# Molecular gas in the most massive spiral galaxies: Superspirals

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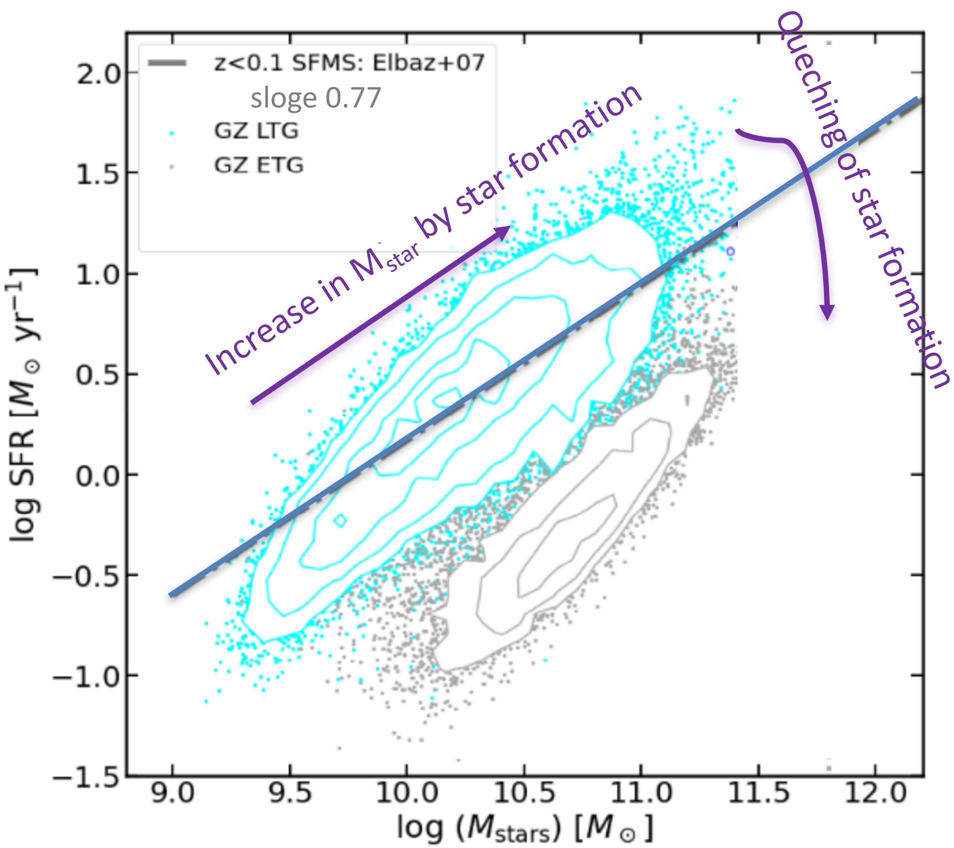
# Galaxy evolution



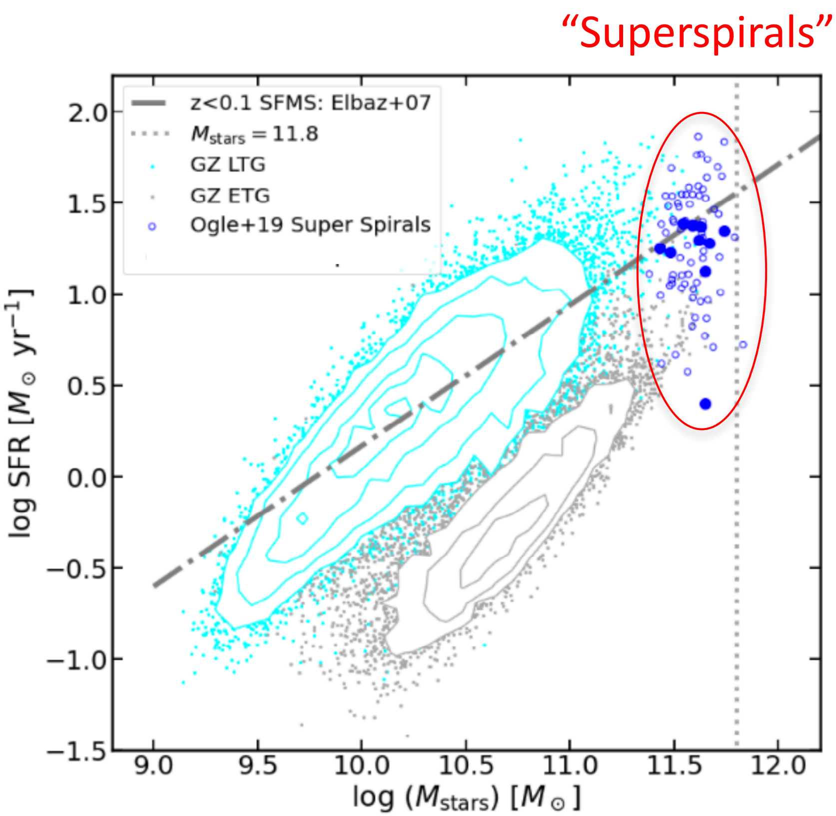

(from Ogle+2019, adapted)

Galaxy Star-Forming Main Sequence

At high $M_{star}$ :

- Less spiral galaxies
- They seem to stop forming stars and become elliptical
- Possible reasons for this quenching can be (among others):
  - ✧ Major merger
  - ✧ AGN feedback
  - ✧ Ram pressure stripping
  - ✧ Gas depletion

