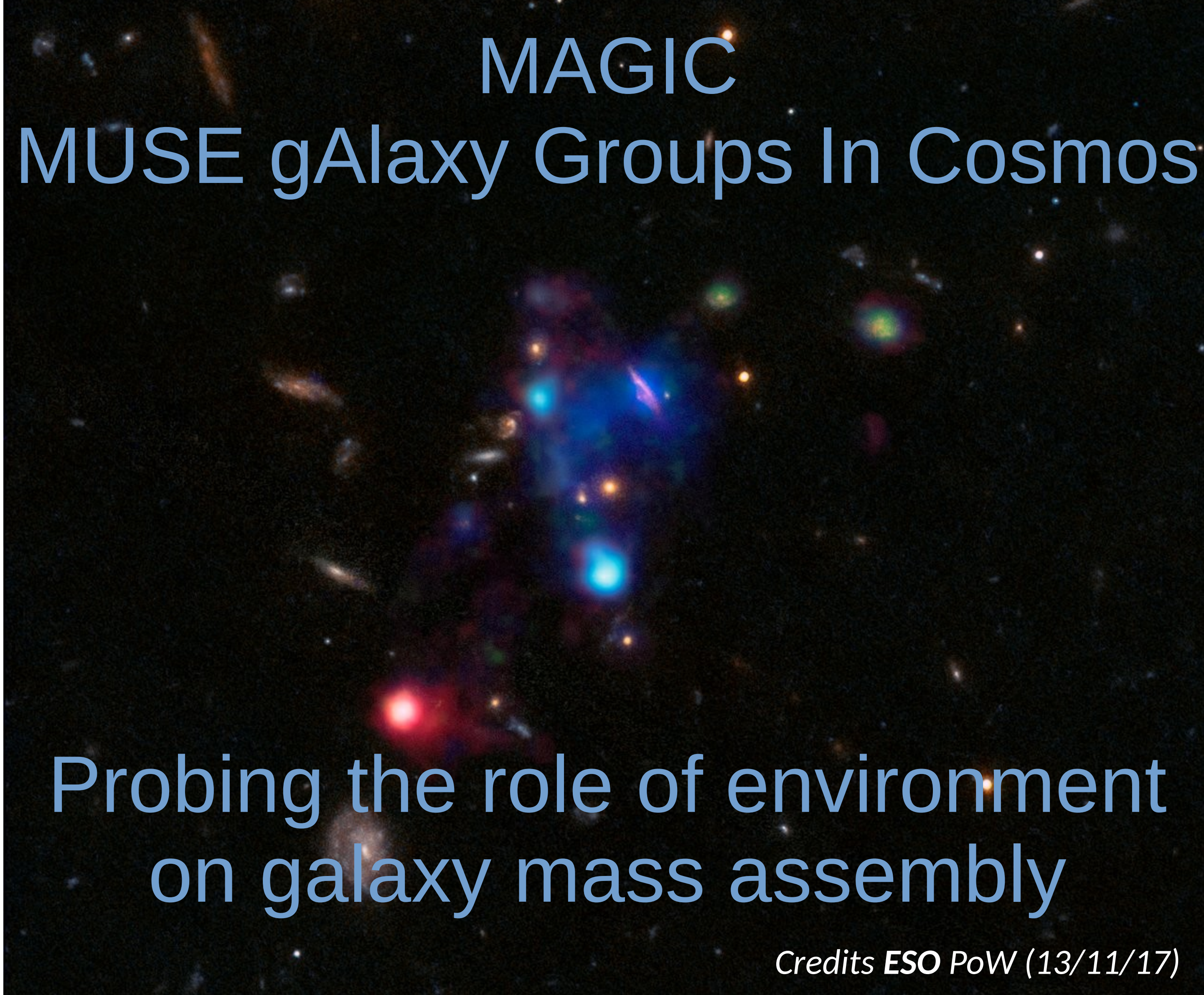
MAGIC
MUSE gAlaxy Groups In Cosmos



Probing the role of environment on galaxy mass assembly

*Credits **ESO** PoW (13/11/17)*

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CFH
irap astrophysique & planétologie
muse multi unit spectroscopic explorer

