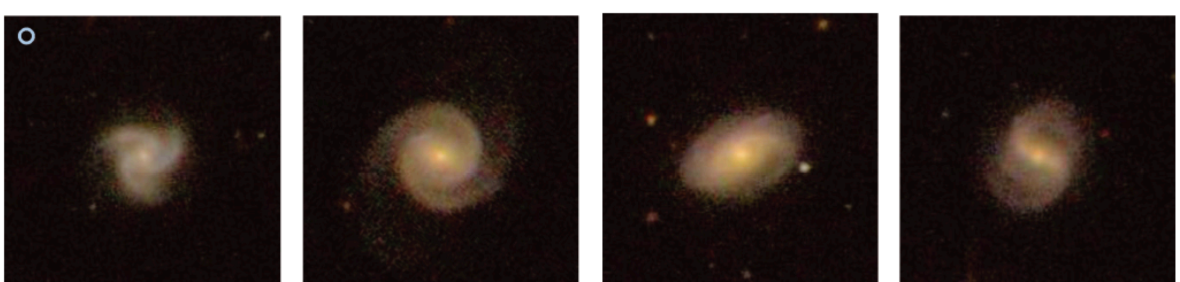



# The Quenching of Massive Spiral Galaxies

MNRAS Letter(arxiv: 2005.09663)
+ working in progress

Xi Kang
Zhejiang University/PMO

Collaborators: Yu Luo (PMO),Yingzhong Xu(ZJU)
Zhiyuan Li (NJU), Zongnan Li(NJU), Peng Wang (AIP)



SHAO, Nov, 26, 2020

# The quenching of massive spiral galaxies ---Background and motivation

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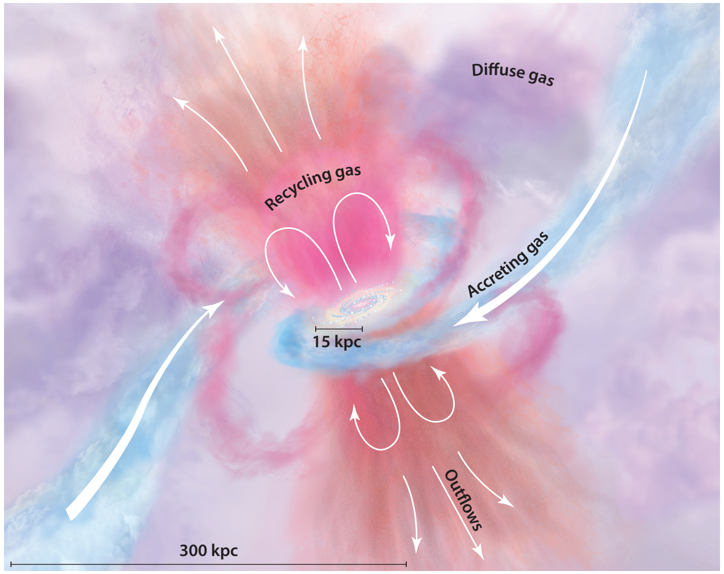
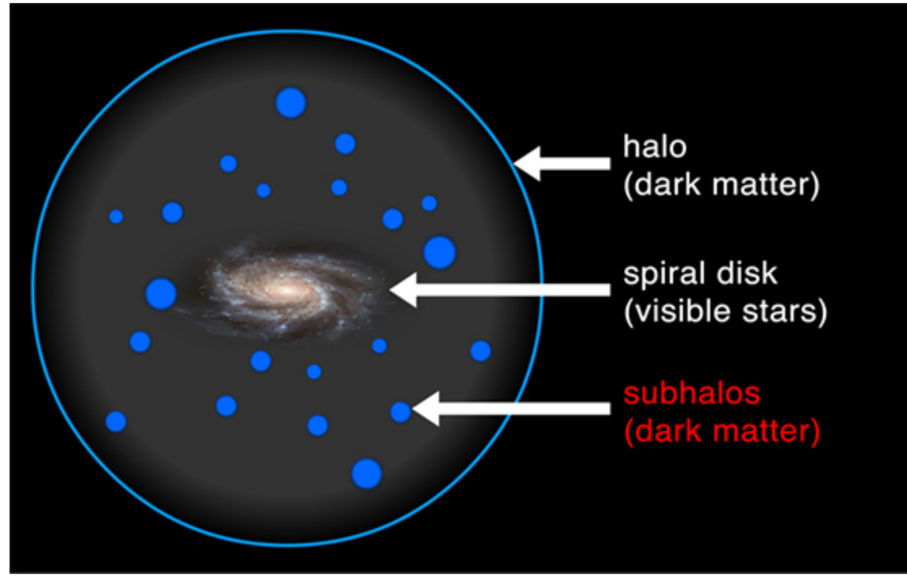


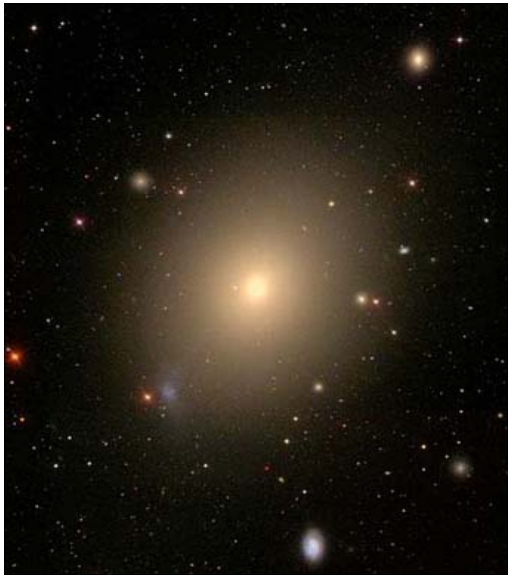

Galaxy lives in complicated Ecosystem

- baryon in different phase (star, cold, hot gas)
- Violent process: star forming, outflow, inflow, supernova & AGN feedback etc
- Massive dark matter halo (>10 times baryon component), usually neglected by observers !

Why DM halo matters

- Halo mass determines the total baryon budget
- Halo mass determines gas temperature (from 10^5-10^7K, fully ionized) and cooling rate depends on density & temperature
  - →Cooling on to central galaxy
  - →Ram pressure on satellite galaxy
- Gas accretion patters (cold vs hot)

## More observational facts about elliptical and spiral galaxies



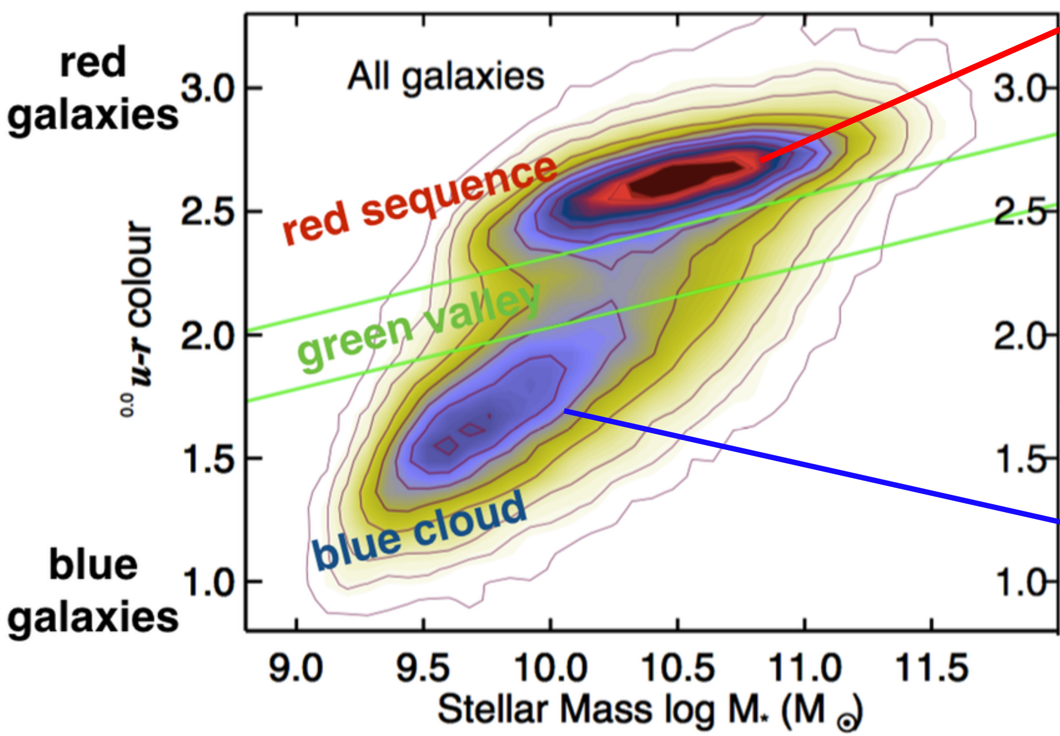
Elliptical galaxies:
Live in massive haloes
Early formation time
Existence of hot circular galactical medium (CGM)
No fresh cold gas

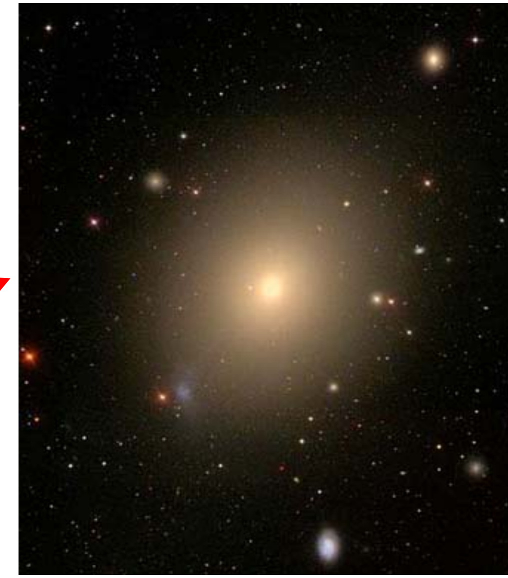
Spiral galaxies:
Halo mass is lower
Late formation time
Not clear of the existent of hot CGM
Plenty cold gas

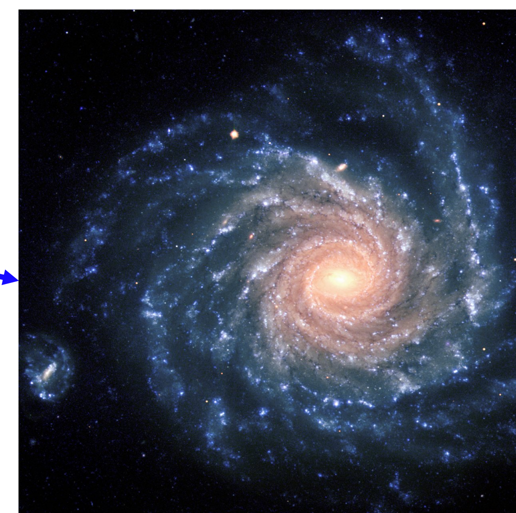
# The quenching of massive spiral galaxies
# ---Background and motivation

Color-magnitude bimodality:

- what leads to the diversity of the two galaxy population?
- how to quench star formation in red galaxy?





Schawinski+ 2014

# Multiple Quenching Mechanisms

- Satellite galaxy: environmental quenching---tidal/ram-pressure stripping

- Central galaxy

Ellipticals: all gas consumed/expelled during merger and hot gas does not cool (energy source: starburst or AGN)

Red Spirals:

- No star formation in disc
  - no cold gas→no quenching needed
  - with gas →morphology quenching?
- No hot CGM hot→no cooling
- With hot CGM→ How to suppress cooling? (no energy source)

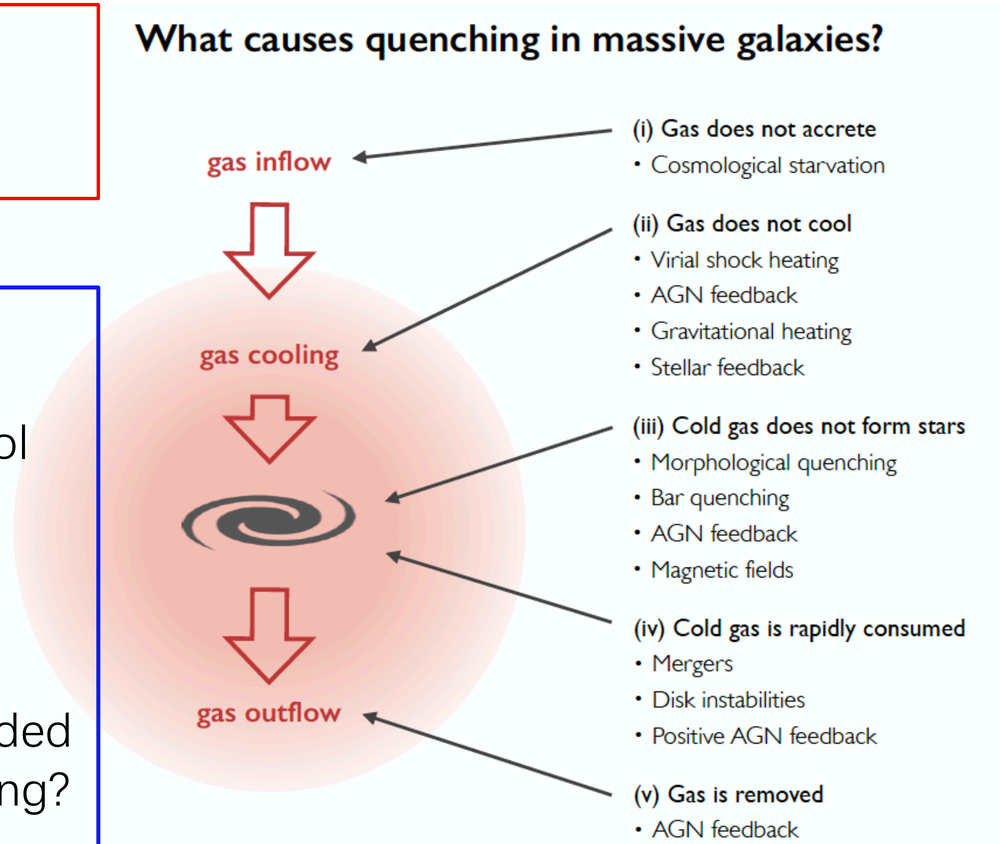



Fig. 1 Schematic diagram listing the plausible quenching mechanisms.

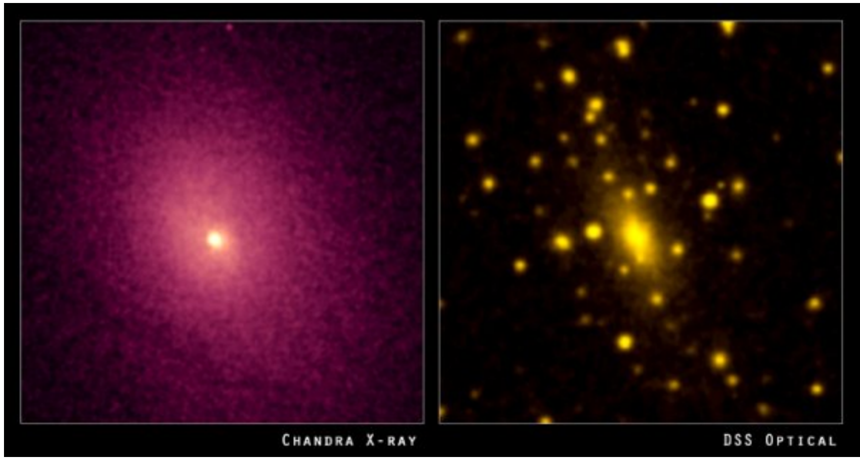
Man & Belli 2019

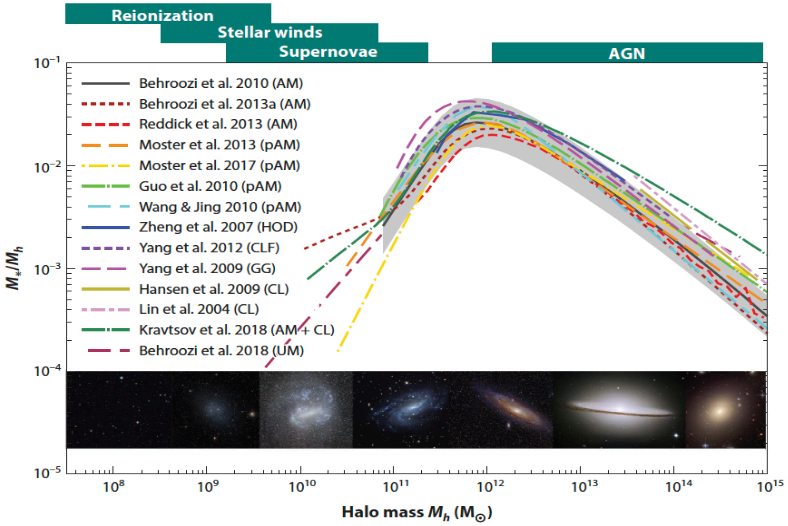
# The quenching of massive spiral galaxies
## ---Background and motivation



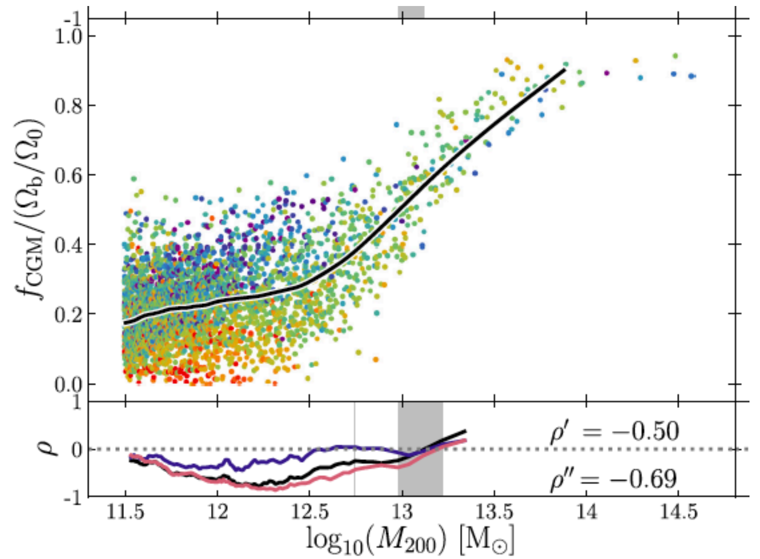
Quenching of massive (elliptical) galaxies-
-- a long last challenge !