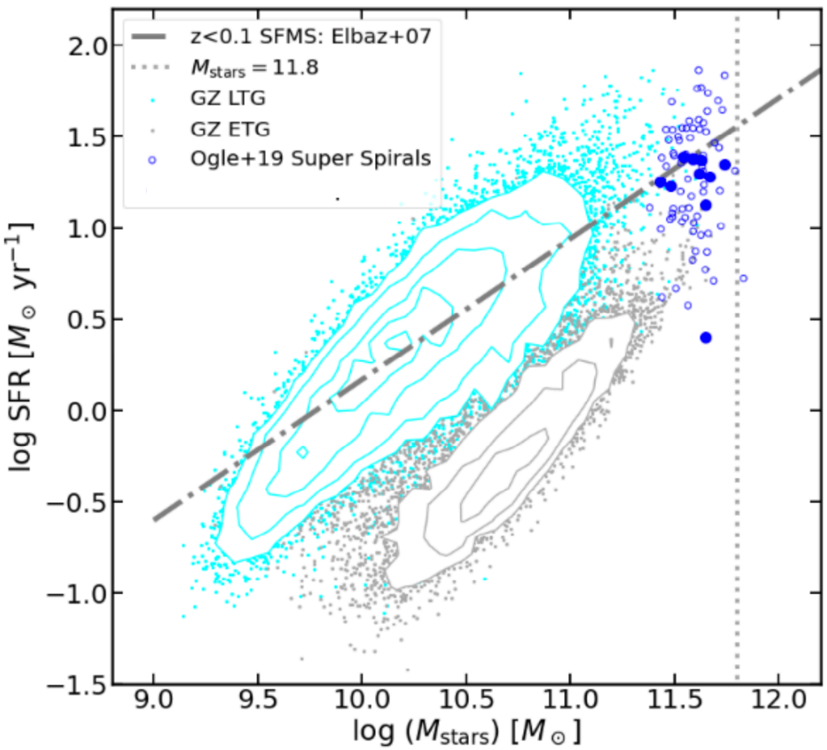
# Very massive spiral galaxies




(from Ogle+2019b, adapted)

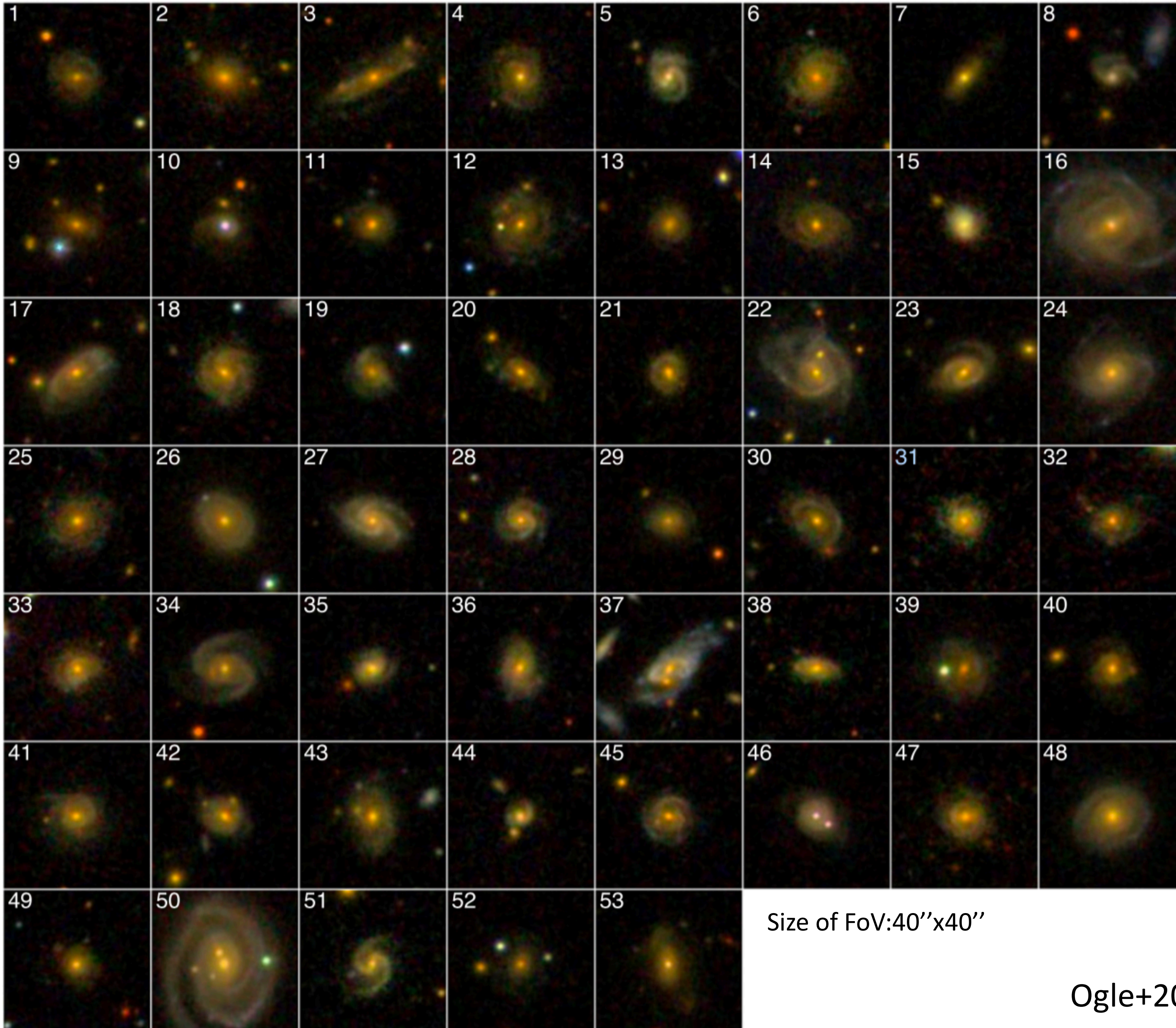
- Ogle+2016 and Ogle+2019a selected and analyzed the most massive spiral galaxies from SLOAN.
- Selection criteria:
  - $L_R > 8\ L_*$
  - $z < 0.3$
  - Visual spiral classification
- → found 84 "superspirals" (8% of populaton with $L_R > 8L_*$)
- Using 2MASX allows to enlarge the sample, including dust-extincted, high-inclination objects (Ogle+2019b).