Gemini Seminar - 05/02/2024

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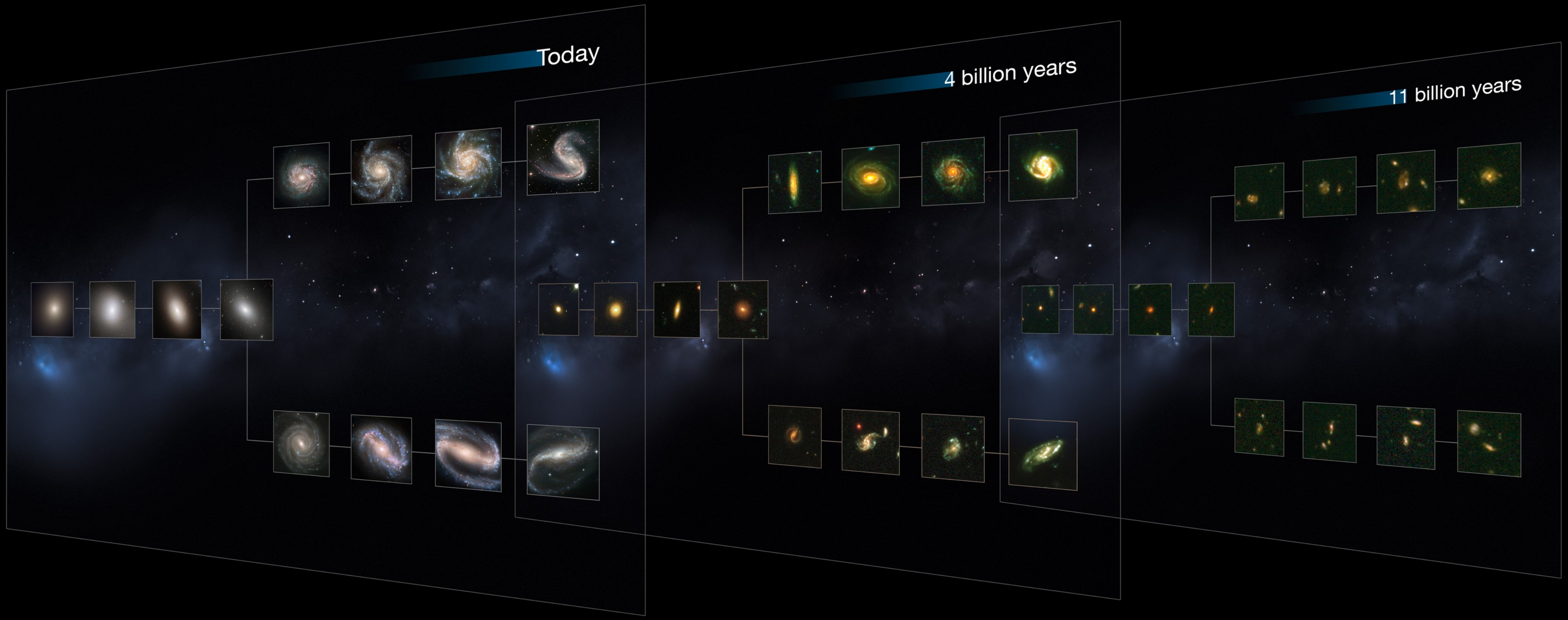
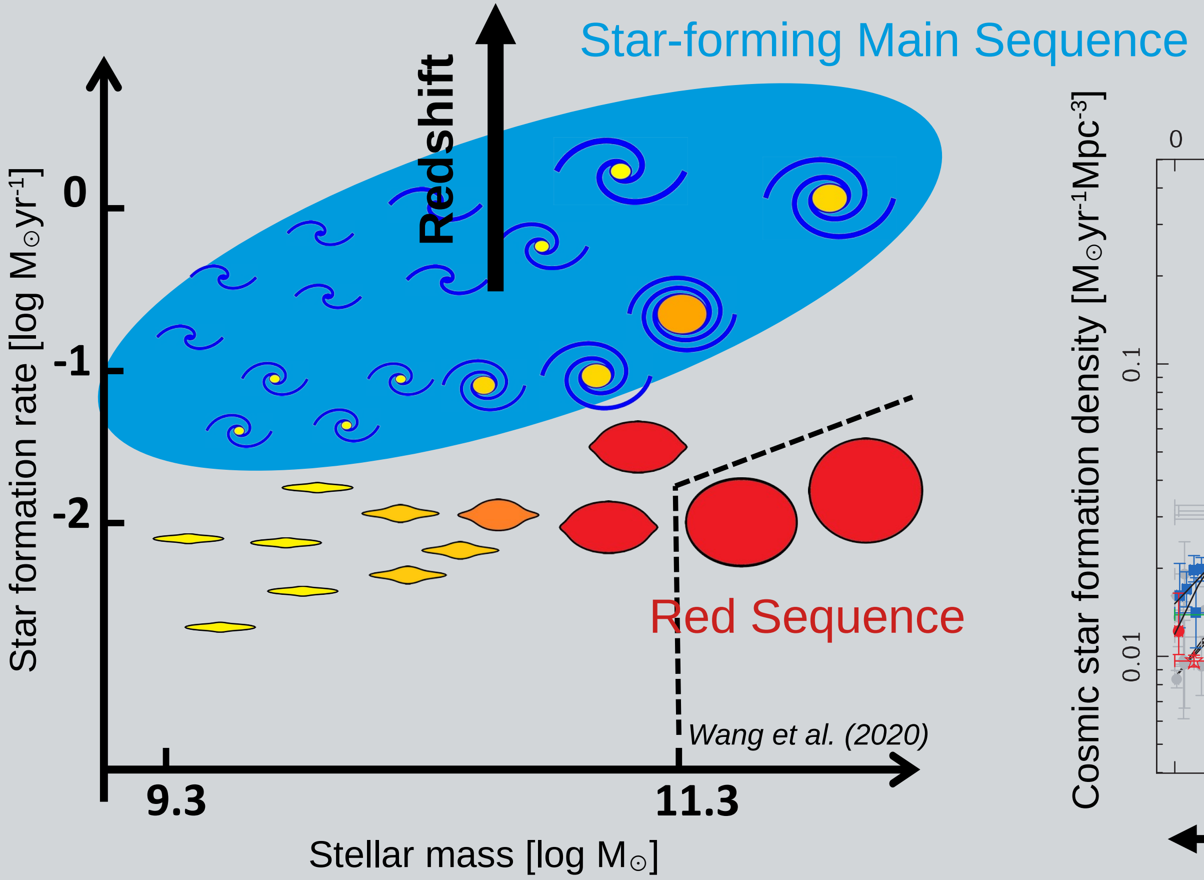
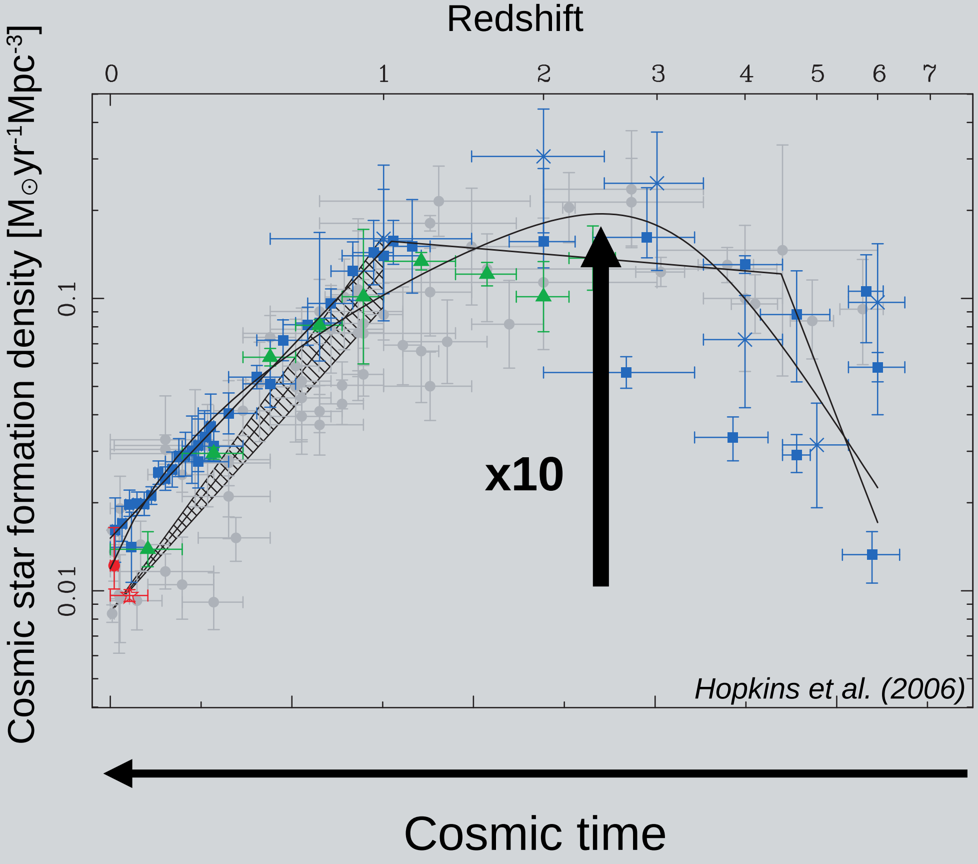
Galaxy evolution across cosmic time