- Massive halos contain nearly universal baryon, most in hot gas
- Stellar mass is at most 10% of gas in massive galaxies ---
Quenching is needed




Wechsler & Tinker 2018




Eagle simulation, Davis+ 2020

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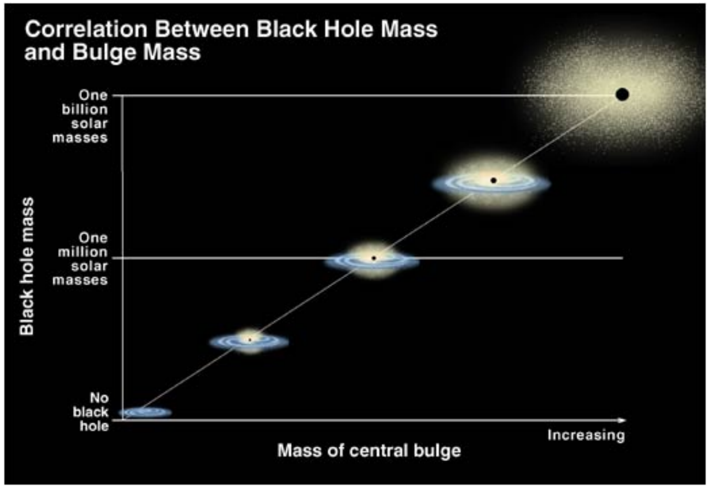
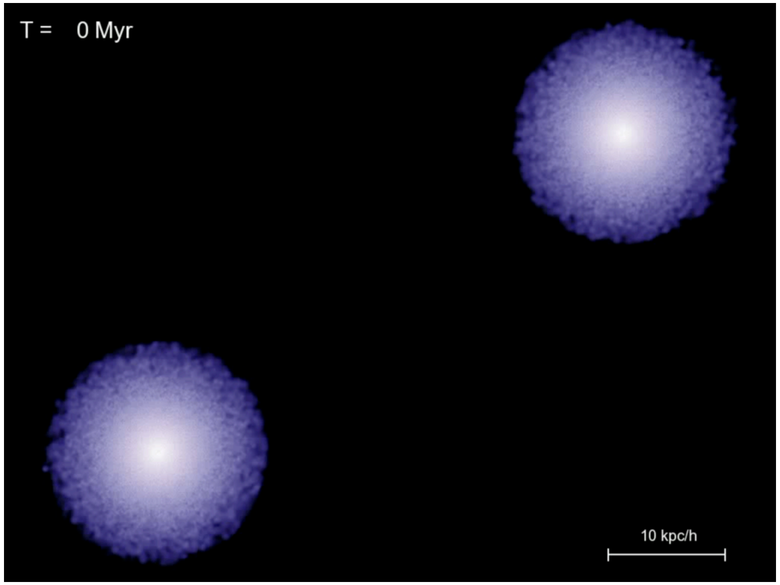
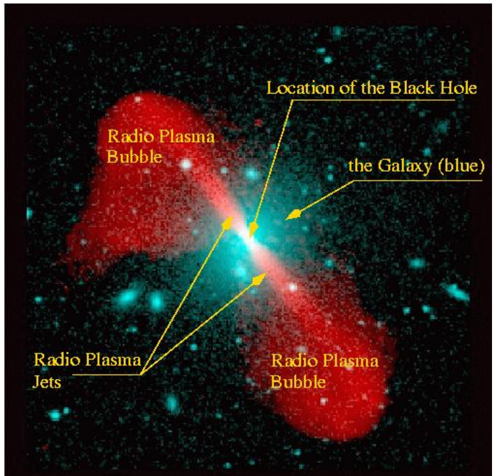
## Black hole and AGN feedback in elliptical galaxies



Radio Galaxy 3C296
Radio/optical superposition
Copyright (c) NRAO/AUI 1999

- Almost all elliptical galaxies have massive black holes
- Feedback from radio AGN/QSO can effectively quench star formation (not clear in detail)

# The quenching of massive spiral galaxies
---Background and motivation

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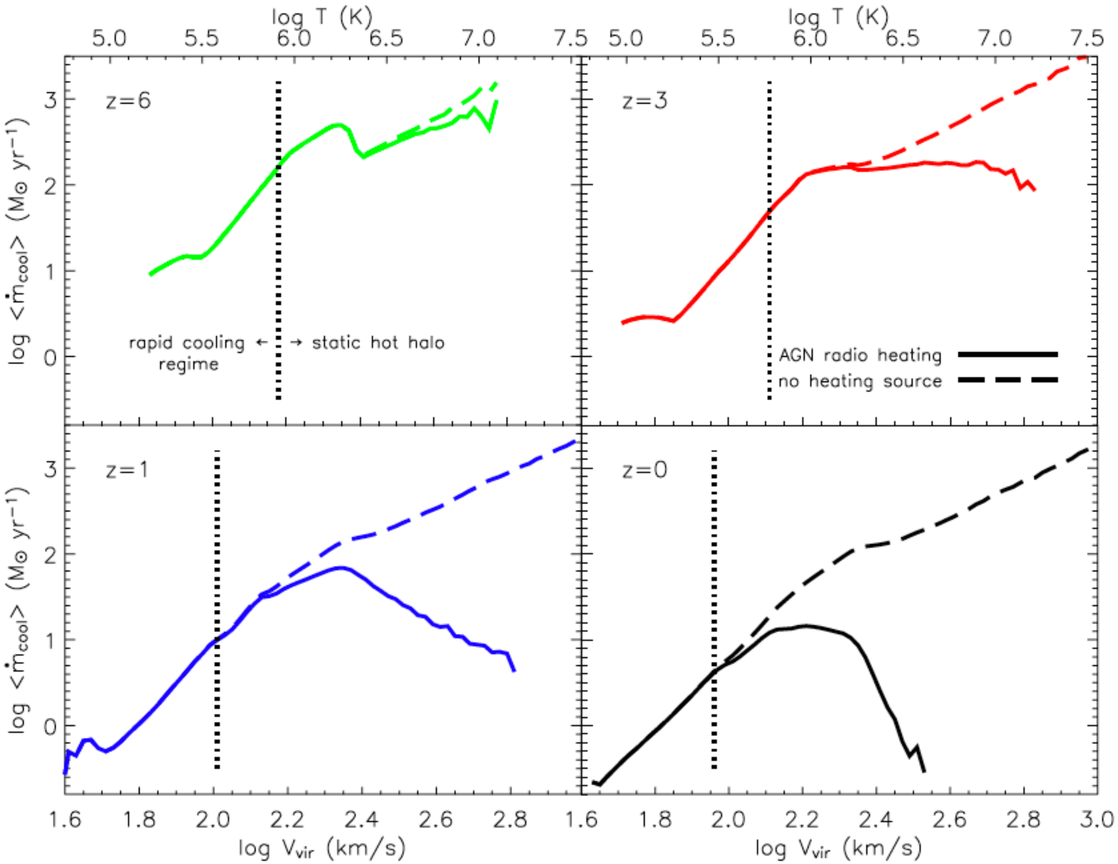
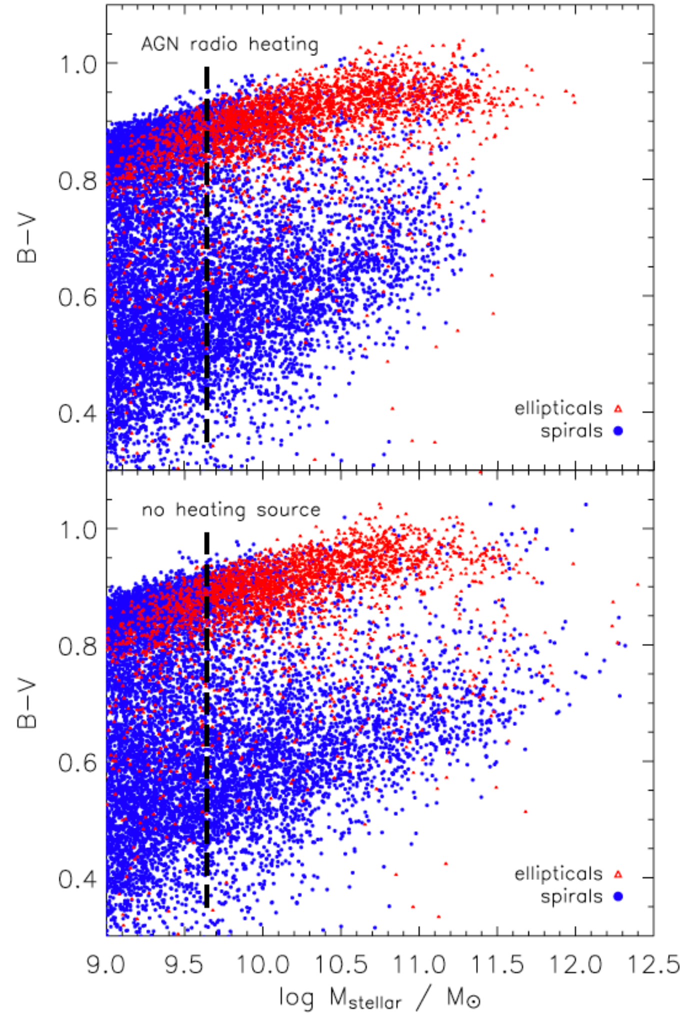
Models of galaxy formation including AGN feedback to suppress gas cooling
---Ellipticals are quenched and red



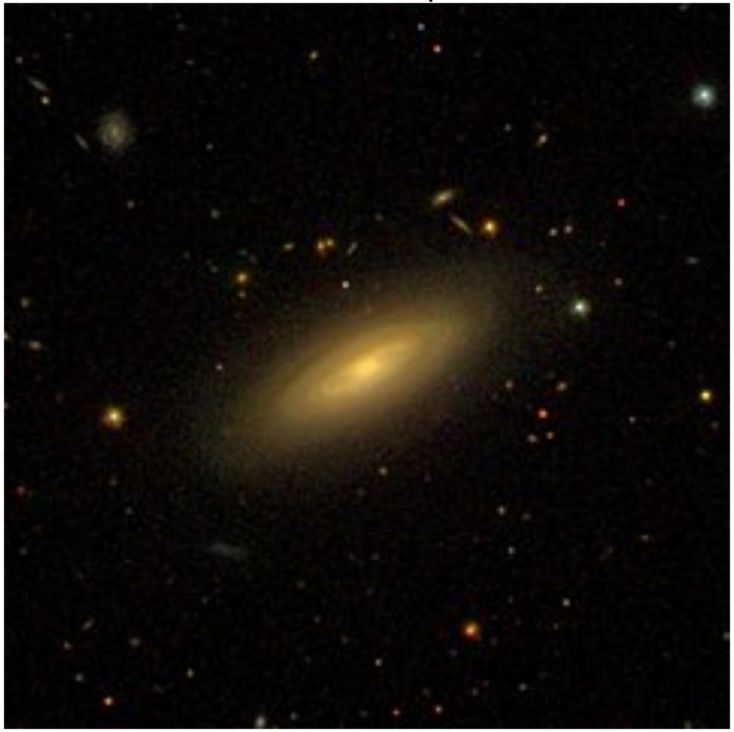

Croton et al. 2006

# The quenching of massive spiral galaxies

Why the two spirals are different?

Blue spiral

Red spiral



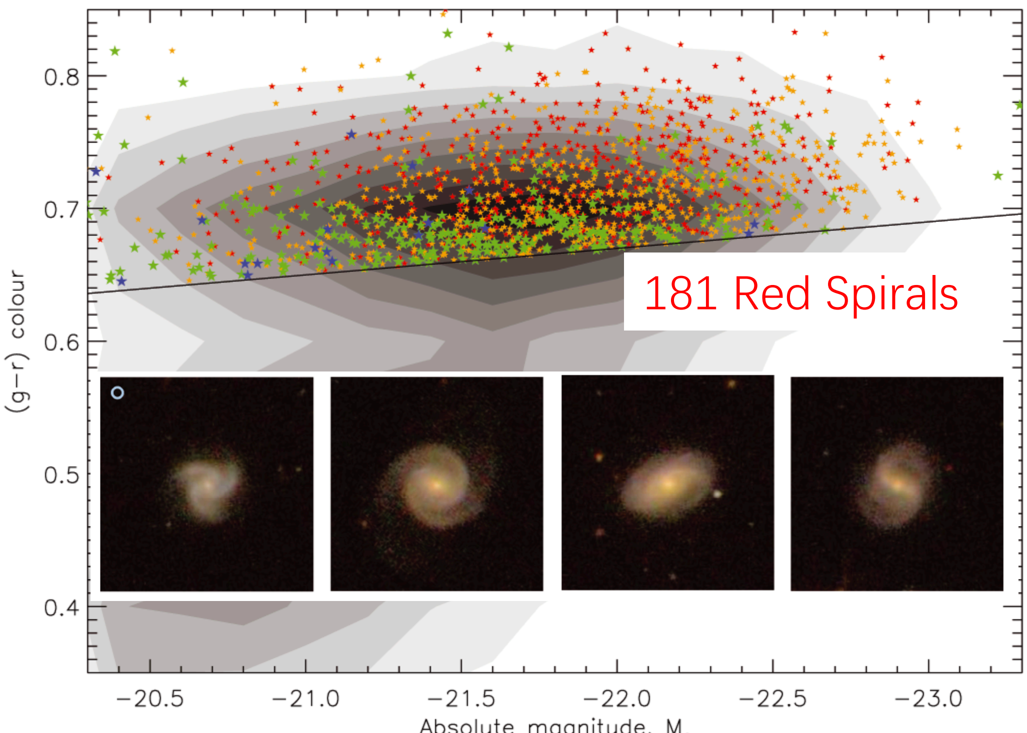
Simple but meaningless answer: red spiral has consumed all its gas

For most galaxies, stellar mass is at most ~30% of its universal baryonic mass
Where is the other baryon component?
Why no new cold gas supply?

The quenching of massive spiral galaxies
---Current status

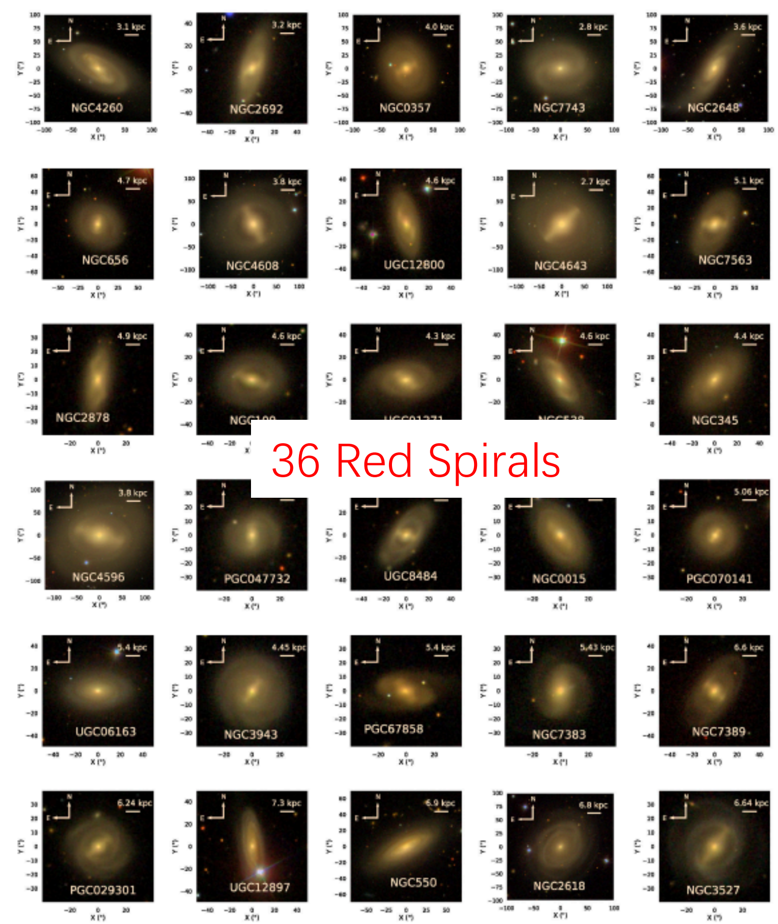
Passive spiral galaxies are rare & not well selected (contaminated)

- dozens of passive spirals are found in galaxy clusters until SDSS
- some are not really passive, but red because of dust




Masters+2010, Galaxy zoo

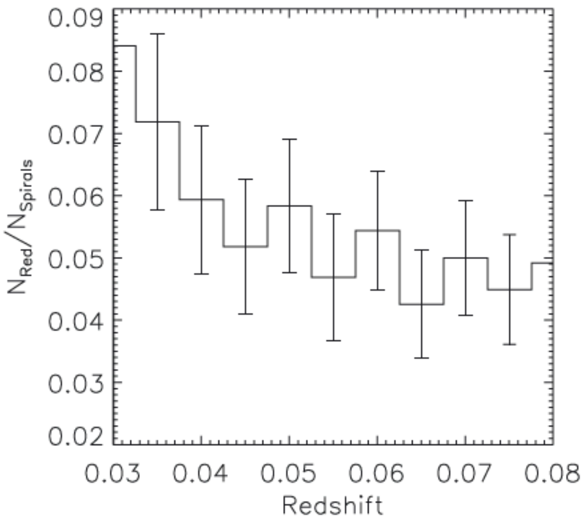
Fraser-McKelvie+ 2017
From 2MASS+SDSS

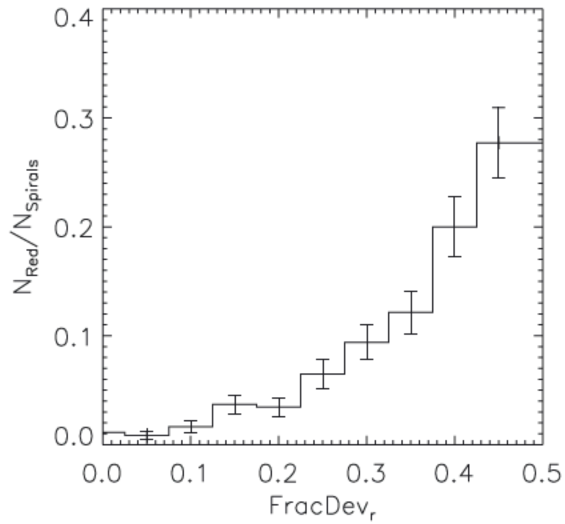


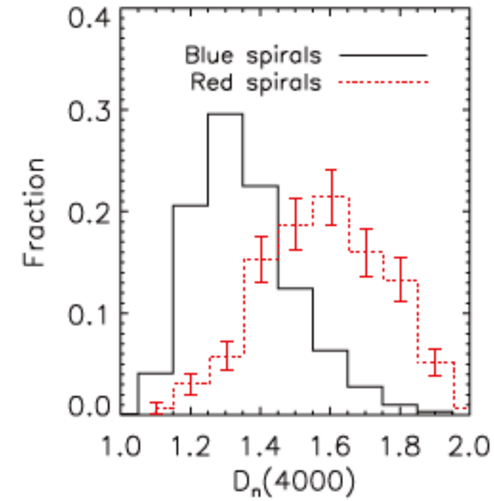
# The quenching of massive spiral galaxies ---Current status