# Main properties of superspirals




(from Ogle+2019b, adapted)

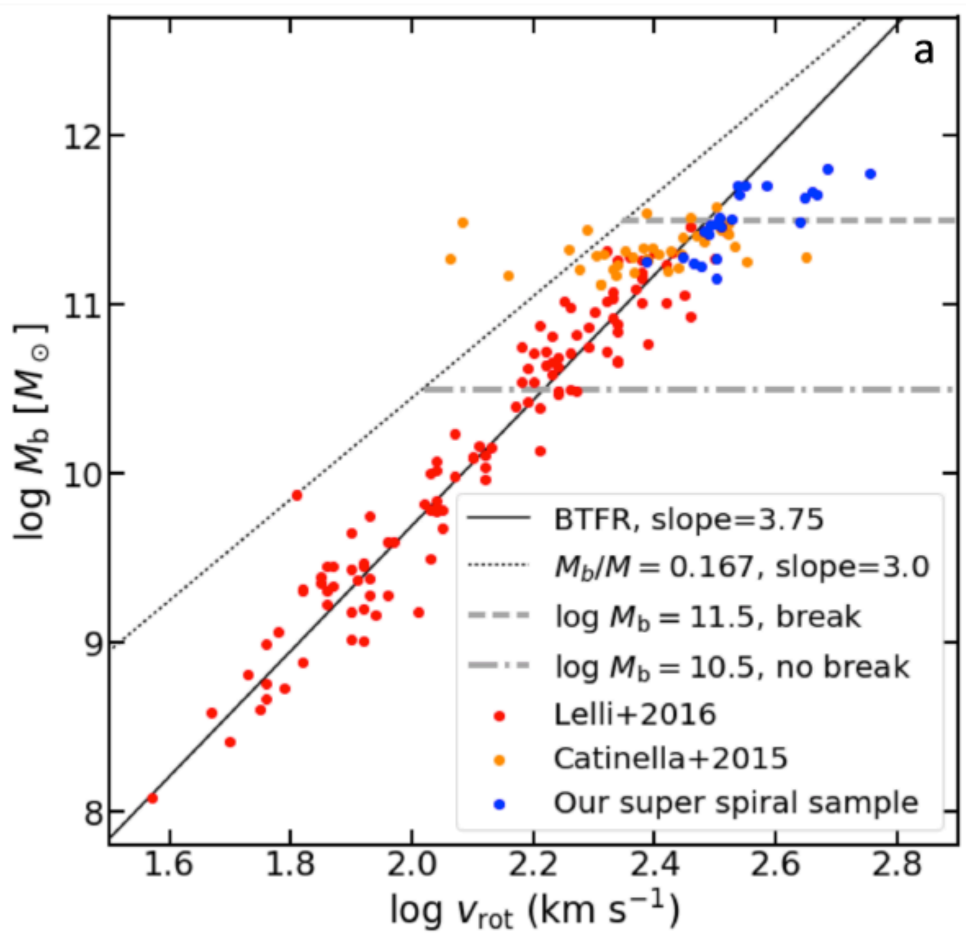
- SFR ~1 – 100 $M_o$ $yr^{-1}$
- SFR on the SFMS: They are unquenched objects!
- $M_{star}$ between $2x10^{11}$ (selection criterion) and $10^{12}$ Mo
- Small bulges: <B/T> = 0.17
- Large size: Isophotal radii between 50 and 140 kpc (mean disk scale length 12 kpc)
- Colors are redder in inner regions of disk, indicating inside-out star formation
- Large fraction (41%) have indications of ongoing (minor) merger (e.g.double nuclei)
- Situated in low and moderate density environment (72%) and outer regions of clusters (28%).
- The closest superspiral is at z = 0.09




Size of FoV:40’’x40’’

Ogle+2016

# Baryonic Tully-Fisher relation (BTFR)




Ogle+2019b

H$\alpha$ rotation curves show a break in the BTFR (Ogle et al. 2019b):

- High $v_{rot}$ indicate a high $M_{halo}$.
- There is a upper limit in $M_{star.}$

Possible reason:

- Large $M_{halo}$ inhibits gas cooling in a dynamical time.
- Predicted critical halo mass is log($M_{halo}$) > 12.7 (White & Rees 1978) is consistent with our value.
- Superspirals can form stars only from cold gas that cooled before halos reached the critical limit.

# Molecular gas in superspirals

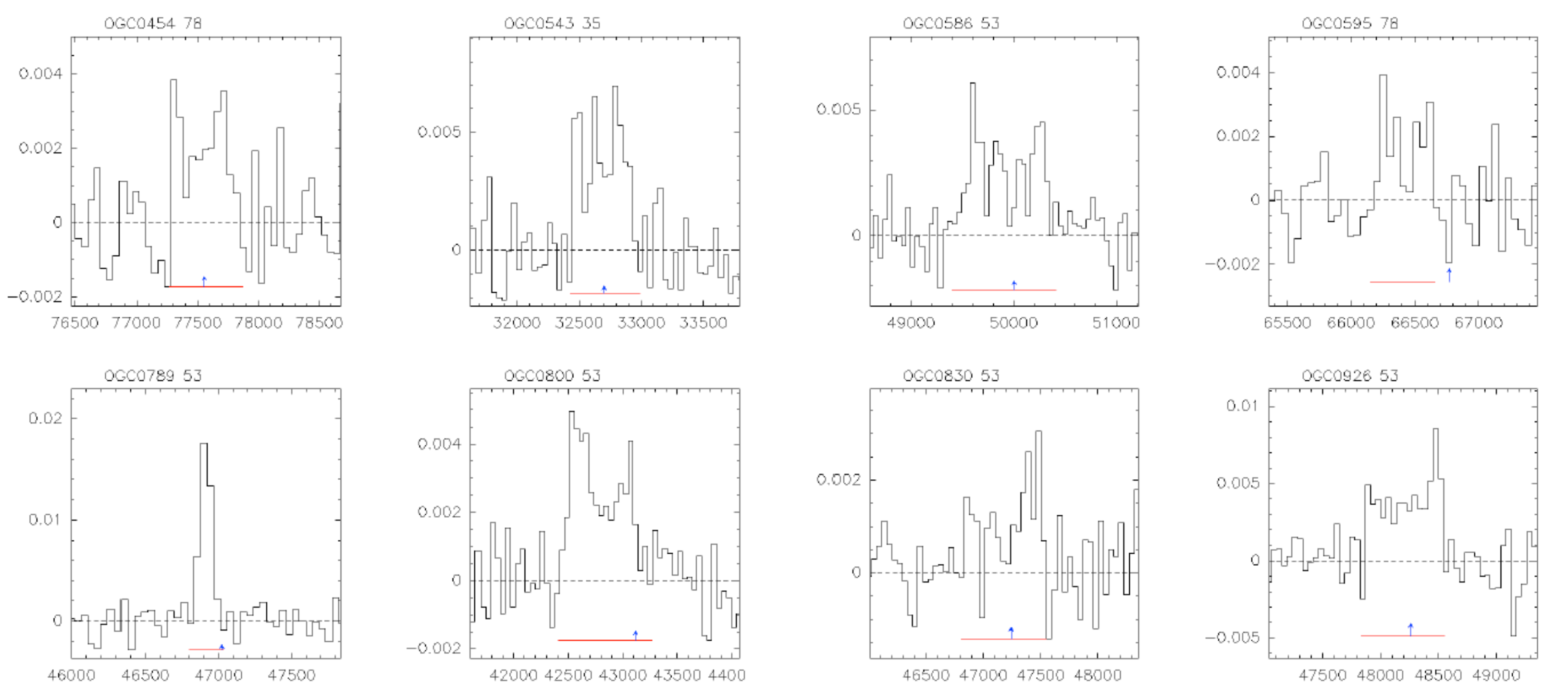
We are observing a sample of superspirals in CO with the IRAM 30m telescope (so far 25 objects, by the end hopefully 50-70).