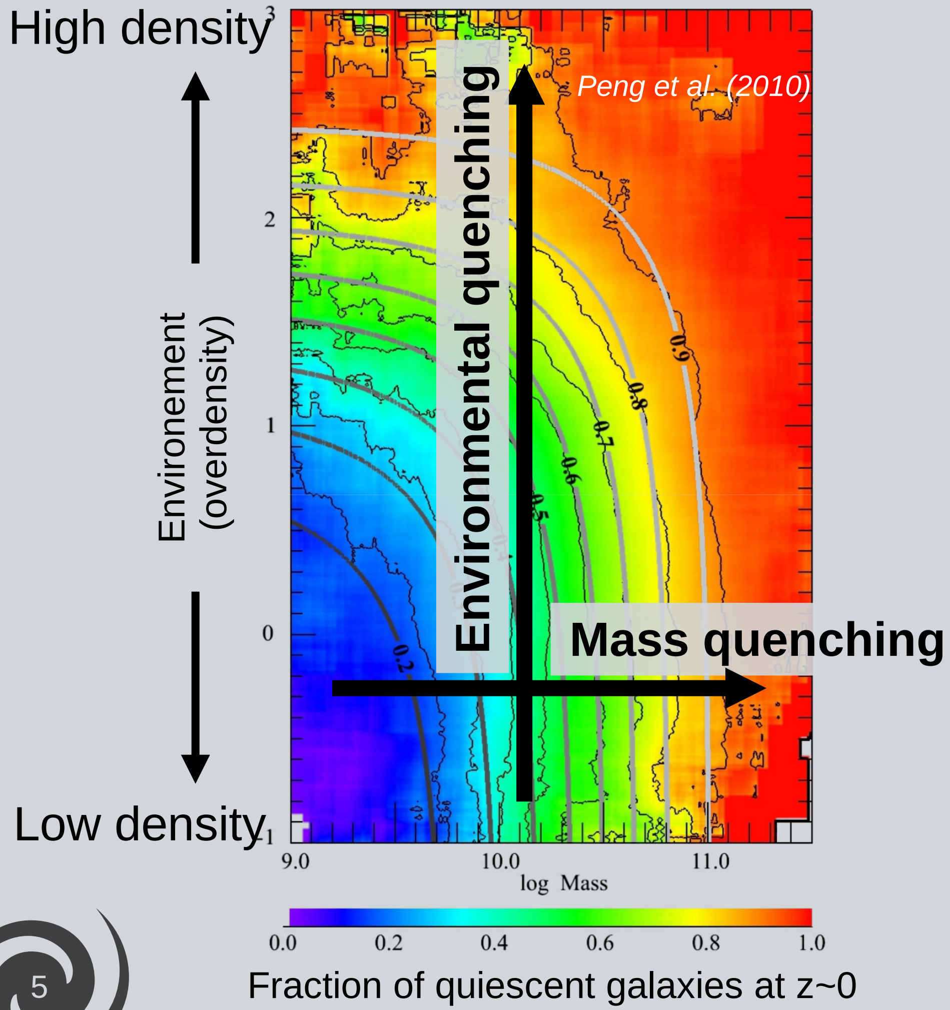
Credit: NASA, ESA, M. Kornmesser; the CANDELS team (H. Ferguson)