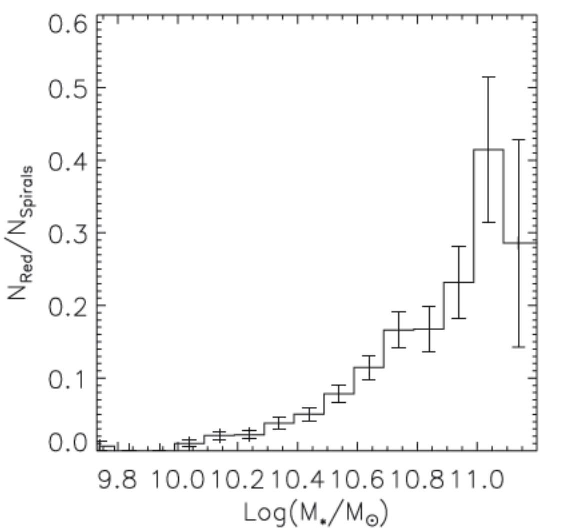
Properties of red spirals

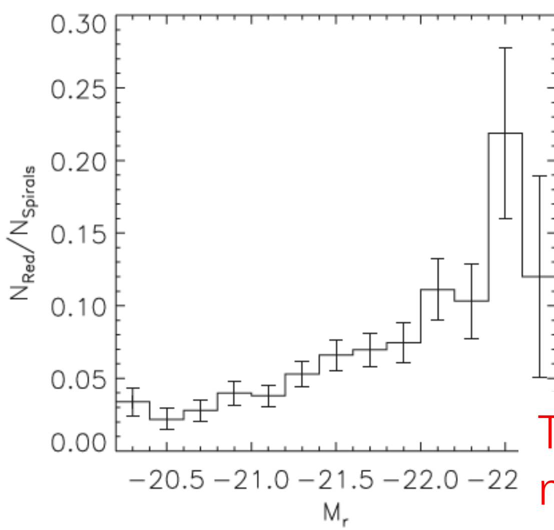
Masters+2010, from galaxy zoo




- Red spirals have old ages
- More red spirals at low-z
- High-mass spirals are more likely to be red

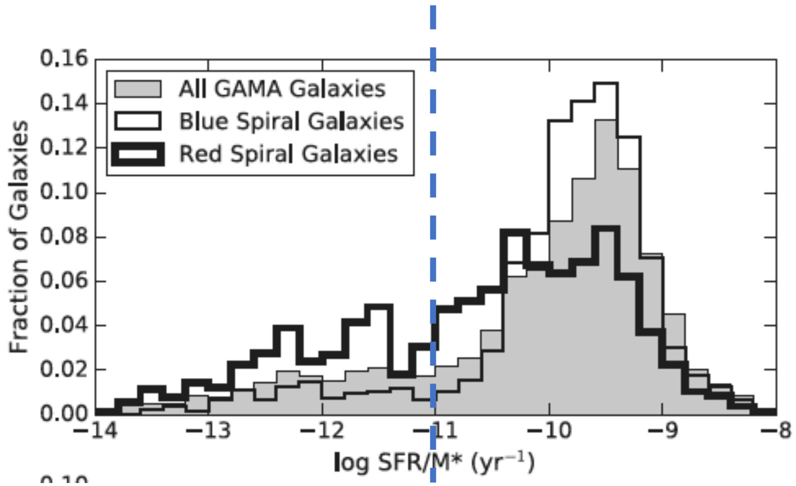
Their bar fraction is too high, most have fracDev>0.1

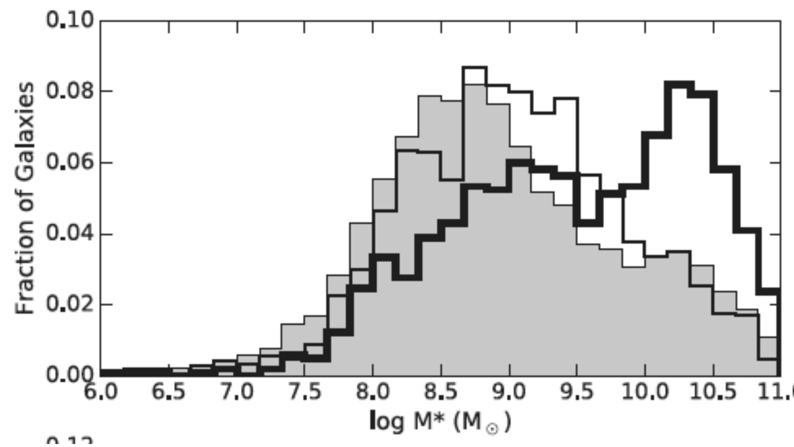
# The quenching of massive spiral galaxies ---Current status

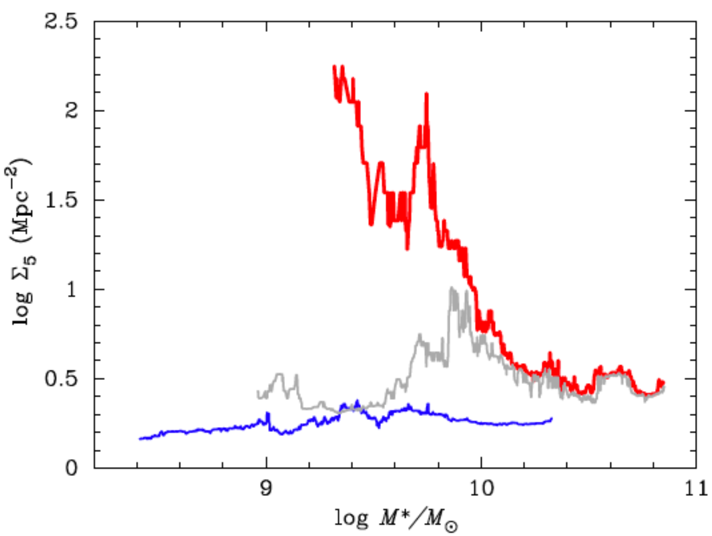
Properties of red spirals

Red ≠ passive

Mahajan+19, Red spiral from GAMA




- Optically selected red spiral has non-negligible SFR
- Red spirals live in more dense region

# The quenching of massive spiral galaxies ---Current status

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Quenching does not mean no gas.
Any cold gas in passive spirals?

https://doi.org/10.3847/2041-8213/ab4ae4



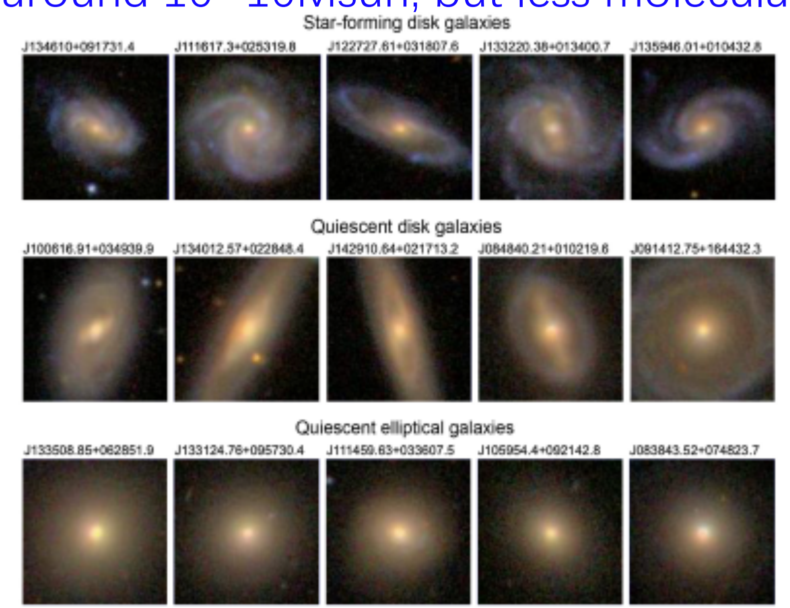
CrossMark

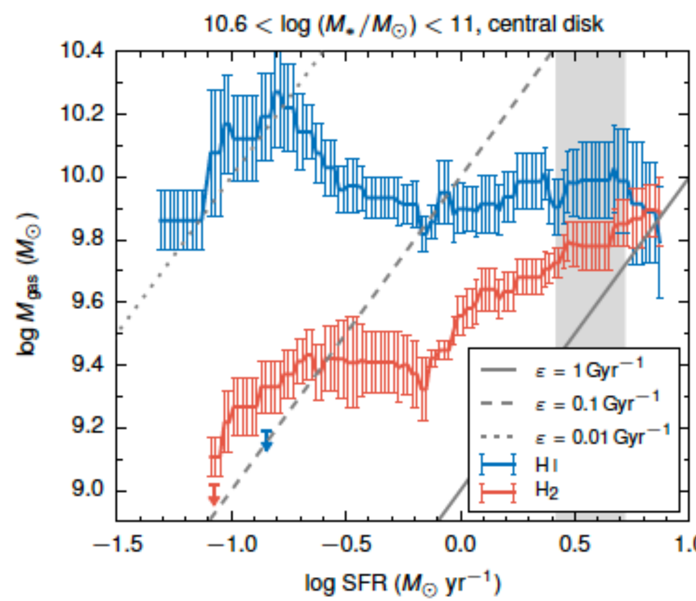
## Nearly all Massive Quiescent Disk Galaxies Have a Surprisingly Large Atomic Gas Reservoir

Chengpeng Zhang[1,2], Yingjie Peng[1], Luis C. Ho[1,2], Roberto Maiolino[3,4], Avishai Dekel[5,6], Qi Guo[7,8], Filippo Mannucci[9], Di Li[8,10], Feng Yuan[11], Alvio Renzini[12], Jing Dou[1,2], Kexin Guo[1,13], Zhongyi Man[1,2], Qiong Li[1,2]

Data from SDSS, ALFALFA, GASS, COLD GASS surveys

Passive Spirals (10.6<lgM<11) have HI gas around 10^10Msun, but less molecular gas



# The quenching of massive spiral galaxies ---Current status

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **494**, L42–L47 (2020) doi:10.1093/mnrasl/slaa032
Advance Access publication 2020 February 19

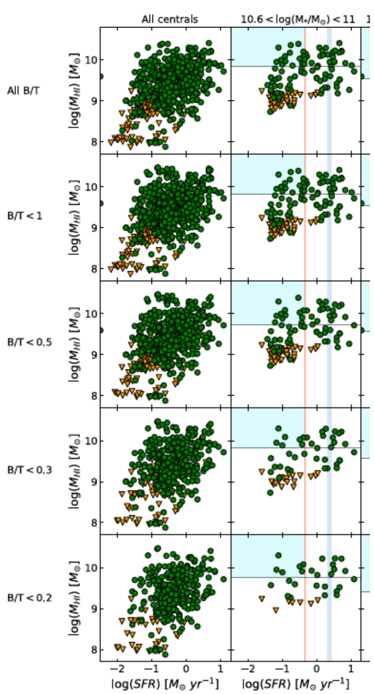
**xGASS: passive discs do not host unexpectedly large reservoirs of cold atomic hydrogen**

L. Cortese[1,2★] B. Catinella[1,2] R. H. W. Cook[1,2] and S. Janowiecki[3]

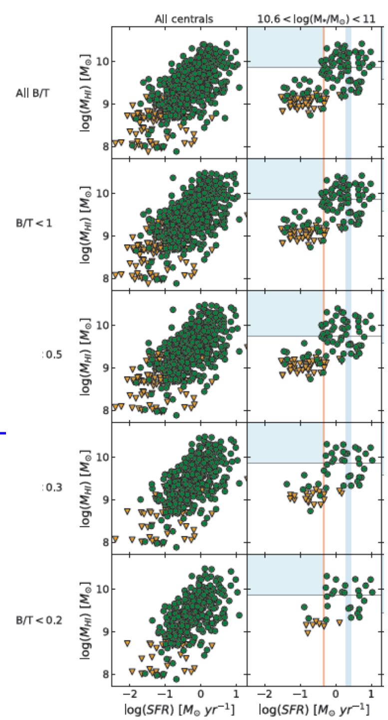
[1] *International Centre for Radio Astronomy Research, The University of Western Australia, 35 Stirling Hw, 6009 Crawley, WA, Australia*
[2] *ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D), Australia*
[3] *Hobby–Eberly Telescope, McDonald Observatory, University of Texas, TX 79734 Austin, USA*

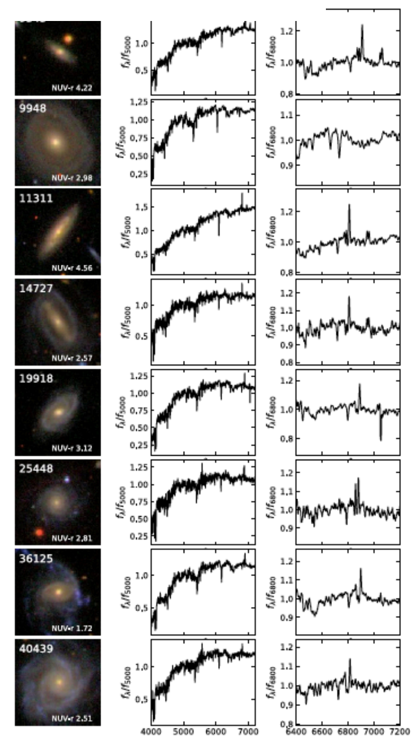
Cortese et al. used the same data set, but SFR from NUV+MIR

SFR from SDSS




SFR from NUV+ MIR



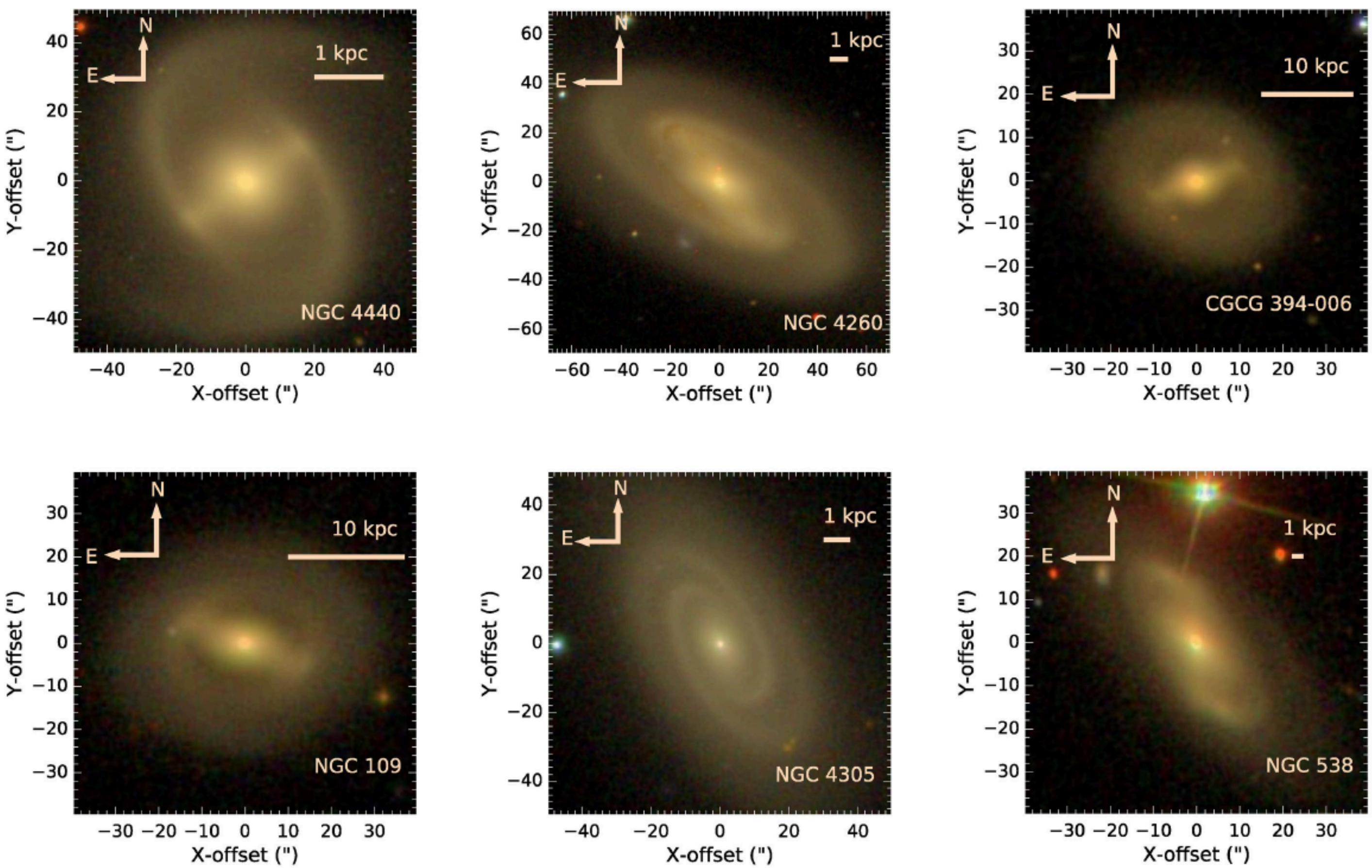




Zhang+ use fiber SFR

Many quenched spirals from Zhang+ show blue spiral arms and Ha lines

## Morphology of Red Spirals

- Most studies show high bar fraction
- Bar can stabilize the gas disk, suppressing star formation