Questions that we would like to answer:

- What is the amount of molecular  gas in superspirals?
- How does star formation proceed at these high masses with respect to the molecular gas?
- Are fast rotator common among superspirals? We can analyze this based on the CO spectra.

# IRAM CO observations

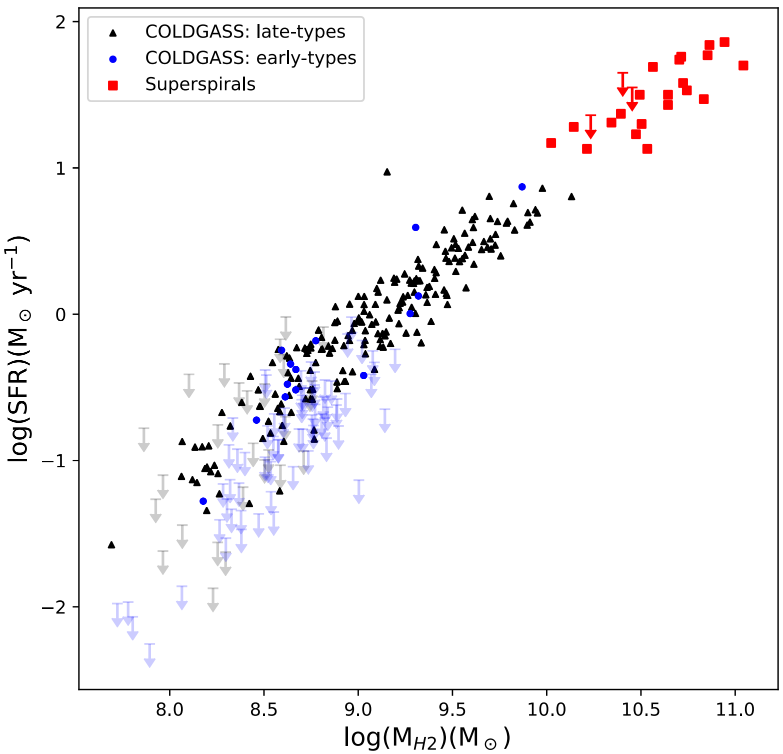
- Beam ~24'' -> cover the entire galaxies
- Sample selected from Ogle+2019a and from 2MASX with similar selection criterions.
- Choose galaxies with SFR >~10 $M_o$ $yr^{-1}$
  - Observed spectra have a high S/N (>5, many >10)
  - Calculate $M_{H2}$ with Galactic X-factor
  - Measure $W_{50}$ which allows to calculate the rotation velocity

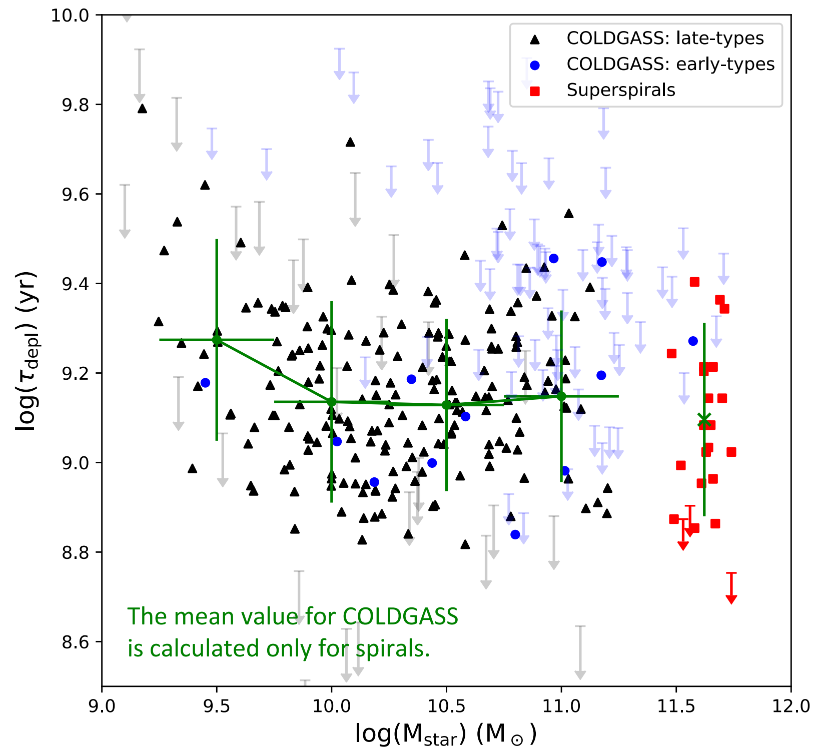


# Analysis

- Comparison sample: xCOLDGASS (Saintonge+2017)
  - Close-by ($z<0.03$) sample of ~500 galaxies selected randomly from SDSS with $M_{star} > 10^9$ Mo
  - CO observed with IRAM 30m
- For both sample we calculated SFR and $M_{star}$ from WISE data:
  - SFR ($M_o$ $yr^{-1}$) = $L_{W3}$ ($L_o$) * $10^{9.8}$ (Chung et al. 2015)
  - $M_{star}$ ($M_o$)= $L_{W1}$ x 0.6 (Ogle+2019b)