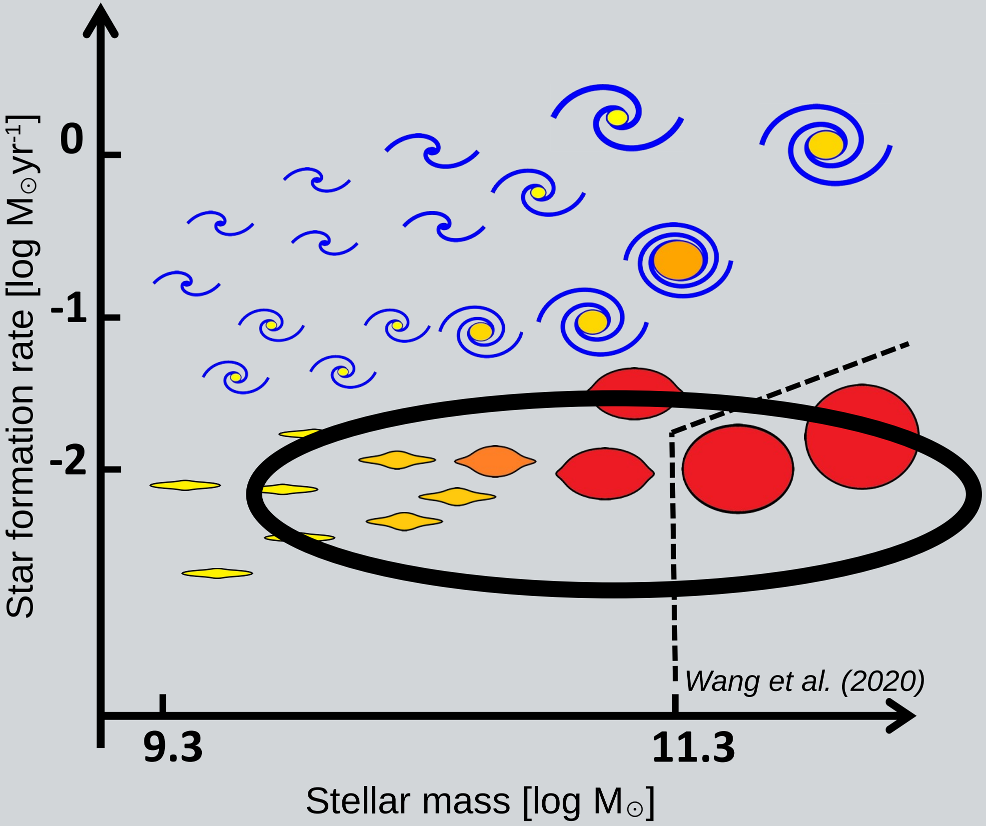
Galaxy evolution across cosmic time





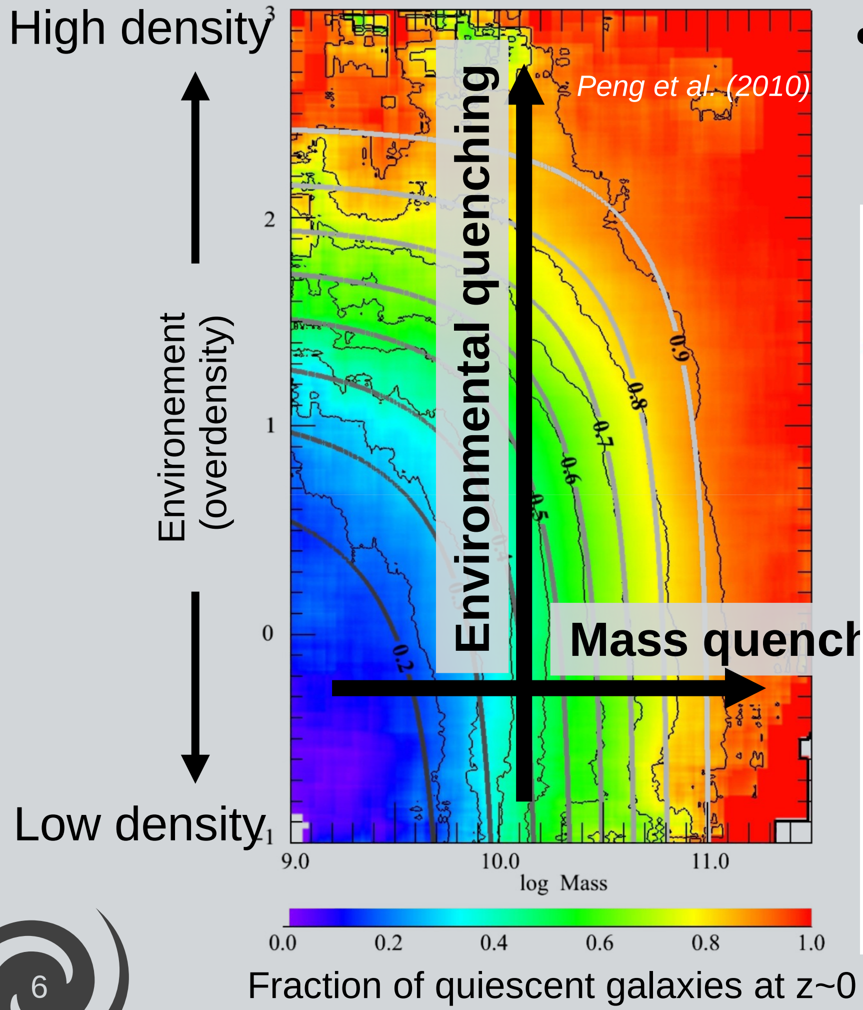
Environment vs. mass driven evolution ?