Bar is present even they select spiral using small fracDev parameter

Fraser-McKelvie+16

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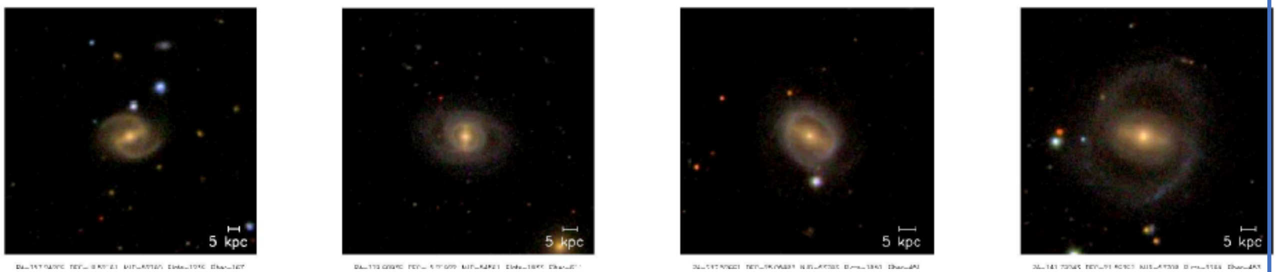
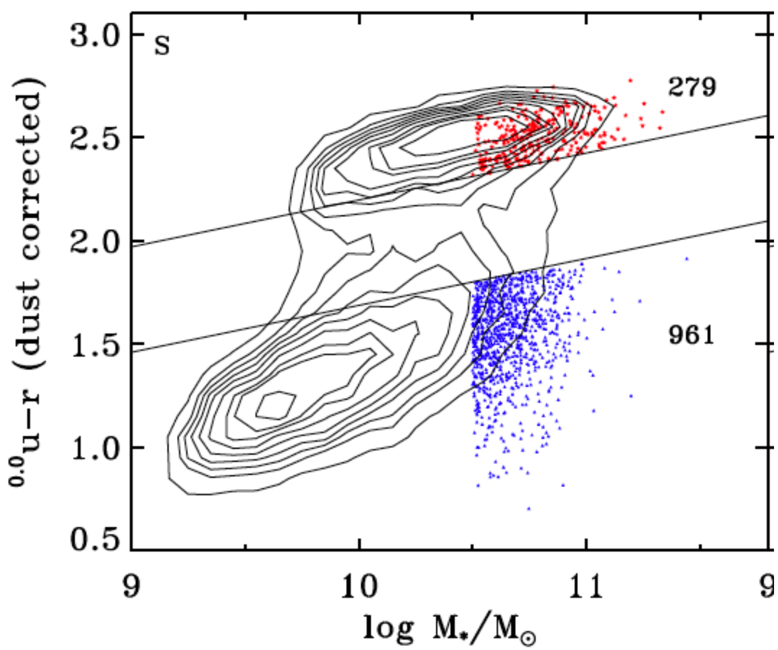
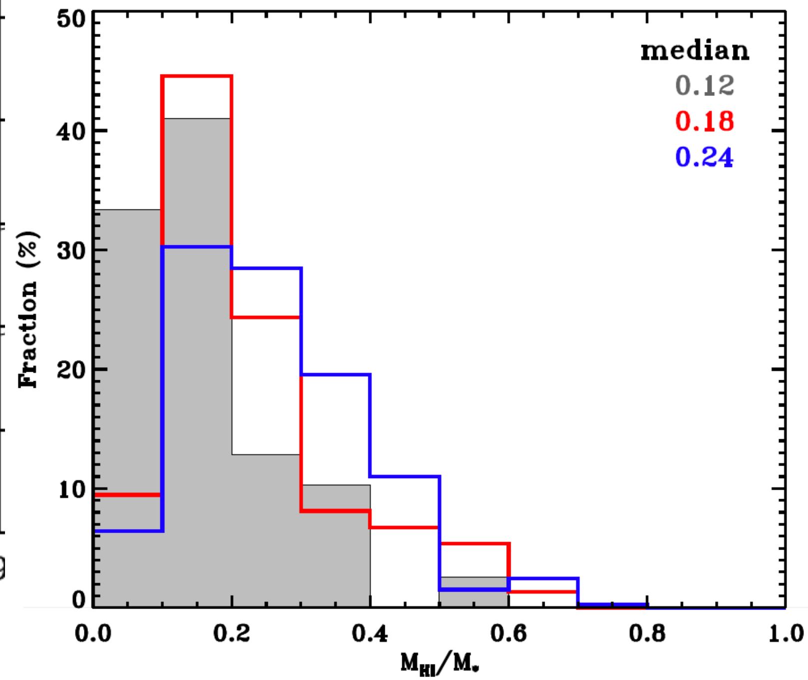
## Morphology of Red Spirals

Guo, Xia+2020, arXiv:2006.05462




- 279 red spiral from 1914 spirals
- Significant bulge/bar in red spirals than in blue spirals
- Cold gas~10%



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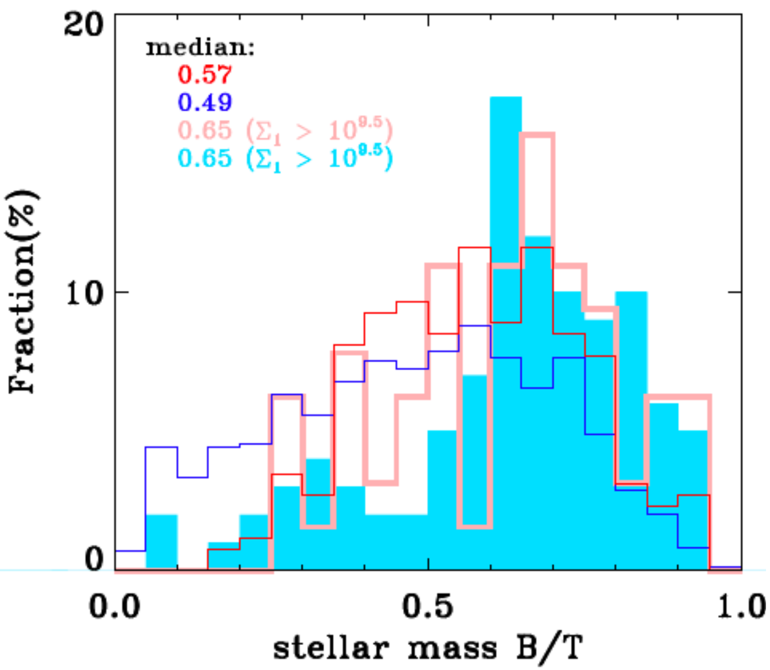
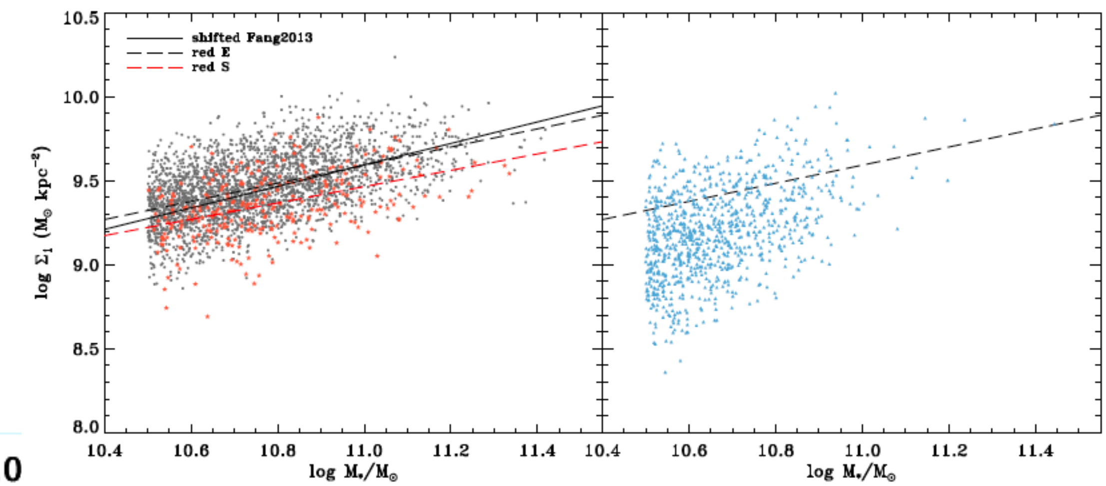
# Bulge and central density of red spirals

- Quenched spirals have larger bulge/bar
- Quenched spirals have higher central density




Guo+2020, arXiv:2006.05462

The quenching of massive spiral galaxies
---Current status

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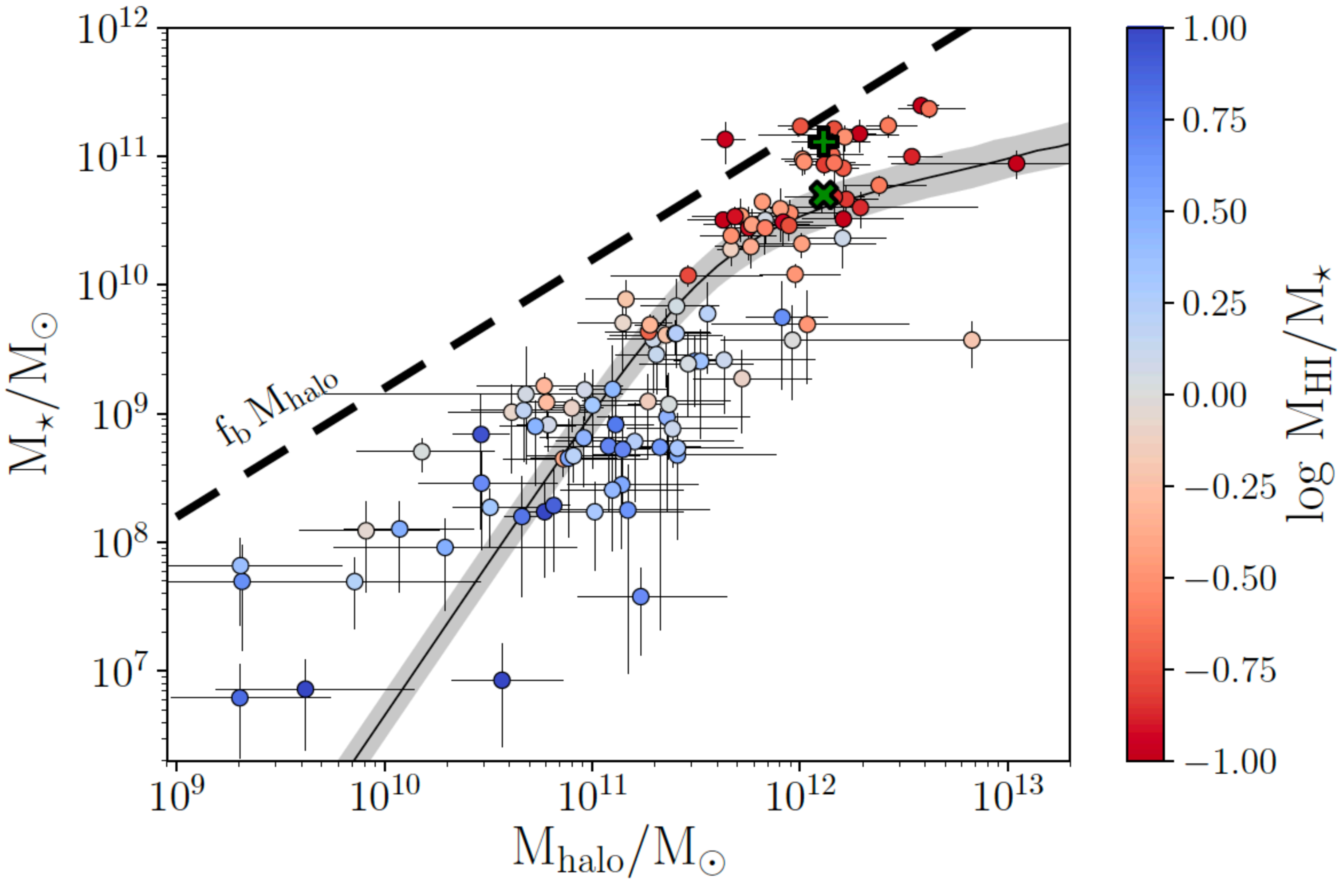
Halo mass of Massive blue spirals

No miss baryon in some massive spirals




Posti et al. 2019

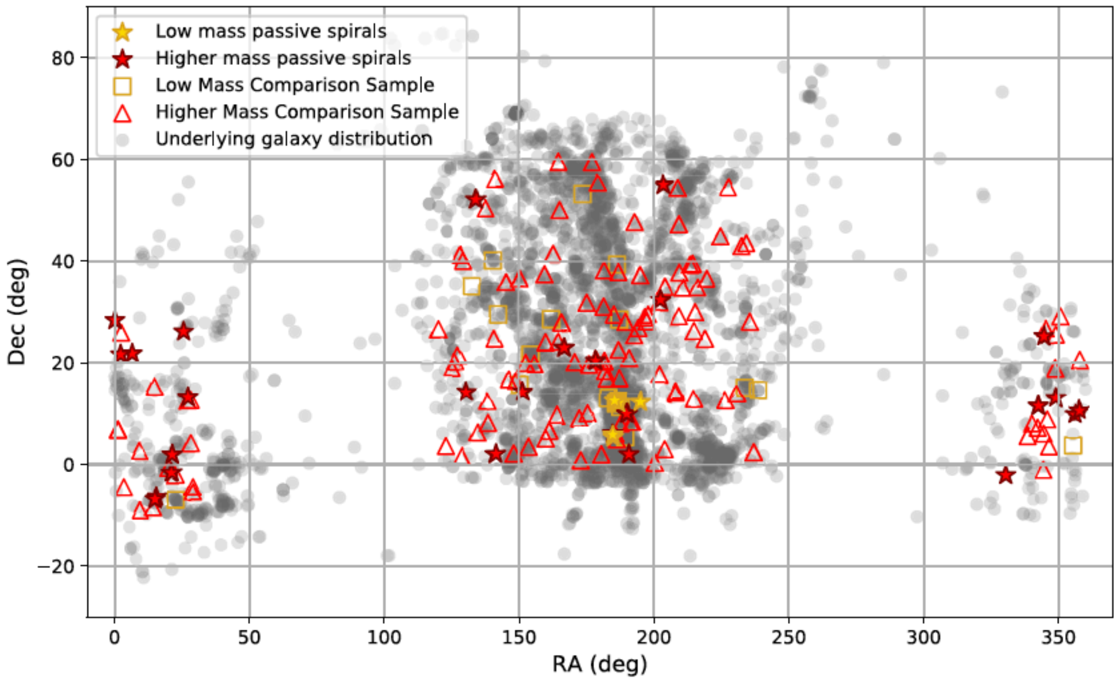
- 175 disc galaxies with near-infrared photometry and HI rotation curves
- Massive blue spirals are in halos mass<$3*10^{12}M_{sun}$, where quick cold accretion is expected

# Quenching of low-mass spirals

For satellite galaxies, environmental effect (tidal stripping/ram-pressure) will reduce the gas content

---most low-mass passive spirals are found in/around clusters

(Bamford+2009, Wolf+2009, Fraser-McKelvie+2010)



# The quenching of massive spiral galaxies
---Our results

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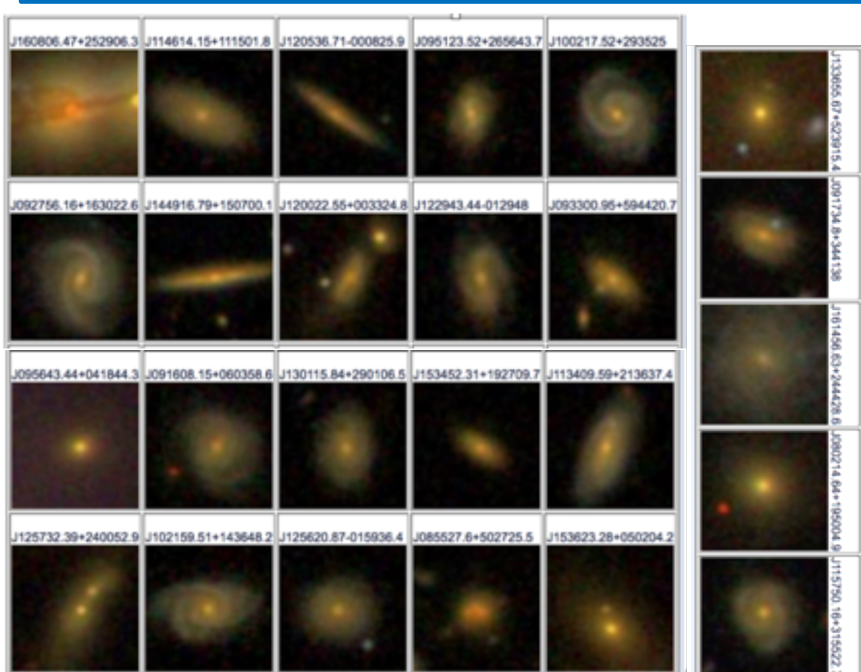
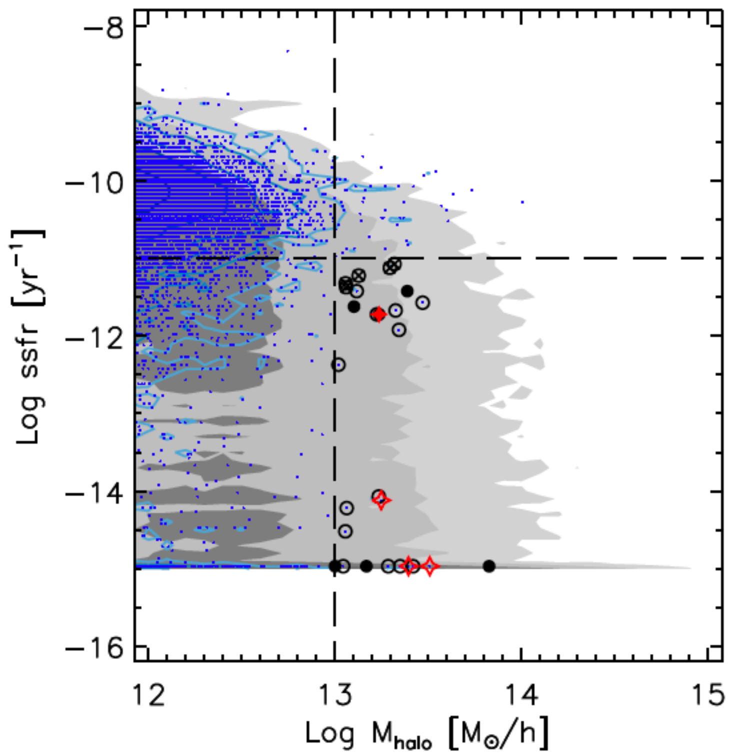
Our Observational Sample