# Molecular gas and SF

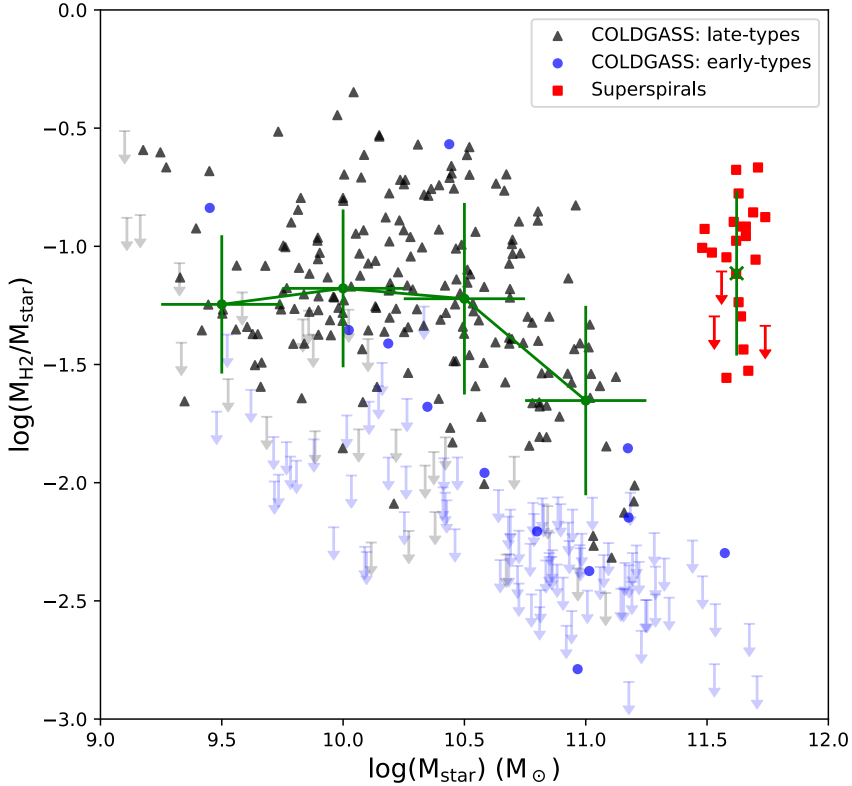


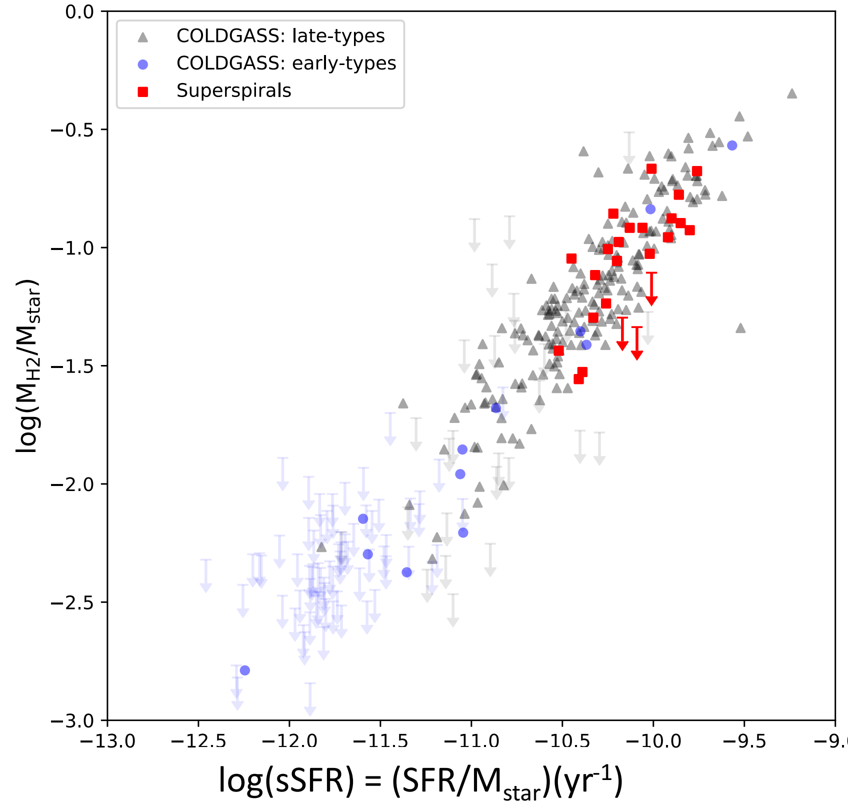




The good correlation between $M_{H2}$ and SFR is extended to high $M_{star}$!

The depletion time, $\tau_{dep} = M_{H2}/SFR$, is the same for superspirals and COLDGASS galaxies

# Molecular gas fraction



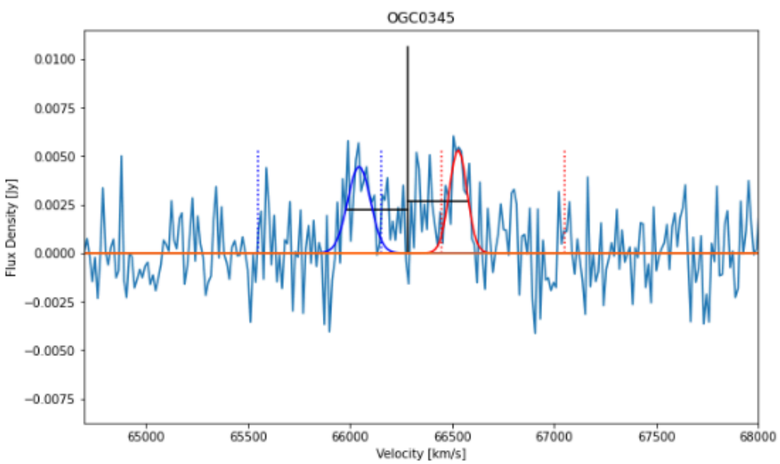

Molecular gas fraction of superspirals is the same as:

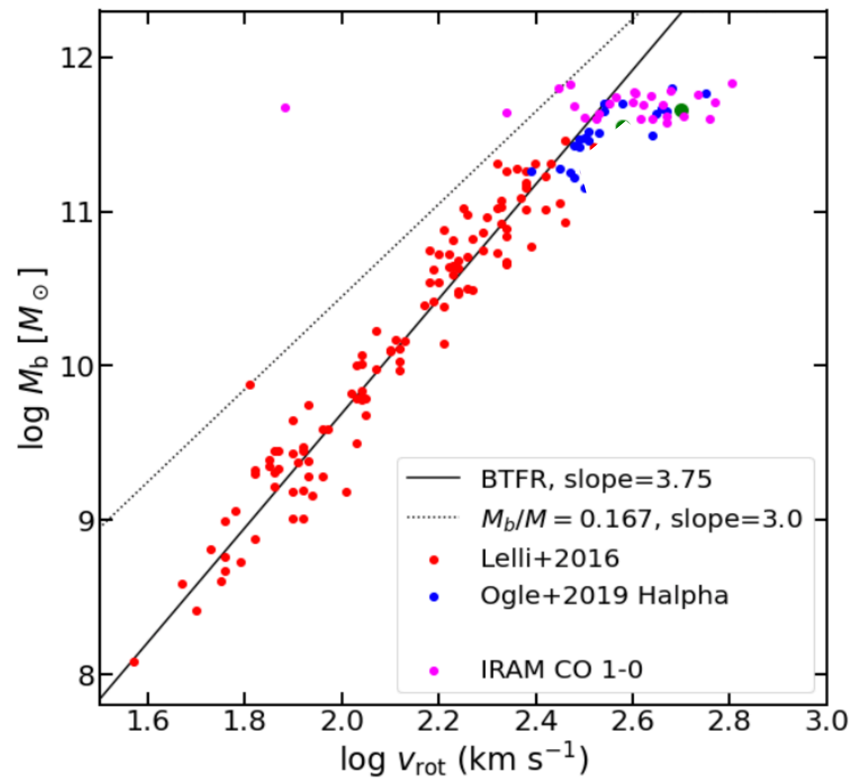
- for lower mass galaxies (log(Mstar) = 9.5-10.5)
- for galaxies with the same sSFR

*Superspirals have not decreased their molecular gas content (yet).*

→ Superspirals are massive, unquenched galaxies with a sufficiently large molecular gas content for active star formation

# Baryonic Tully-Fisher relation




Fit to the CO spectra with a double Gaussian

- derive $W_{50}$
- $v_{rot} = W_{50}/(2*\sin(\text{inclination}))$

- For cases where CO is concentrated in the inner part of the galaxies, $v_{rot}$ is a lower limit → conclusions about break in BTFR are unaffected.

CO data confirms break in BTFR

# Summary and conclusions

- Superspirals are a rare population of the most massive spiral galaxies (between ~$2x10^{11}$ and $10^{12}$ $M_0$) which are actively star forming, following the SFMS.
- The relation between molecular gas, SFR and Mstar ($\tau_{dep}$, $M_{H2}/M_{star}$) are the same as for lower mass galaxies

  → There is abundant molecular gas to fuel SF and the process of SF is “normal”. Superspirals

  → Superspirals are unquenched galaxies. Most likely they have been forming stars actively at a moderate rate during all their life.

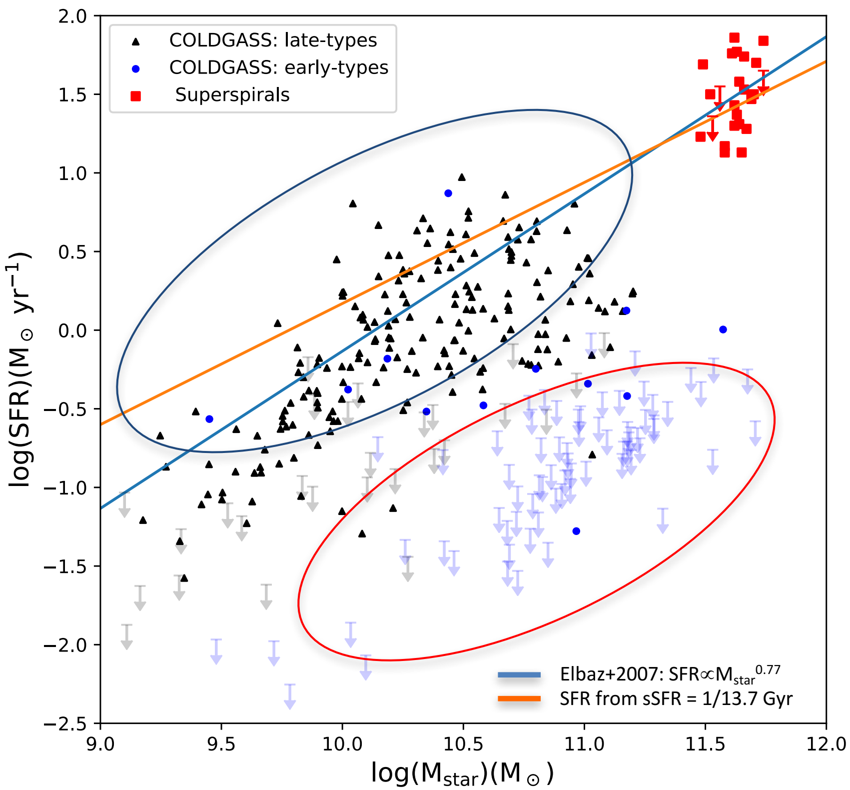
- Kinematical data (from Hα rotation curves and CO line width) reveals a break in the Baryonic Tully-Fisher relation:

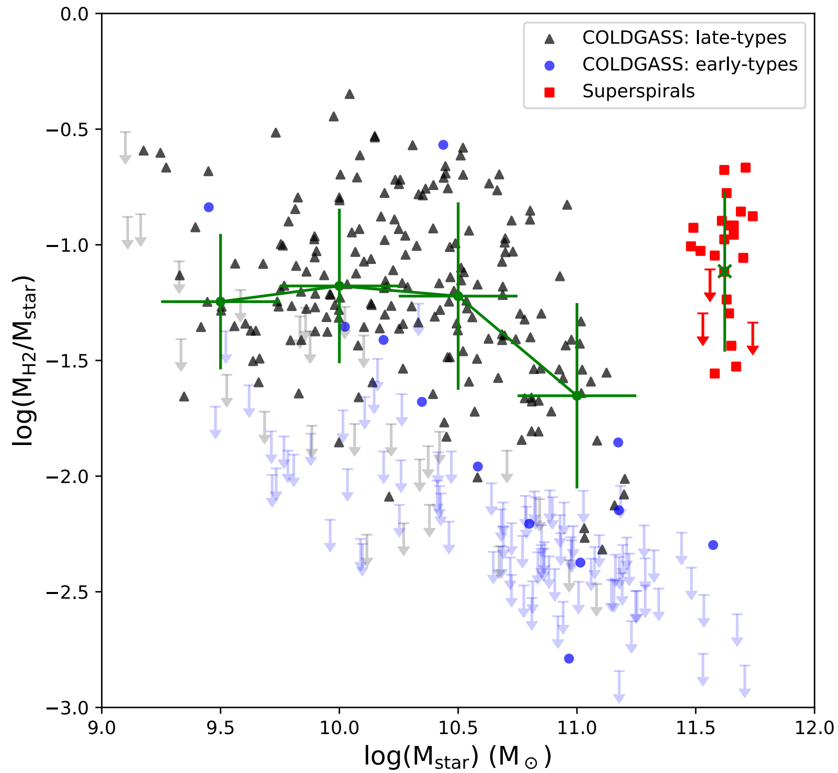
  → There is a upper limit in stellar mass in spiral galaxies.

  → In massive halos baryonic mass is underrepresented.

# Thank you for your attention

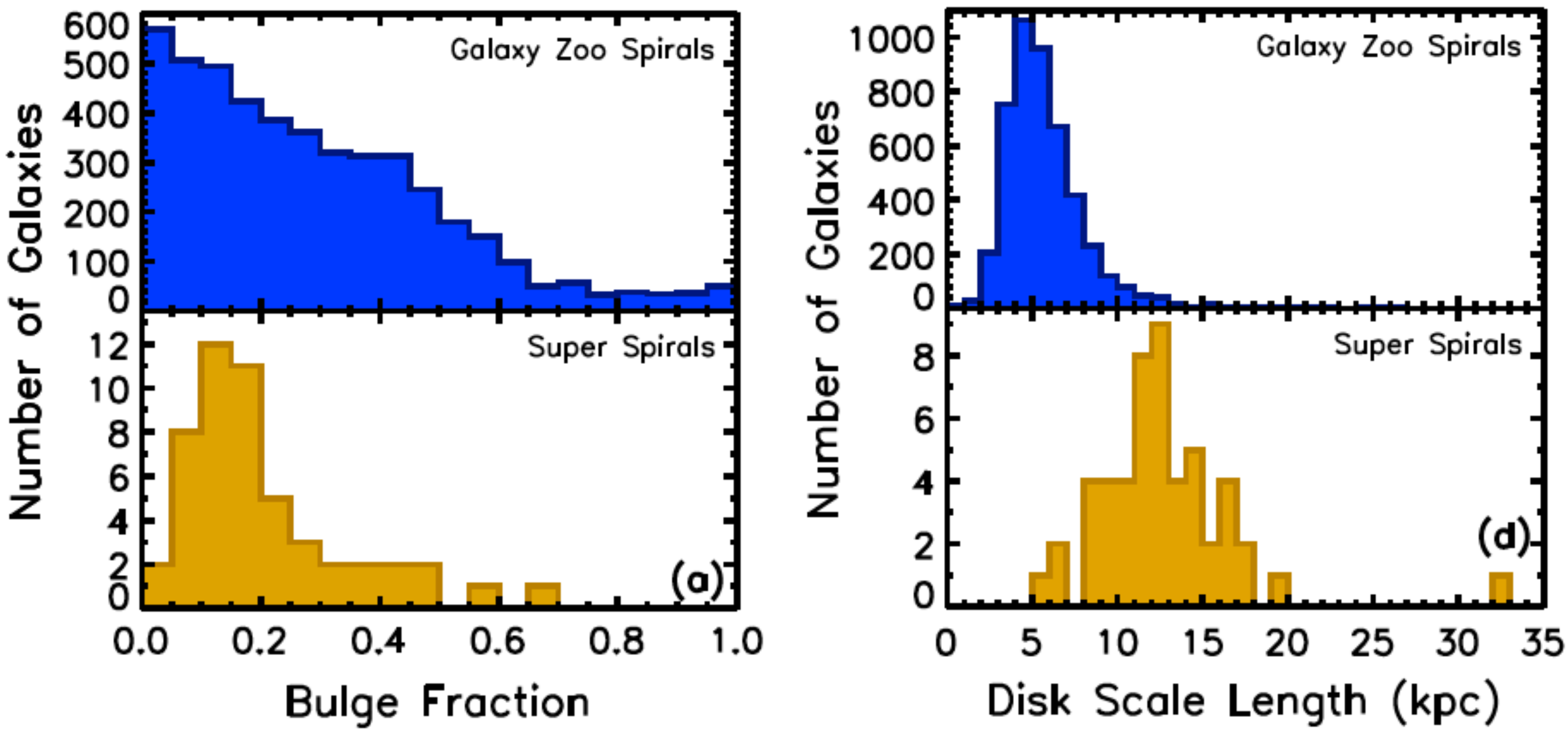
# SFR and sSFR (=SFR/$M_{star}$)