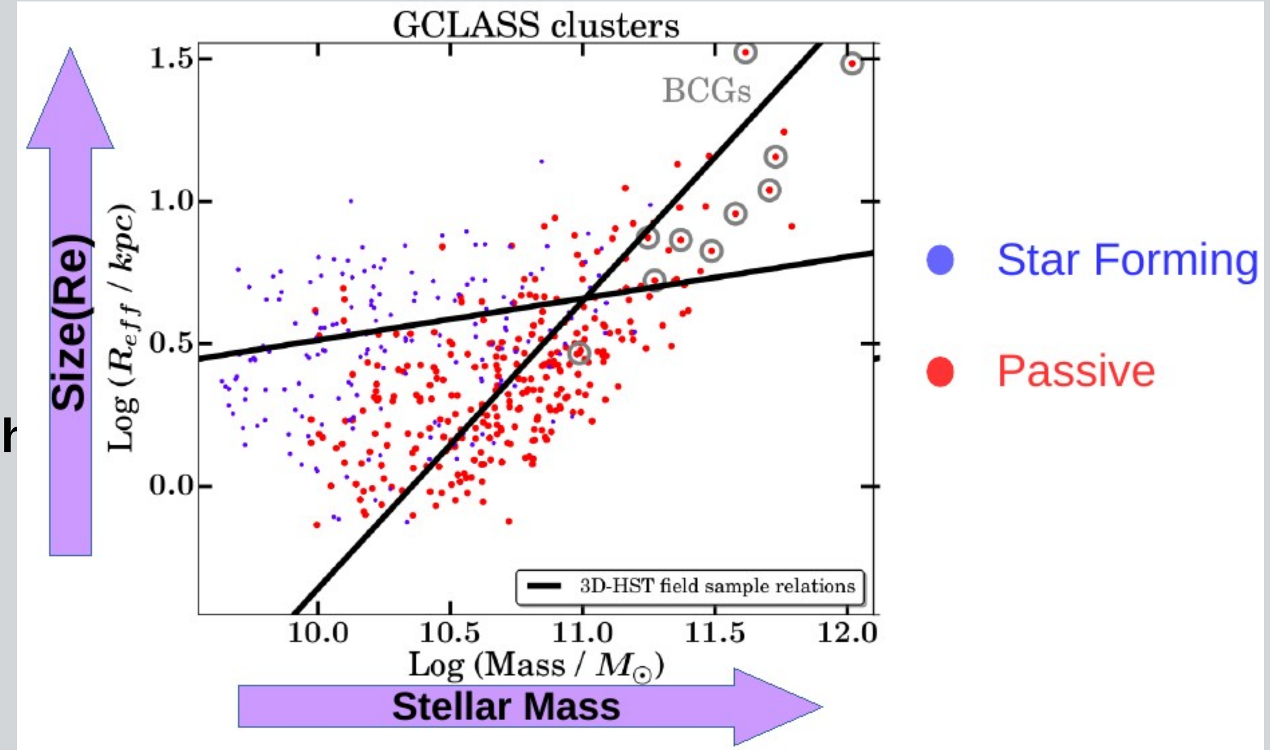


Environment vs. mass driven evolution ?

- Quenching of SF



- Contraction of baryons

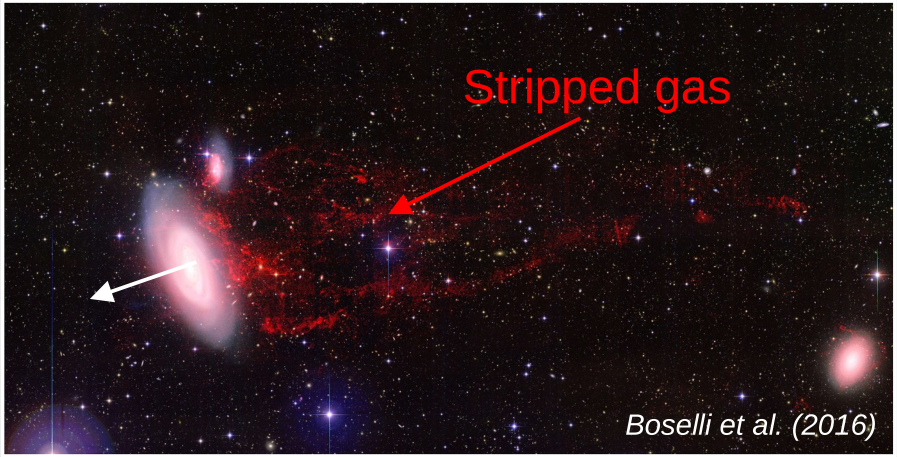


Environmental driven physical mechanisms

Hydrodynamical mechanisms

- Ram-pressure stripping
- Strangulation
- Evaporation

→ **Quenching of star formation**

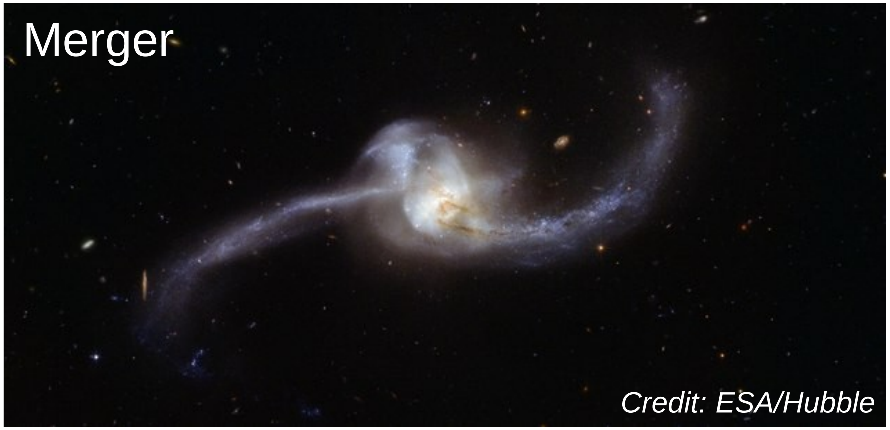


Boselli et al. (2016)