- SDSS+Yang Group catalog+Chang catalog (WISE)
- Central Galaxies with Mhalo>$10^{13}$ Msun & fdev<0.1
  72 galaxies in total
- sSFR<$10^{-11}$
  27 Quenched, 52 star forming



Luo, KX+, 2020, MNRAS Letter



# The quenching of massive spiral galaxies ---Our results

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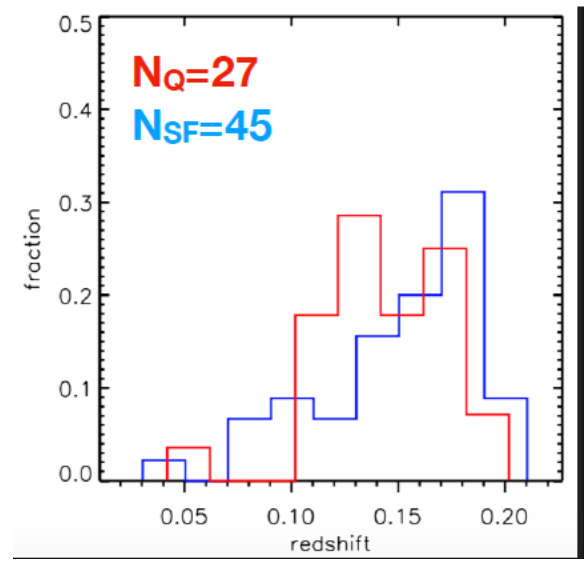
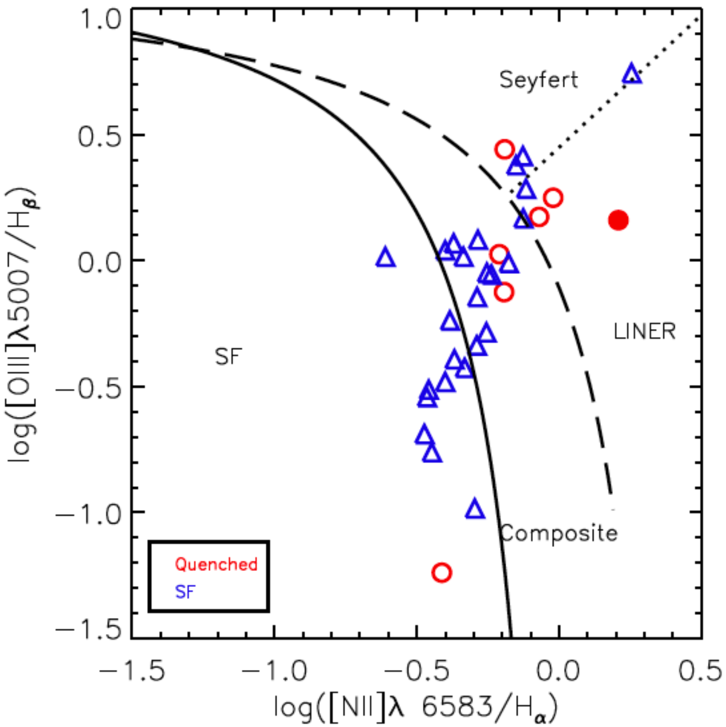
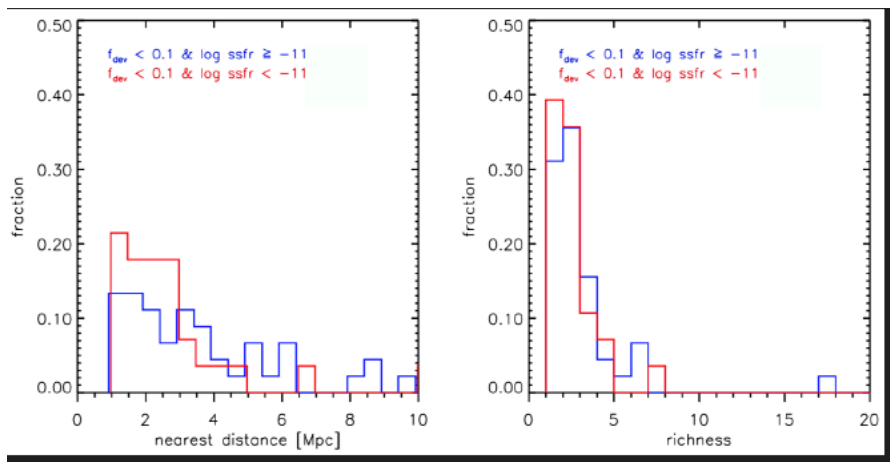
## Our sample

- Most at z>0.1 (no cold gas data)
- In isolated environment
- 6 among 27 quenched galaxies show AGN activities, others lack emission lines



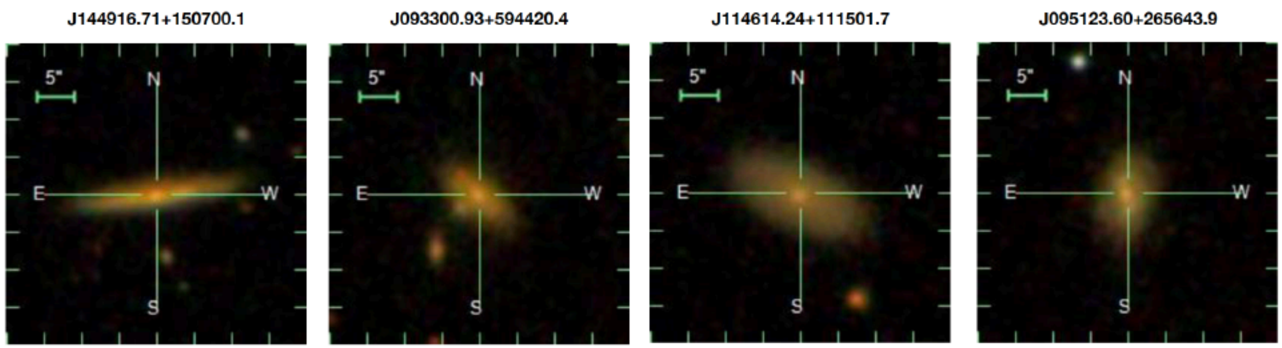



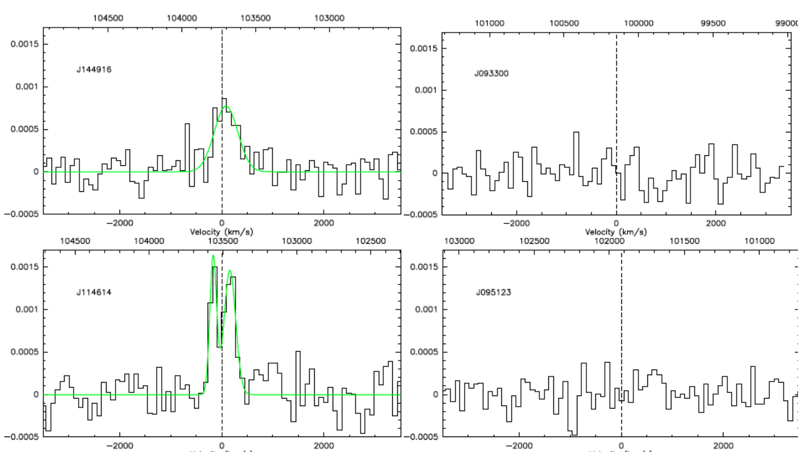

Distances to nearest neighbor



## The quenching of massive spiral galaxies ---Our results

We randomly select 4 quenched galaxies for CO detection using IRAM 30m for 20 hours




CO(1-0) spectra

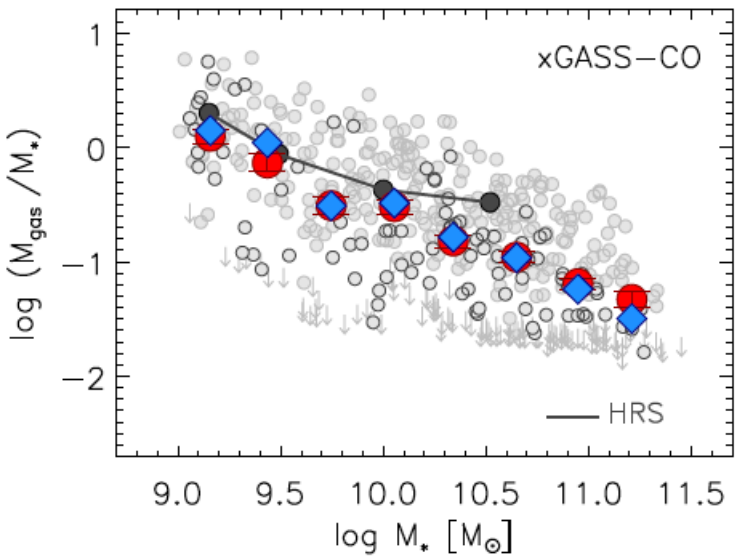
Two have CO detection. All have cold gas $<10^{10}$Msun ($M_{cold}/M_*<0.05$)

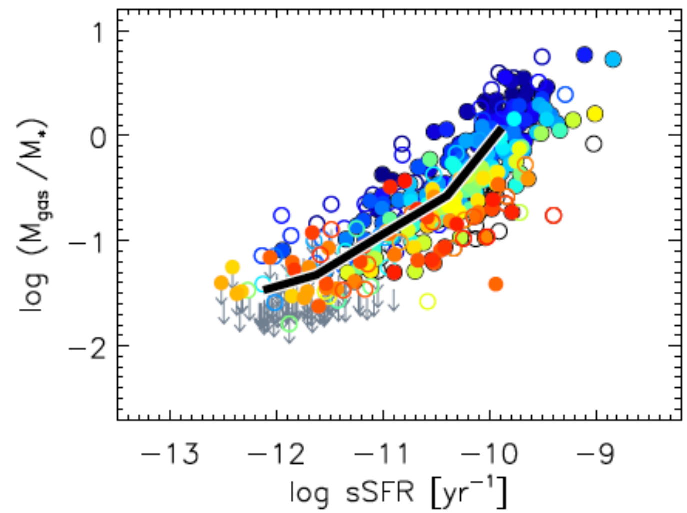
Table 1. Basic information and observation log of our target galaxies.

| Name | J144916.71+150700.1 | J093300.93+594420.4 | J114614.24+111501.7 | J095123.60+265643.9 |
|---|---|---|---|---|
| RA (J2000) | 222.320 | 143.254 | 176.559 | 147.848 |
| Dec. (J2000) | 15.117 | 59.739 | 11.251 | 26.946 |
| $z$ | 0.111 | 0.151 | 0.114 | 0.131 |
| $\log M_{\rm halo}$ ($M_\odot$)[a] | ~~13.40~~ 13.1 | 13.55 | 13.66 | ~~13.29~~ 13 |
| $\log M_*$ ($M_\odot$)[b] | 11.20 | 11.29 | 11.12 | 11.02 |
| log sSFR ($\rm yr^{-1}$)[c] | −14.12 | −14.97 | −14.97 | −11.72 |
| Frequency (GHz) | 103.75 | 100.15 | 103.48 | 101.92 |
| $T_{\rm int}$ (h)[d] | 4.5 | 5 | 3 | 4.4 |
| rms[e] (mK) | 0.15 | 0.17 | 0.22 | 0.15 |
| Velocity[f] ($\rm km\ s^{-1}$) | 82.47 ± 34.21 | – | −169.40 ± 12.31<br>157.77 ± 17.30 | – |
| FWHM[g] ($\rm km\ s^{-1}$) | 547.74 ± 100.90 | – | 155.36 ± 36.09<br>267.31 ± 43.26 | – |
| $T_{\rm mb,peak}$[h] (mK) | 0.93 ± 0.15 | – | 1.95 ± 0.22<br>1.76 ± 0.22 | – |
| $I_{\rm CO}$[i] ($\rm K\ km\ s^{-1}$) | 0.54 ± 0.07 | <0.31[j] | 0.33 ± 0.06<br>0.51 ± 0.07 | <0.28[j] |
| $\log L_{\rm CO}$ ($L_\odot$)[k] | 9.20 ± 0.06 | < 9.24 | 9.41 ± 0.05 | < 9.06 |
| $\log M_{\rm H_2,0}$ ($M_\odot$)[l] | 9.84 ± 0.06 | < 9.88 | 10.05 ± 0.05 | < 9.70 |
| $\log M_{\rm gas,p}$ ($M_\odot$)[m] | 9.98 | 10.02 | 9.95 | 9.91 |

## The quenching of massive spiral galaxies ---Our results

We lack HI data. The Catinella+ results suggest that for massive, passive galaxies, total gas fraction is at most 10%



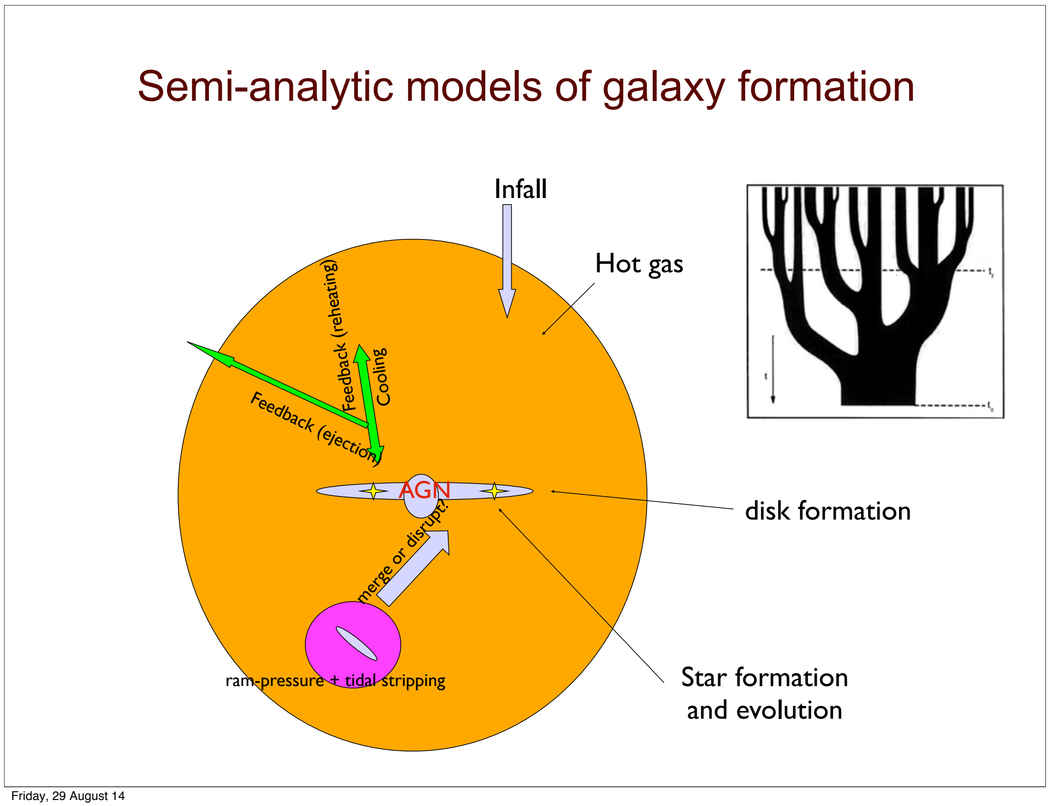

Catinella+ 2018
For galaxies with both CO and HI detection

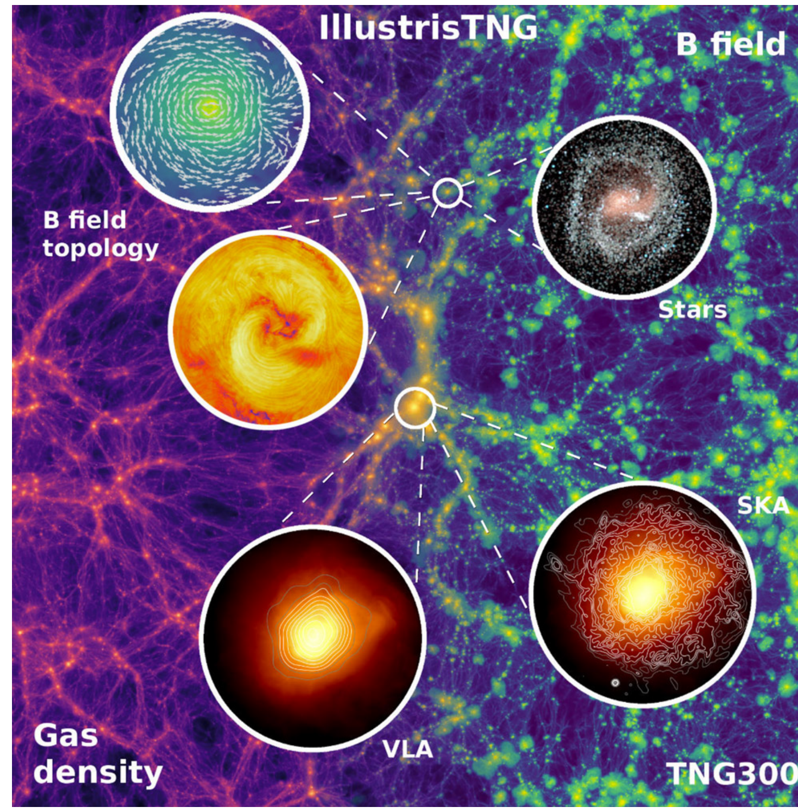
For our sample, halo mass is around 10^13 solar mass
No massive cold gas
→what has quenched the cooling of halo hot gas?

## The quenching of massive spiral galaxies ---Our results

We use both semi-analytical model and hydro-simulation to see

- If models predict such massive quenched spiral galaxies
- If any, Why they are quenched?