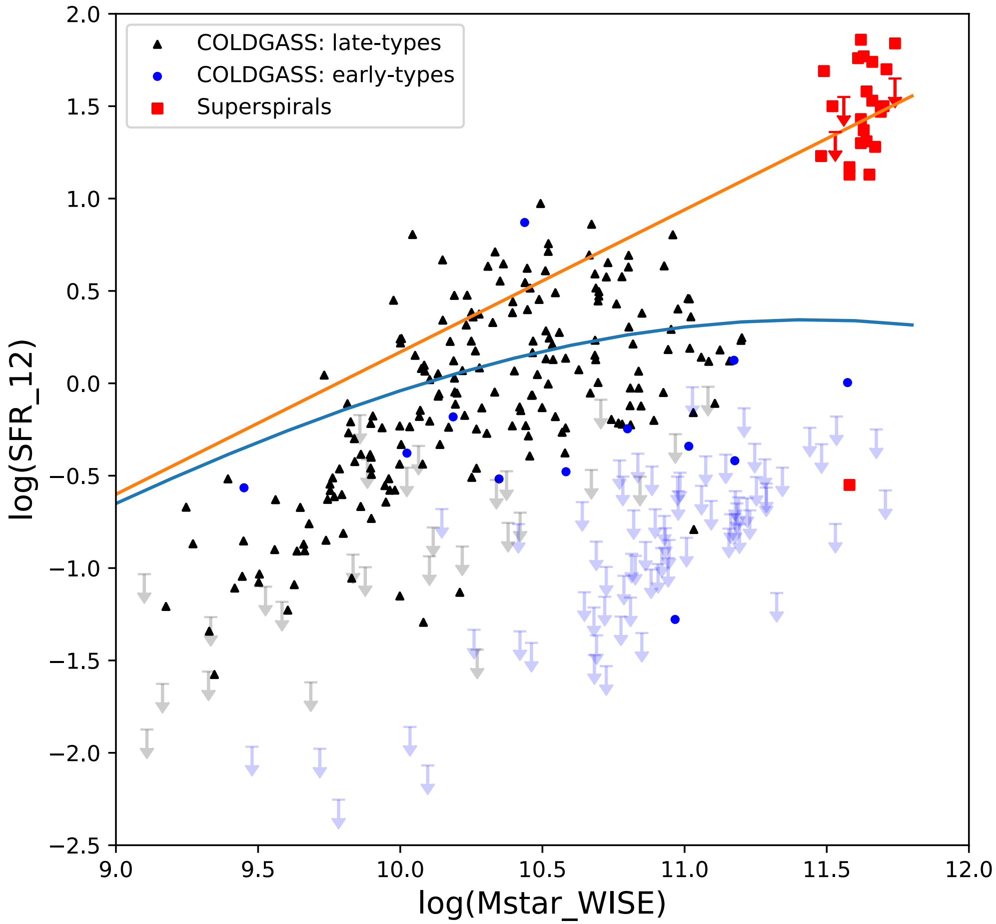



Superspirals are massive, unquenched galaxies (with a sufficiently large molecular gas content for active star formation)

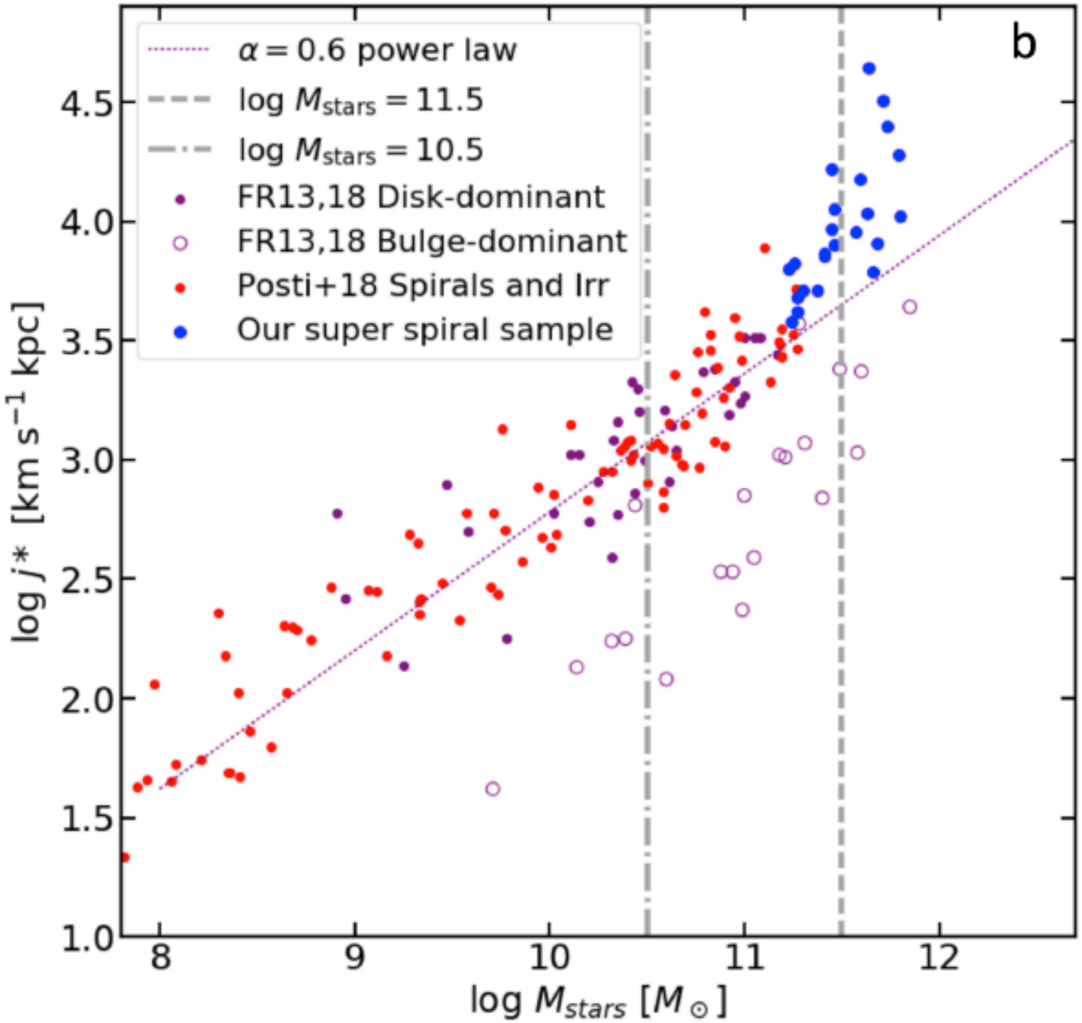
# Properties of superspirals





COLDGASS: late-types
COLDGASS: early-types
Superspirals
log(SFR_12)
log(Mstar_WISE)
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0

# Fall relation




Ogle+2019b