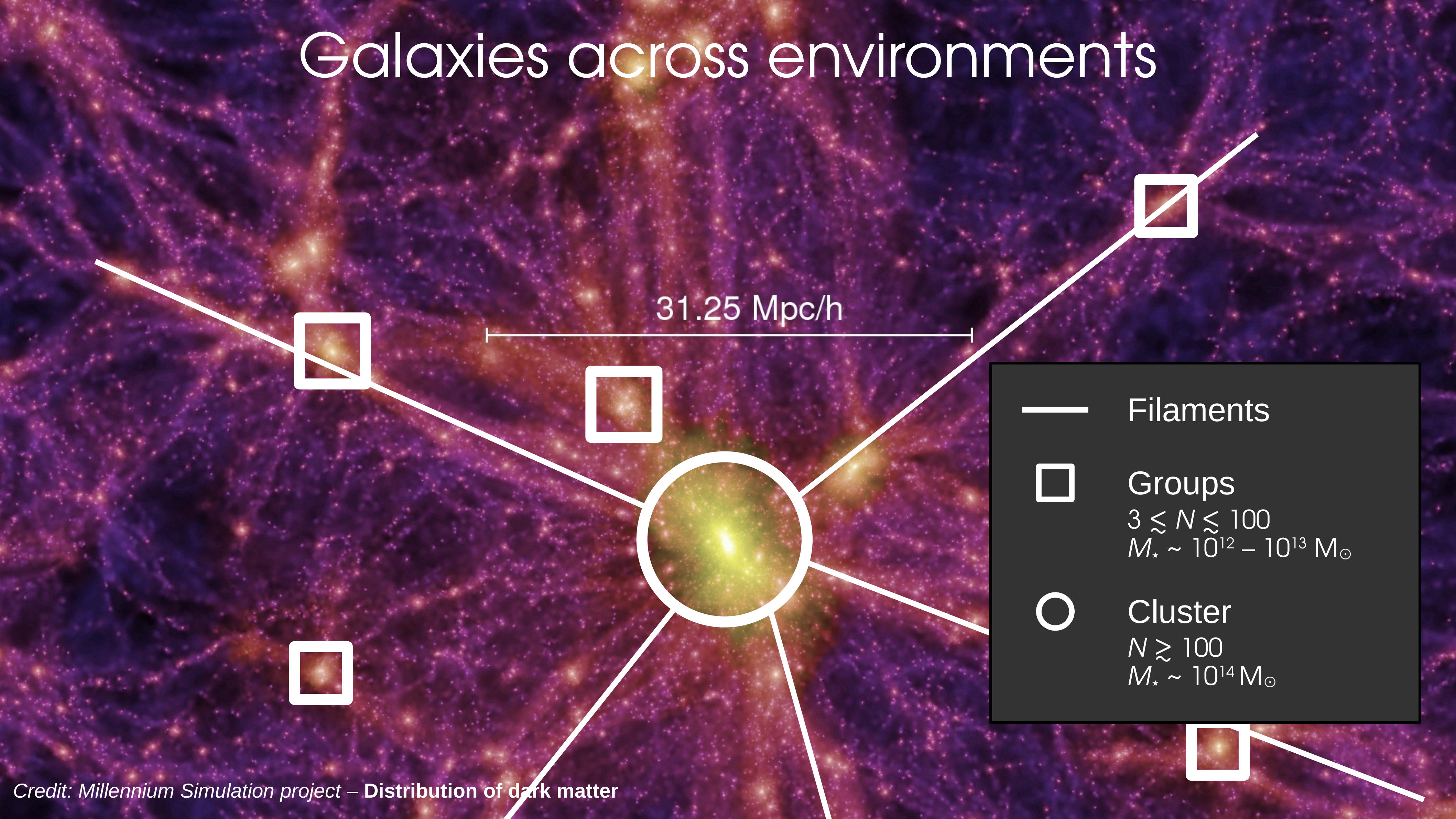
Gravitational mechanisms

- Galaxy-galaxy interaction
  incl. fly-by, mergers, harassment
- Galaxy-cluster interaction