# The quenching of massive spiral galaxies ---Model predictions

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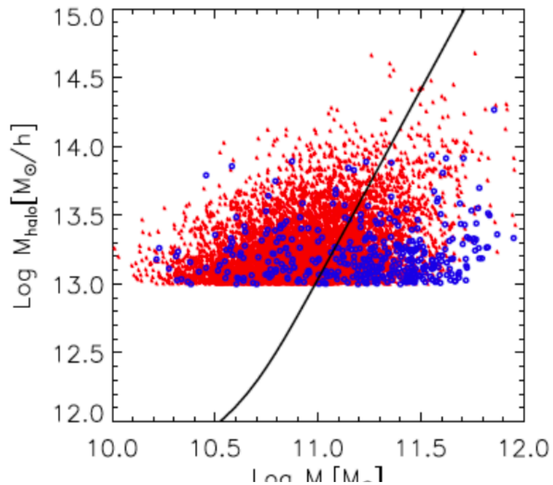
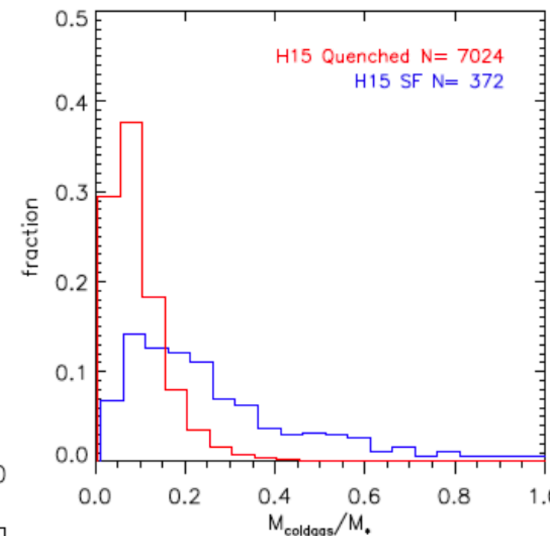
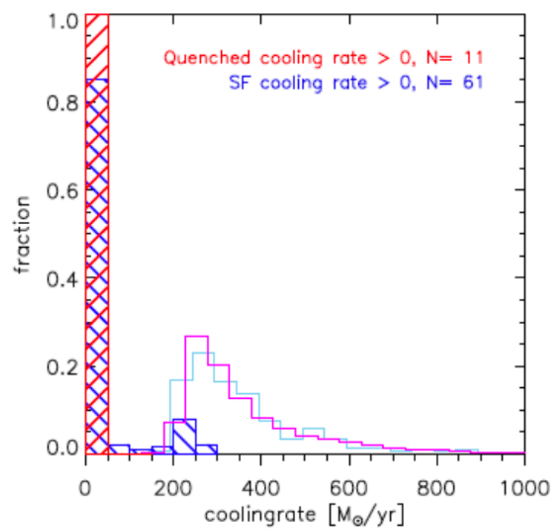
We use the SAM data from Henriques+2015 and apply the same criteria to select massive spiral galaxies

- The fraction of quenched spiral galaxies is too high in the model
- Quenched spirals have slightly more hot gas, but cooling rate is ~ 0
- By turning off  AGN feedback, all spirals have cooling rate above $200M_{sun}$/year and they becomes blue



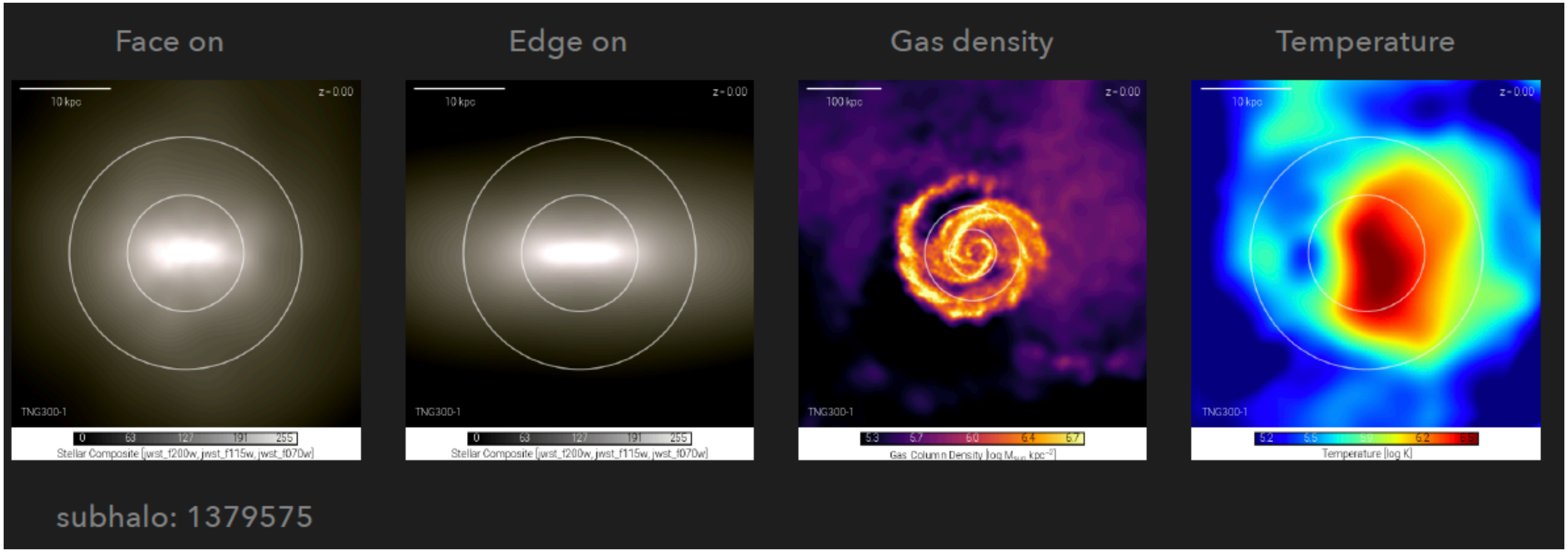



# The quenching of massive spiral galaxies ---Model predictions

Using the TNG simulation, we find the quenched spirals

- TNG300-1 data, galaxies with $M_* > 10^{11}$ solar mass
- We decompose stellar into bulge+disk, select fdev<0.1
- There are 8 quenched spiral galaxies

One of our 8 galaxies



# The quenching of massive spiral galaxies

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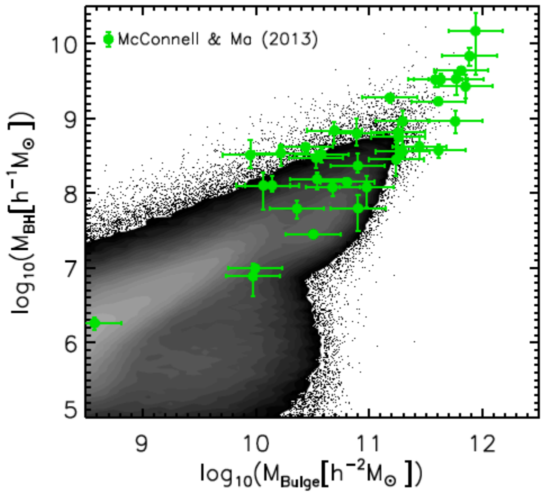
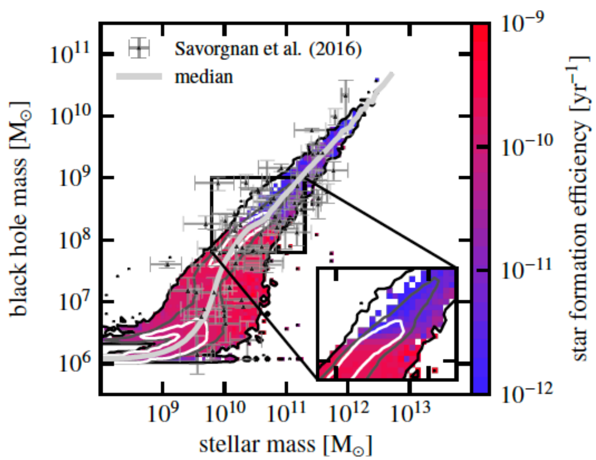
## Black hole mass-Bulge mass relation in SAM and Simulations

All galaxies: BH mass are not over-predicted

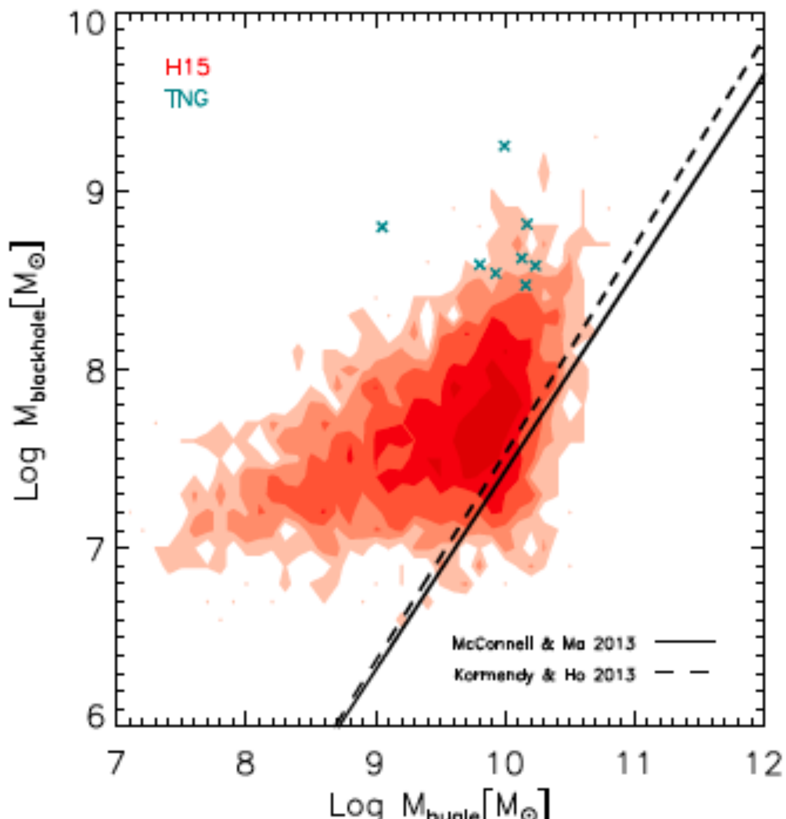
S
A
M




Hydro-simulations




Quenched spiral galaxies

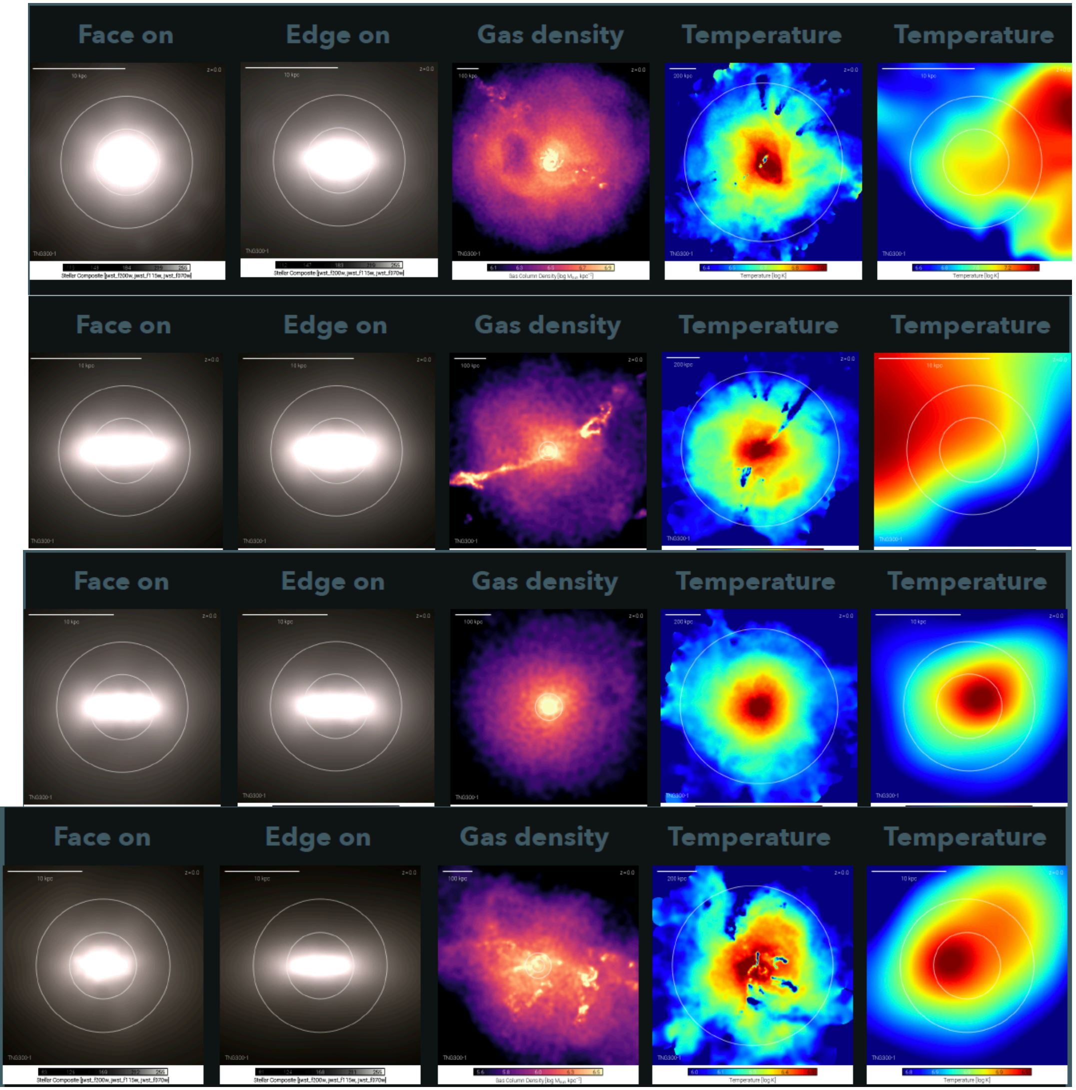


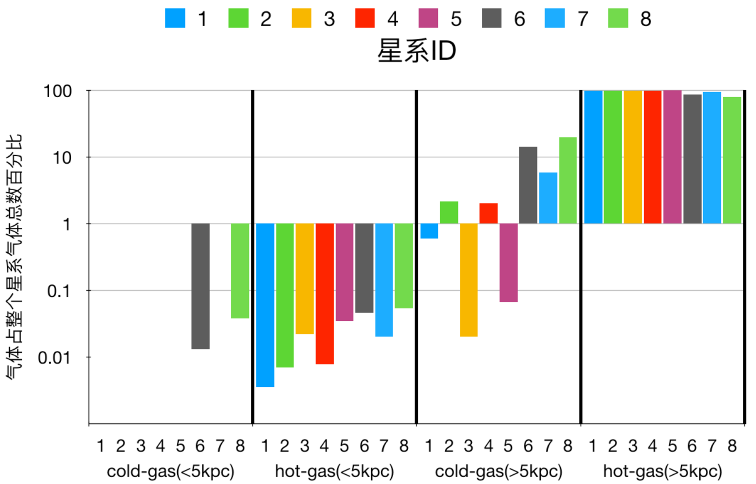

Quenched spirals have massive black holes compared to their bulges

# The quenching of massive spiral galaxies

Content of hot gas around passive spirals in Illustris-TNG:

Baryon fraction ~0.3-0.5, most in hot phase



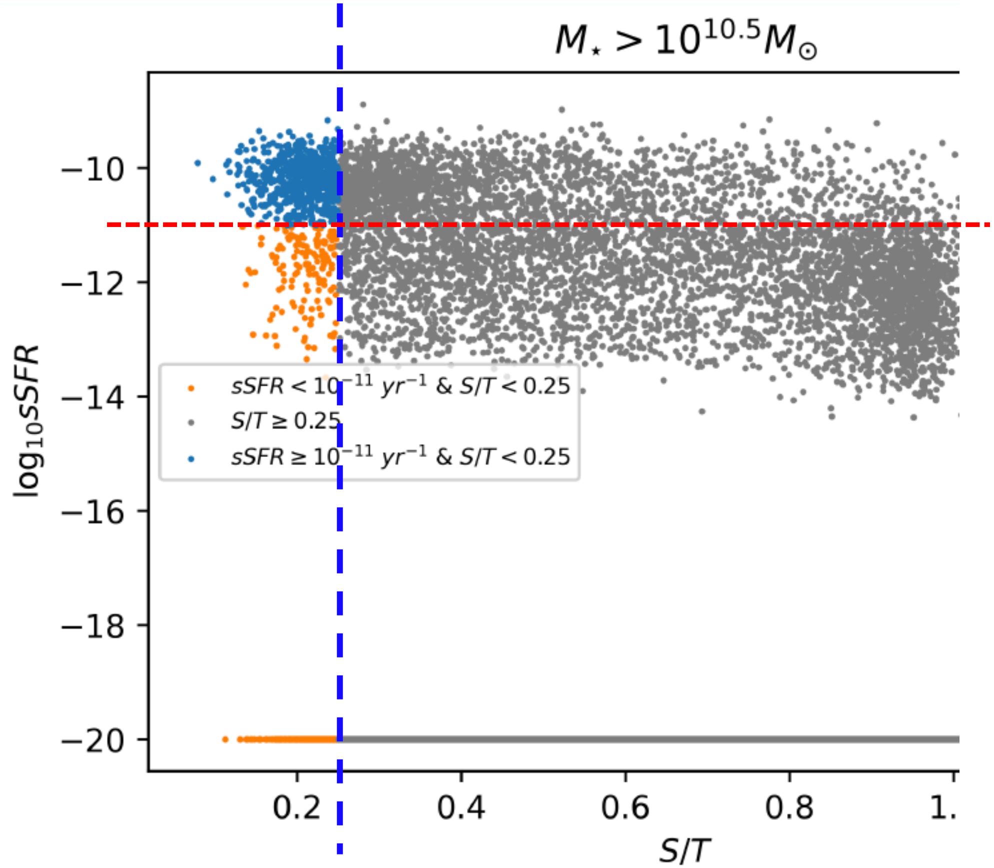




| ID | Mh/fb*Mh (10^10) | Stellar mass(10^10) | Hot baryon fraction |
|---|---|---|---|
| 1 | 2511/416 | 18.9 | 0.47 |
| 2 | 1000/166 | 12.6 | 0.34 |
| 3 | 912/151 | 15.04 | 0.28 |
| 4 | 776/128 | 10.96 | 0.39 |
| 5 | 707/117 | 11.22 | 0.38 |
| 6 | 588/97.6 | 13.22 | 0.25 |
| 7 | 446/74 | 11.6 | 0.26 |