→ **Impact morphology & kinematics**



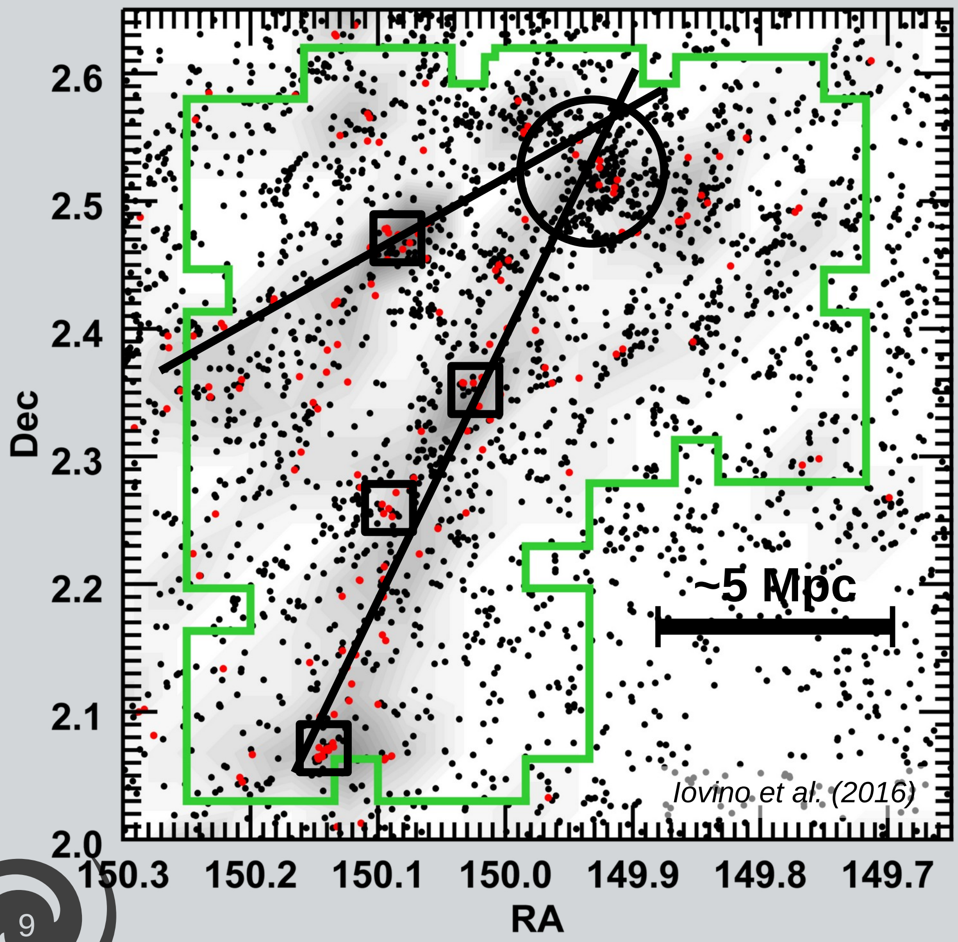
Credit: ESA/Hubble

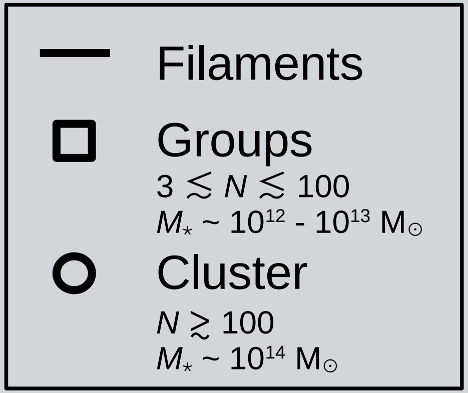


Credit: Millennium Simulation project – **Distribution of dark matter**

Galaxies across environments

COSMOS-Wall structure (z~0.7)





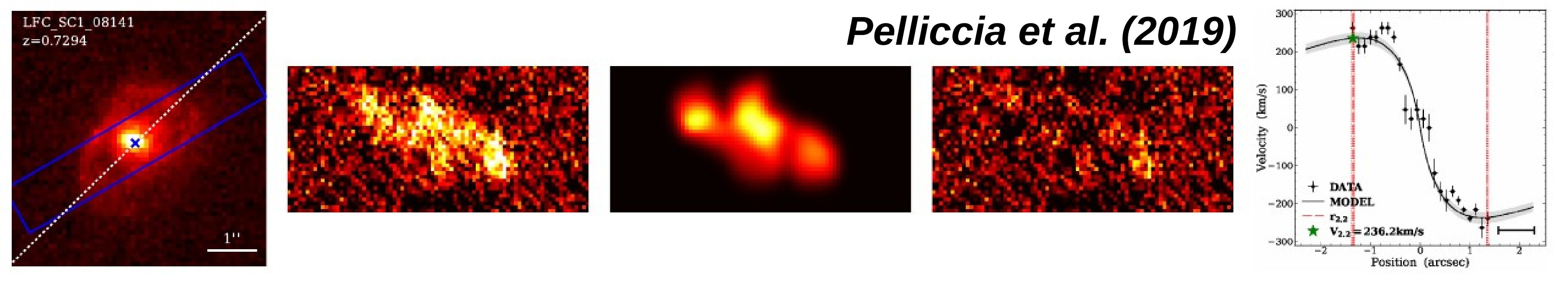
Around z ~ 1:

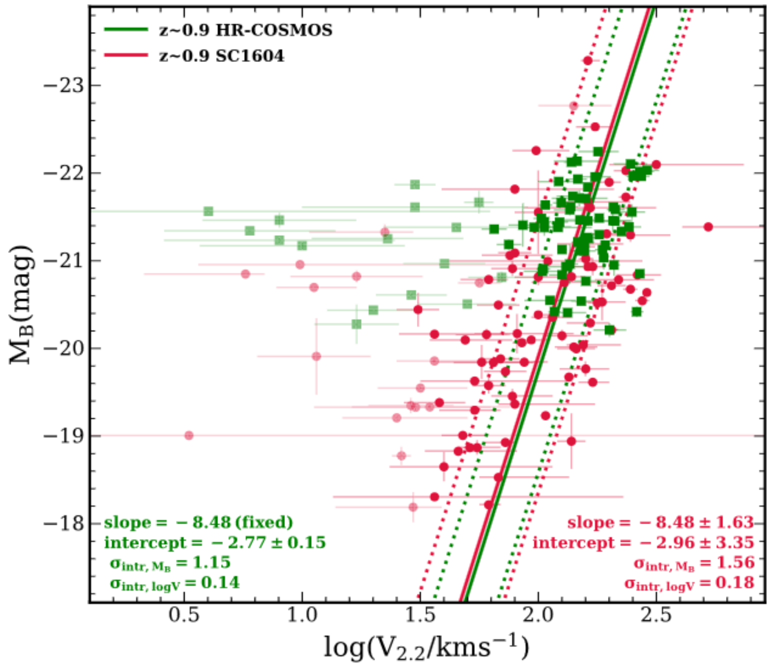
- clusters still assembling their mass (proto-clusters and pre-processing)
- structures virialize
- right after the peak of star formation