# The quenching of massive spiral galaxies

Recent work using TNG300-1

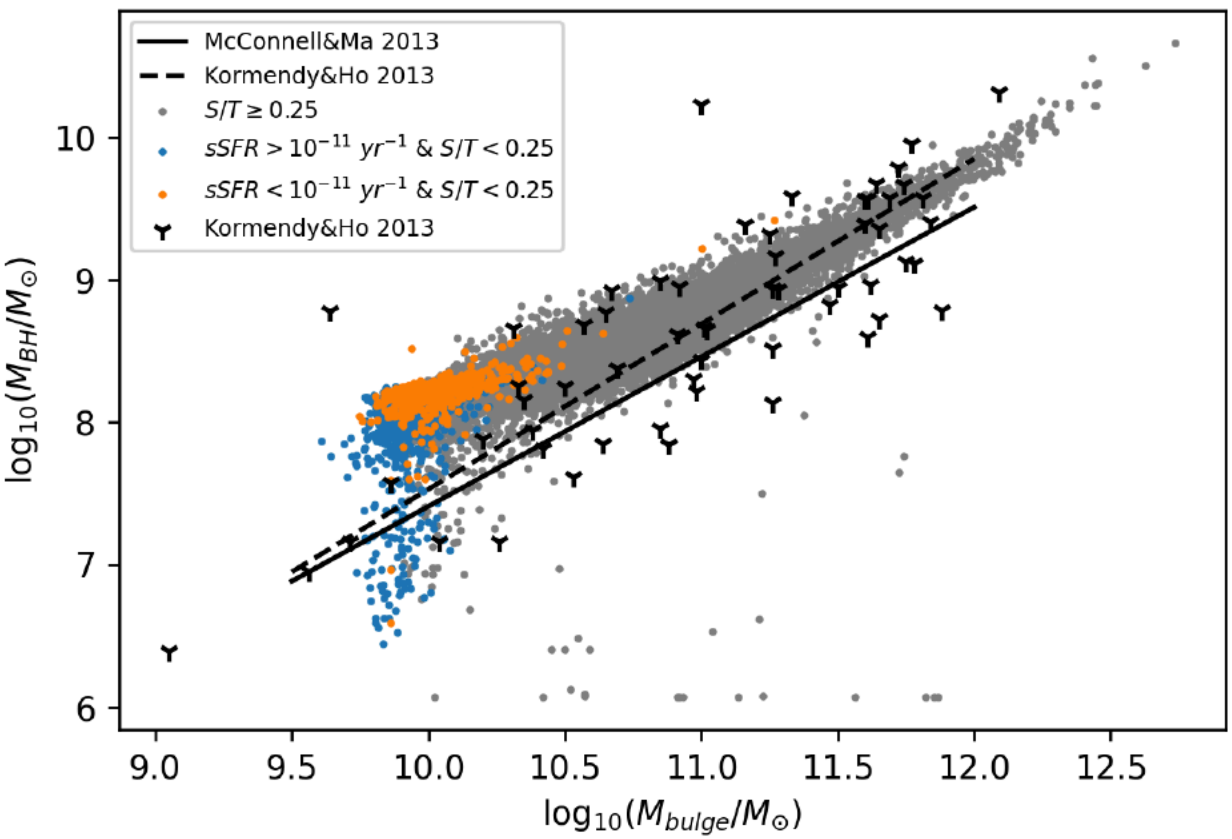
- Increase the sample size by selecting galaxies with M*>10.5 solar mass
- Select galaxies with disk morphology (S/T <0.25)
- Classify galaxies into star forming and quenched (sSFR = $10^{-11}$)




Simulation reproduces observational trend that sSFR is correlated with bulge mass

# The quenching of massive spiral galaxies

Results from TNG300-1




BH mass- bulge mass relation

- Quenched disks have higher BH mass than than the data
- Star forming disks have larger scatter.

# The quenching of massive spiral galaxies

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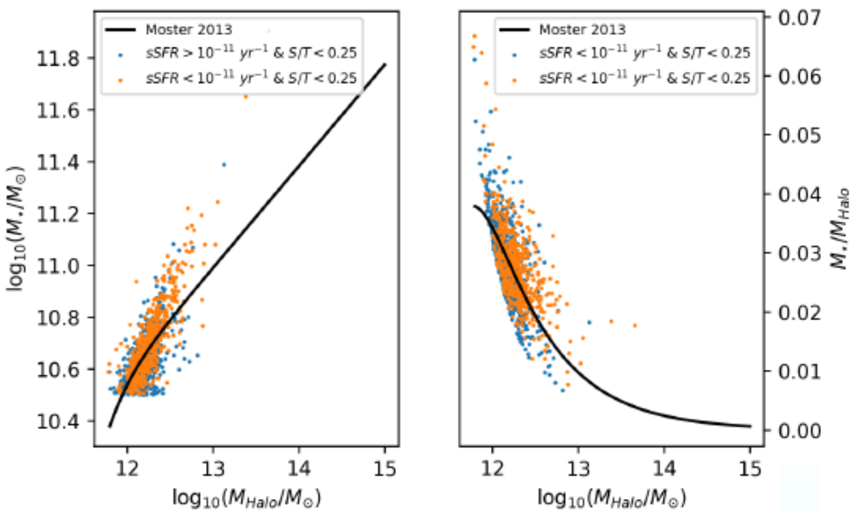
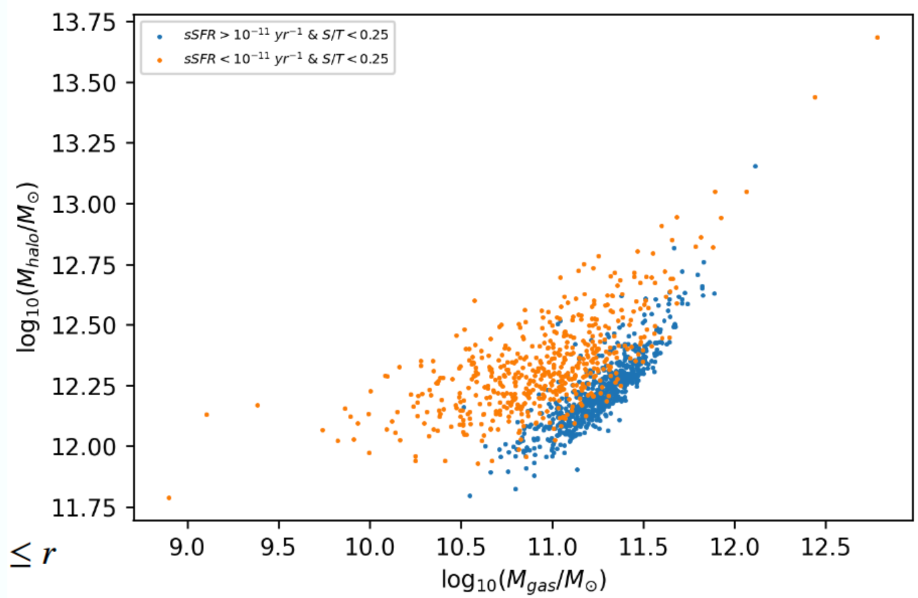
## Results from TNG300-1




- SF disk and quenched disk have similar halo mass
- Quenched disks have less gas (cold+hot)
  - SF: baryonic fraction ~0.8
  - Quenched: ~0.4




$0 \leq r$

# The quenching of massive spiral galaxies

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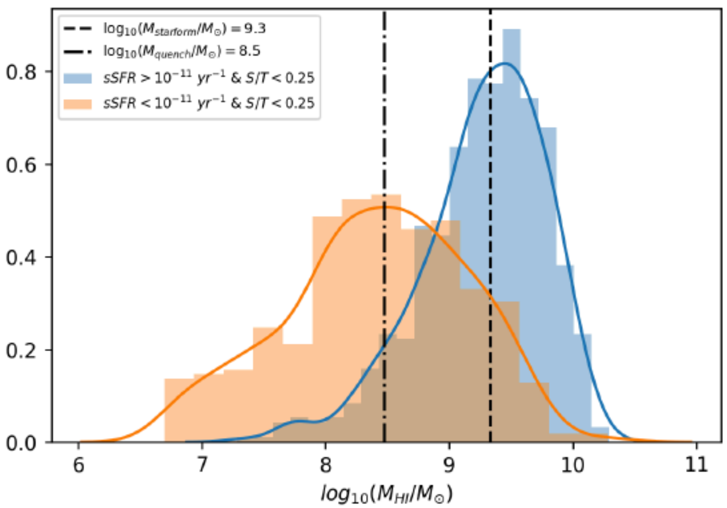
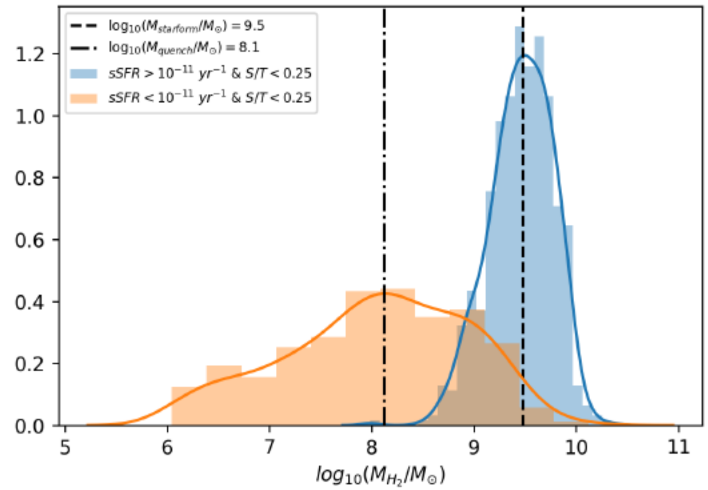
## Results from TNG300-1

### Gas content within r<2Re




HI Gas

H2 Gas

- Quenched spirals have considerable less HI and H2 gas than star forming ones
- Only a few percent quenched galaxies have HI $>10^{9.5}$ (value used in Zhang+ 2019)

# The quenching of massive spiral galaxies

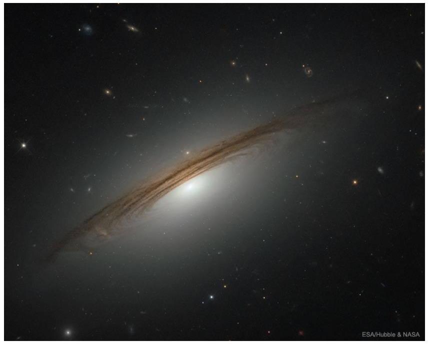
## Content of hot gas around local very massive spirals in X-ray observations

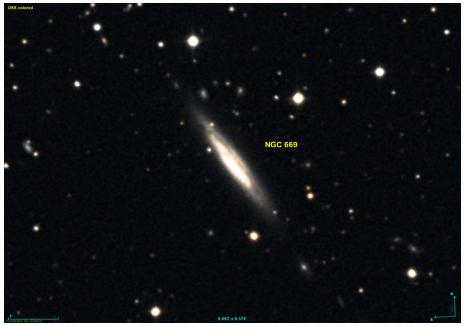
All are passive with sSFR$<10^{-11}$

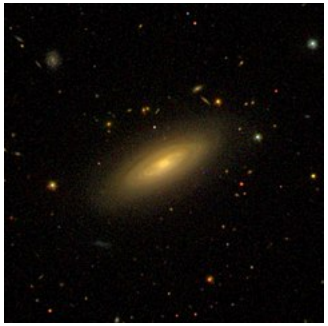
**Table 1**
Properties of the CGM-MASS Galaxies

| Galaxy | Scale kpc arcm$^{-1}$ | $M_*$ $10^{11}\ M_\odot$ | $M_*/L_K$ $M_\odot/L_\odot$ | SFR $M_\odot$ yr$^{-1}$ | $M_{TF}$ $10^{11}\ M_\odot$ |
|---|---|---|---|---|---|
| UGC 12591 | 27.45 | $5.92^{+0.14}_{-0.74}$ | 0.773 | $1.17 \pm 0.13$ | $16.1 \pm 1.5$ |
| NGC 669 | 22.63 | $3.32^{+0.02}_{-0.17}$ | 0.893 | $0.77 \pm 0.07$ | 5.32 |
| ESO142-G019 | 18.78 | $2.49^{+0.05}_{-0.24}$ | 1.137 | $0.37 \pm 0.06$ | $5.07 \pm 0.90$ |
| NGC 5908 | 15.10 | $2.56^{+0.02}_{-0.15}$ | 0.842 | $3.81 \pm 0.09$ | $4.88 \pm 0.60$ |
| UGCA 145 | 20.17 | $1.47^{+0.01}_{-0.08}$ | 0.595 | $2.75 \pm 0.11$ | 4.03 |
| NGC 550 | 27.09 | $2.58^{+0.04}_{-0.28}$ | 0.773 | $0.38 \pm 0.09$ | $5.08 \pm 1.81$ |

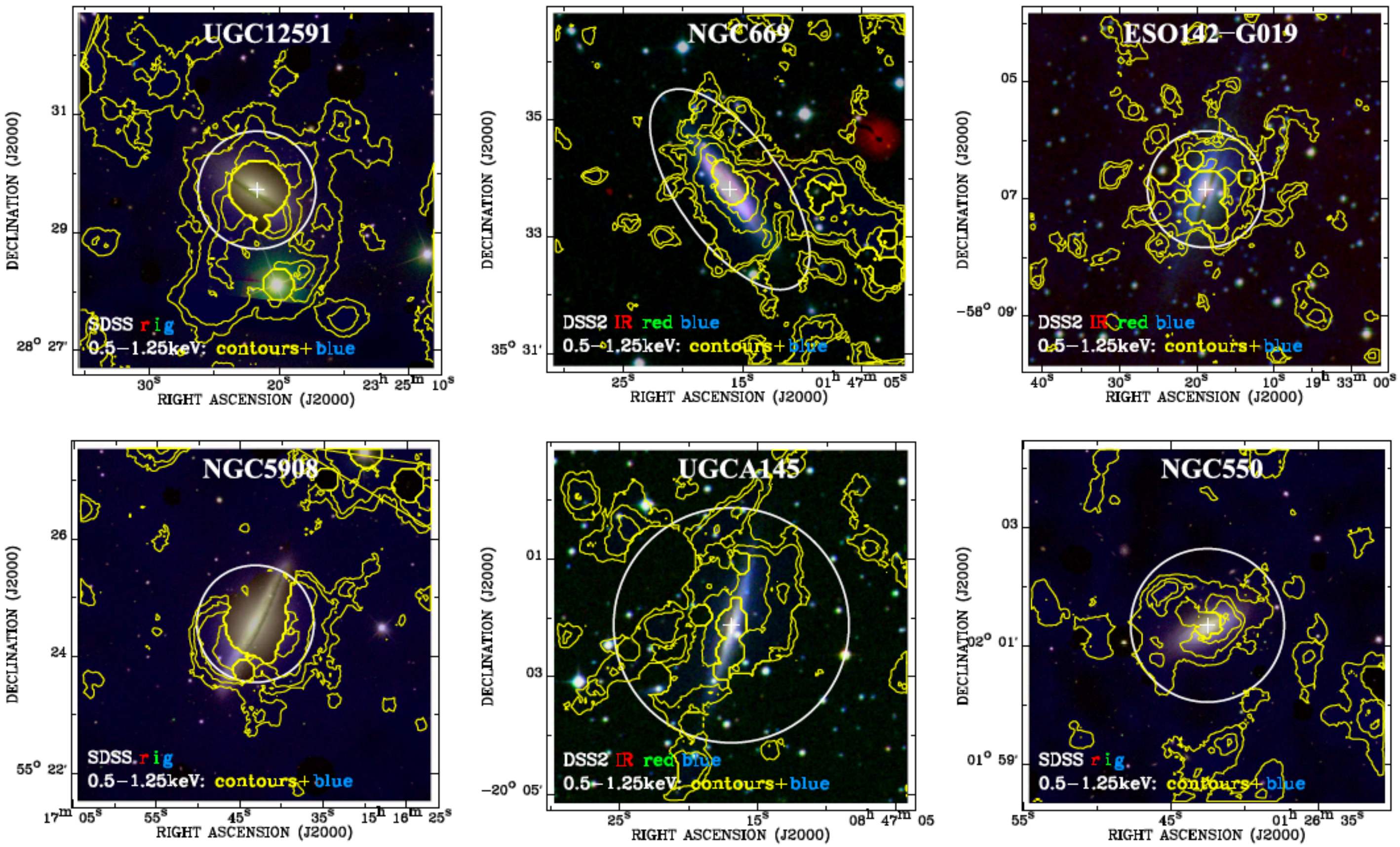
Li J.T et al. 2017



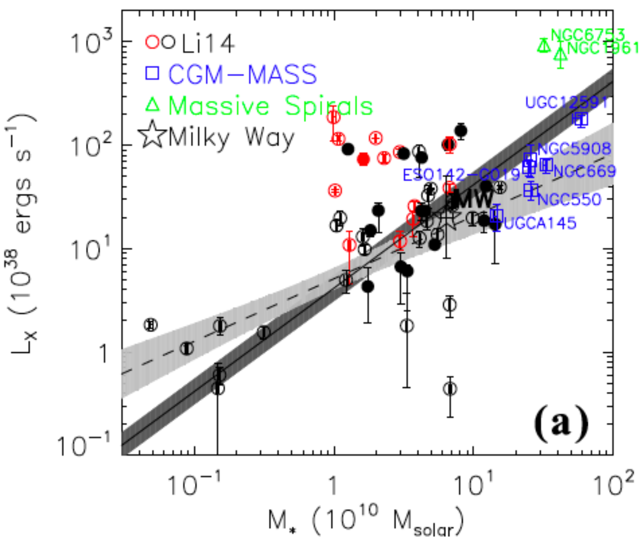



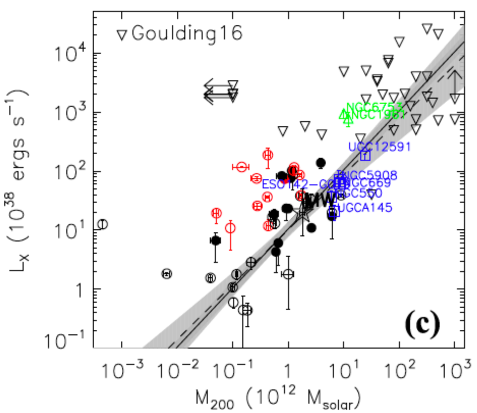



## Content of hot gas around passive spirals---Xray images



# Content of hot gas around passive spirals---Xray images

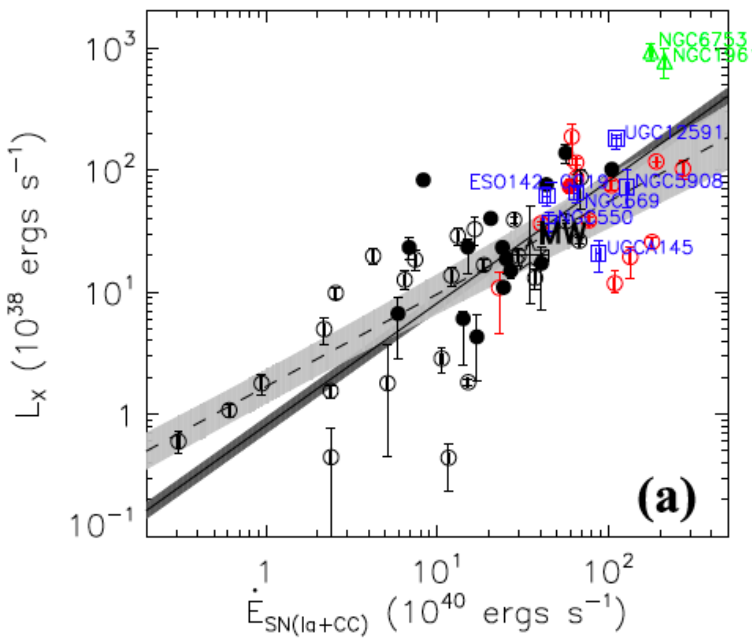



Gas cooling time is long

1% of SNe energy can explain the x-ray luminosity

No additional energy source is needed



# The quenching of massive spiral galaxies

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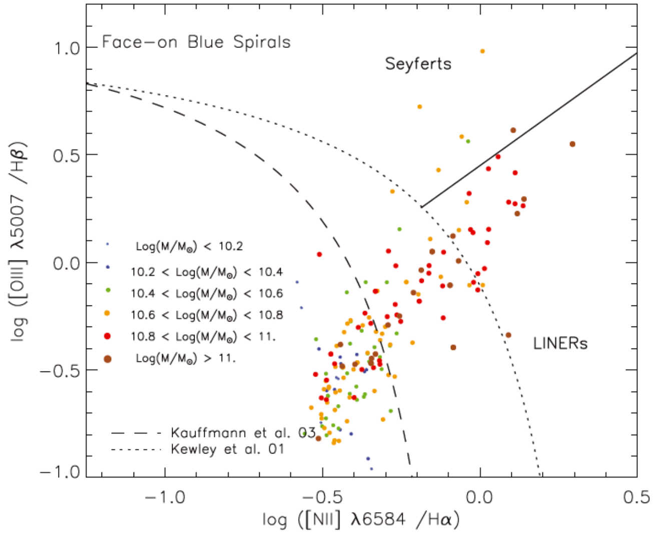
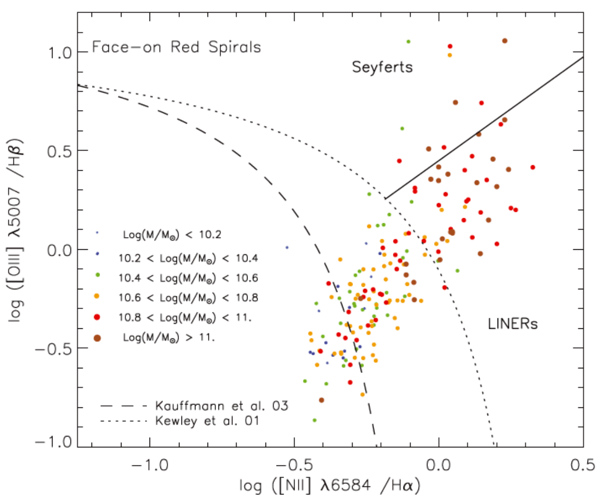
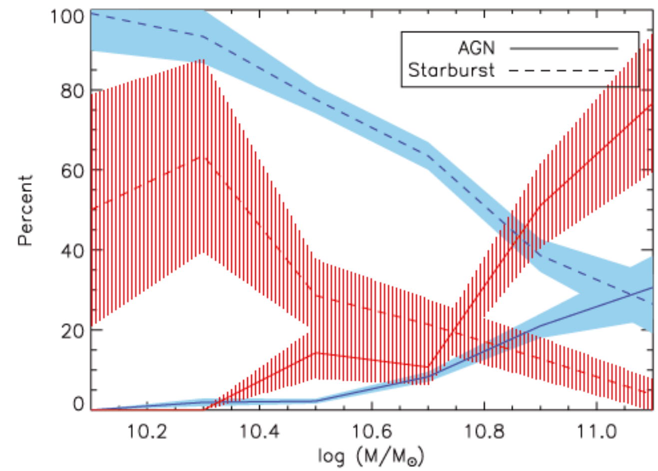
## AGN activities in local passive spirals?




Masters+2010, from galaxy zoo




AGN fraction increases in quenched massive spirals

# The quenching of massive spiral galaxies

AGN in spirals at moderate redshifts?

Bizzocchi+2014 identify 19,225 bulgeless galaxies from COSMOS, AEGIS, GEMS, GOODS at 0.4<z<1.0

Most spirals are not quenched, but red

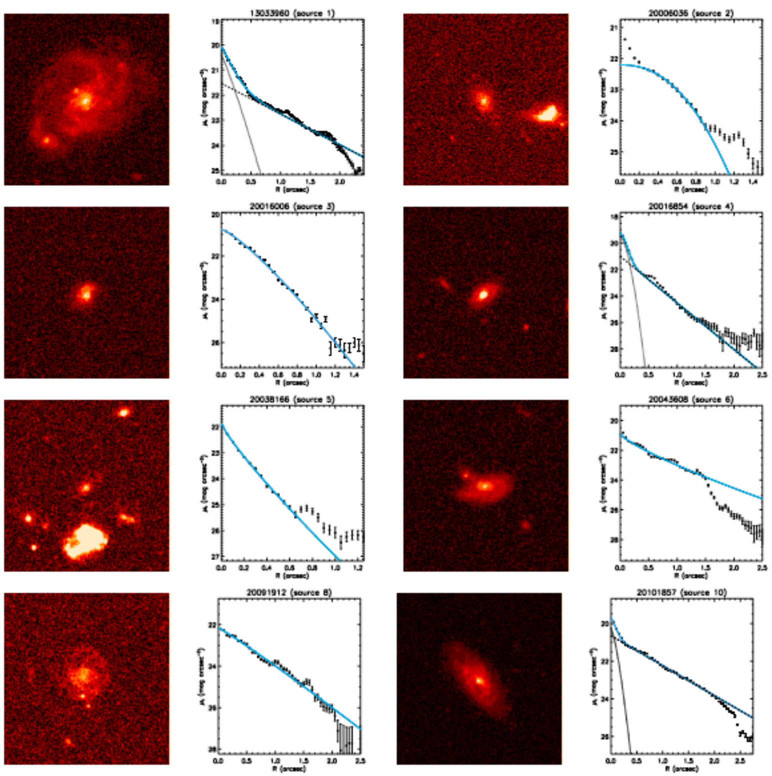


**Figure 11.** *HST*/ACS images and surface brightness profile of the AGN bulgeless host galaxy candidates with $n < 1.5$ and disk/irregular morphology.
(A color version of this figure is available in the online journal.)

**Table 2**
Catalog Selection Statistics Split by Field ($0.4 \leqslant z \leqslant 1.0$)

| Field | Total | spec-$z$ | $n \leqslant 1.5$ | $1.5 < n \leqslant 3.0$ | $n > 3.0$ |
|---|---|---|---|---|---|
| COSMOS | 31714 | 3116 | 14139 | 7259 | 10316 |
| AEGIS | 2848 | 1451 | 1588 | 576 | 684 |
| GEMS | 3595 | 1382 | 2267 | 793 | 535 |
| GOODS-S | 852 | 524 | 482 | 199 | 171 |
| GOODS-N | 843 | 648 | 749 | 74 | 20 |
| *Total* | 39852 | 7121 | 19225 | 8901 | 11726 |

Only 30 (0.2%) massive quenched spirals have AGN

# The quenching of massive spiral galaxies

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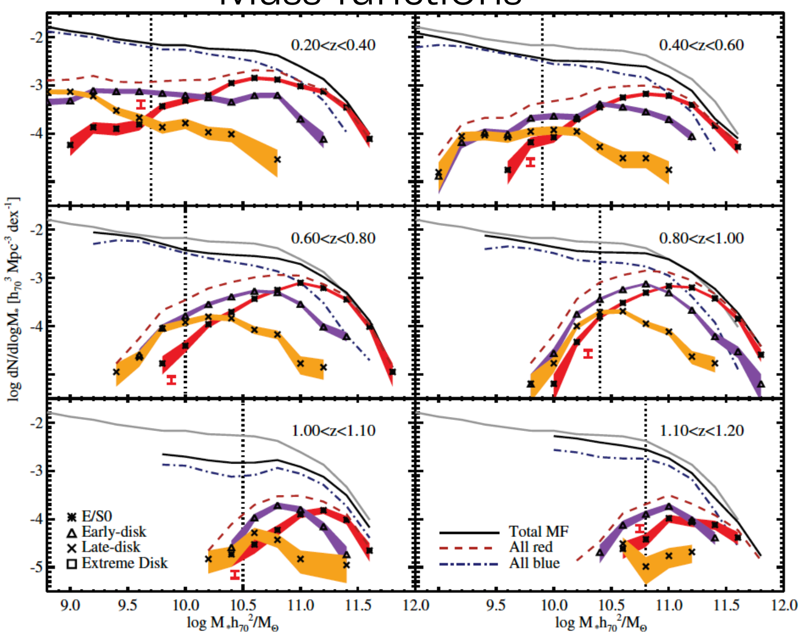
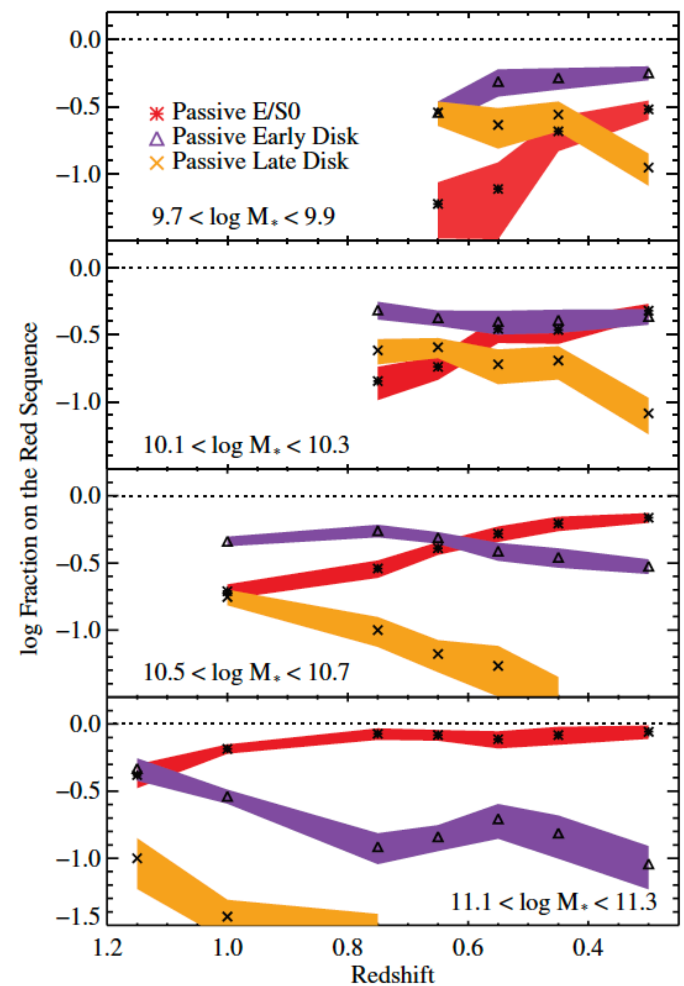
evolution of passive spirals population
Bundy et al. 2010 using COSMOS data

Mass functions




Fraction of red galaxy




- Absolute number density of passive disks increase with time (more at low-z)
- Fraction of passive disk declines with z, as more quenched disks turn into passive E/S0 at low-z

# Summary

Observational results:

- Quenched spirals are rare, but more frequent in high-mass spirals
- Most red spirals have bars, indicating bar can suppress star formation in the disk
- Contradictory results on HI gas content in quenched galaxies

Simulation and Model results

- Quenched spirals have larger BH mass than the Magorrian relation, suggesting AGN feedback might be effective
- Quenched spirals have less cold and hot gas than star forming ones

Future: need to know why Quenched spirals have less hot gas
Searching AGN activity and X-ray observation are important

Thanks for your attention

# The quenching of massive spiral galaxies

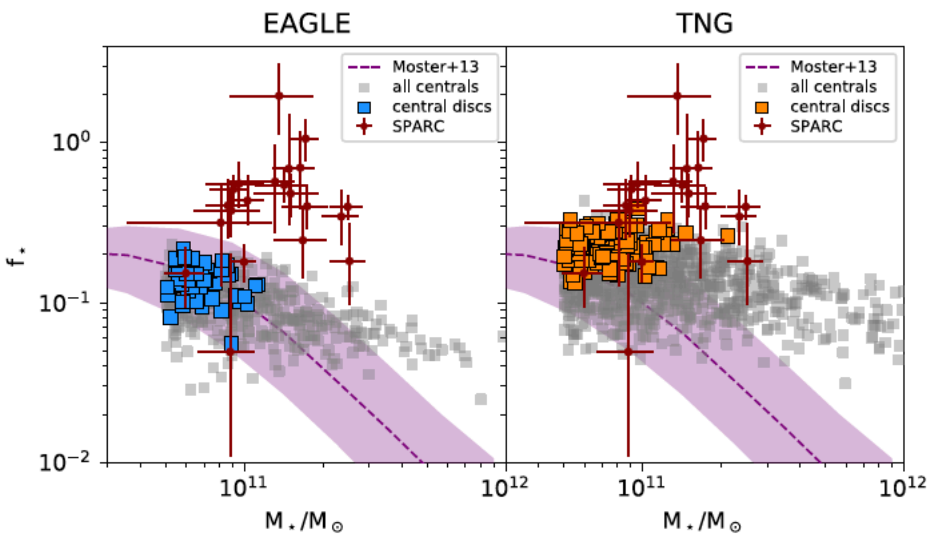
Discussion: halo mass is crucial

--it determines the baryonic budget-→need quenching or not

*Astronomy & Astrophysics* manuscript no. shmr_sims ©ESO 2020
May 6, 2020

**Massive disc galaxies in cosmological hydrodynamical simulations are too dark matter-dominated**

A. Marasco[1], L. Posti[2], K. Oman[3], B. Famaey[2], G. Cresci[1] and F. Fraternali[4]

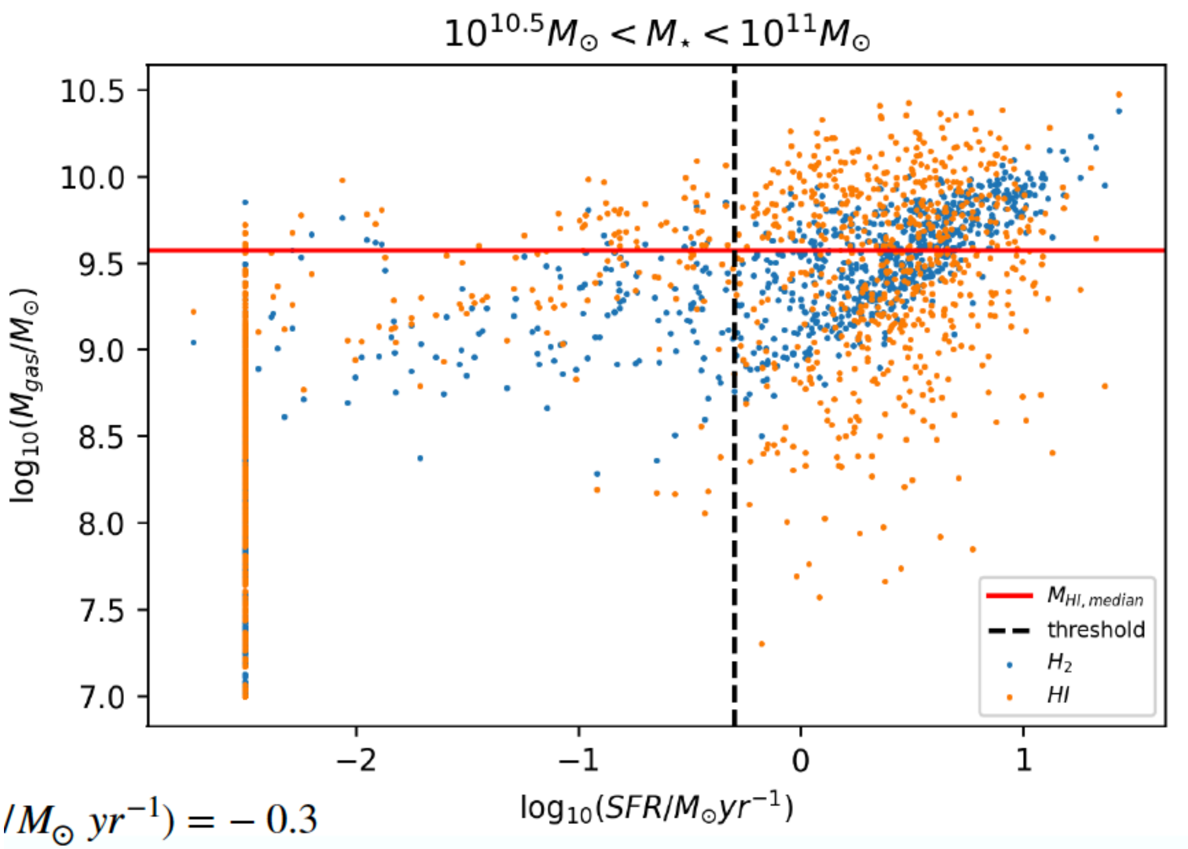



For star forming spirals, the halo mass in simulation is too large, partly due to too-efficient feedback

But for passive spiral, how can we measure the halo mass or hot CGM?

X-ray data is key

# The quenching of massive spiral galaxies




~1 percent quenched have HI>10^9.5

If using SFR within 1Re, Some star forming galaxies become quenched