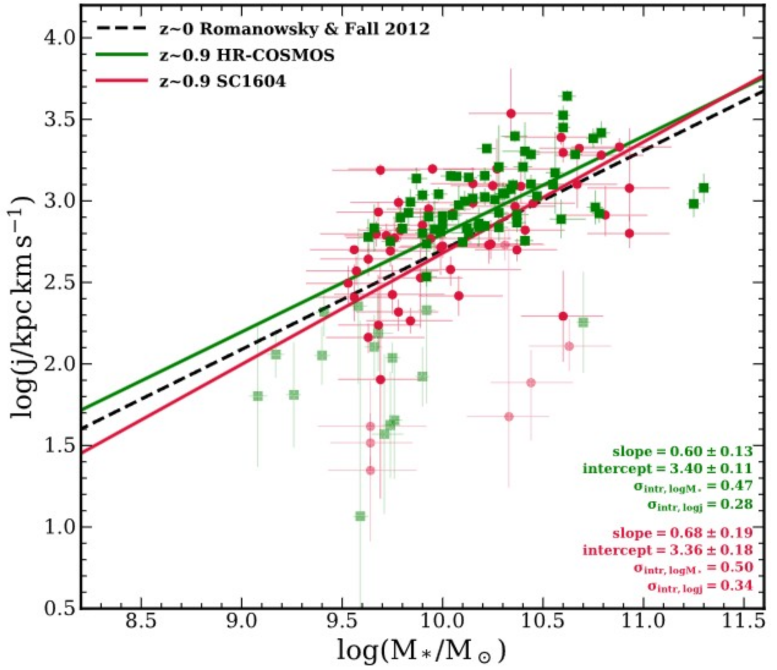
→ **intermediate redshift is ideal to probe the environmental impact on galaxy evolution**

Impact of environment on galaxy kinematics

Pelliccia et al. (2019)





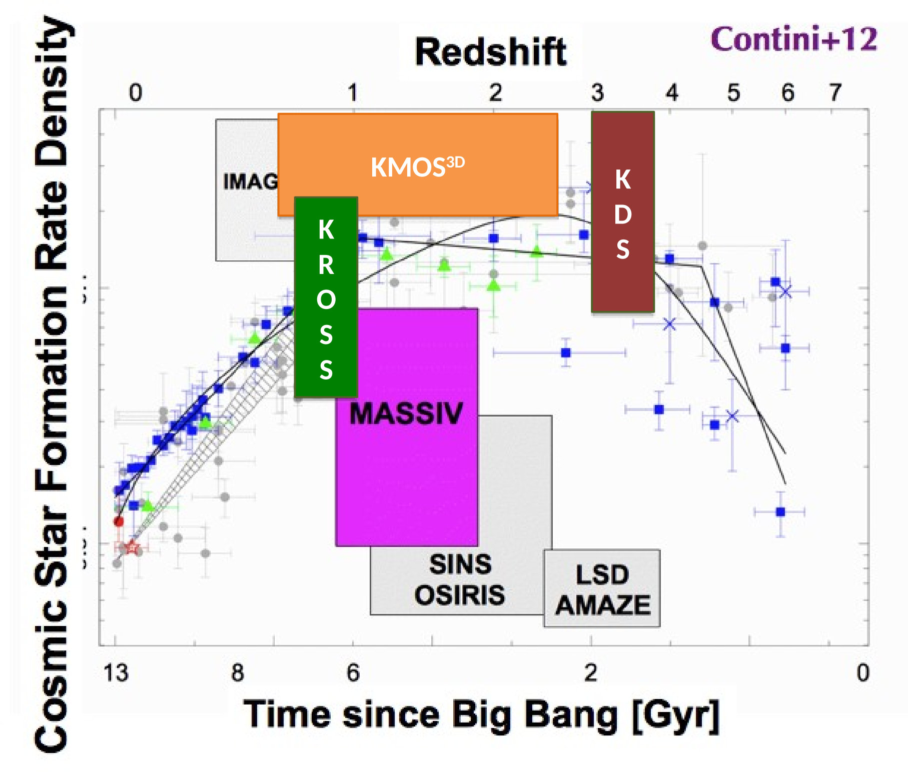


Goals of the MAGIC survey

1. Impact of environment on scaling relations @ z~1
   - SFR-mass (Main sequence)
   - size-mass
   - mass-rotation velocity (Tully-Fisher relation)
   - mass-angular momentum (Fall relation)

2. Minimize biases
   - low mass galaxies
   - good completion
   - comparable samples in various environments studied using a samilar methodology

3. Sensitive to intra-group/cluster medium



Large samples up to 800 galaxies
BUT

- Mainly massive (>10^{10} M_{sun}) star-forming galaxies
- Studies independent from environment (local & global)

2. Description of the MAGIC survey

Epinat et al. (2024)

The MUSE-gAlaxy Groups In Cosmos survey

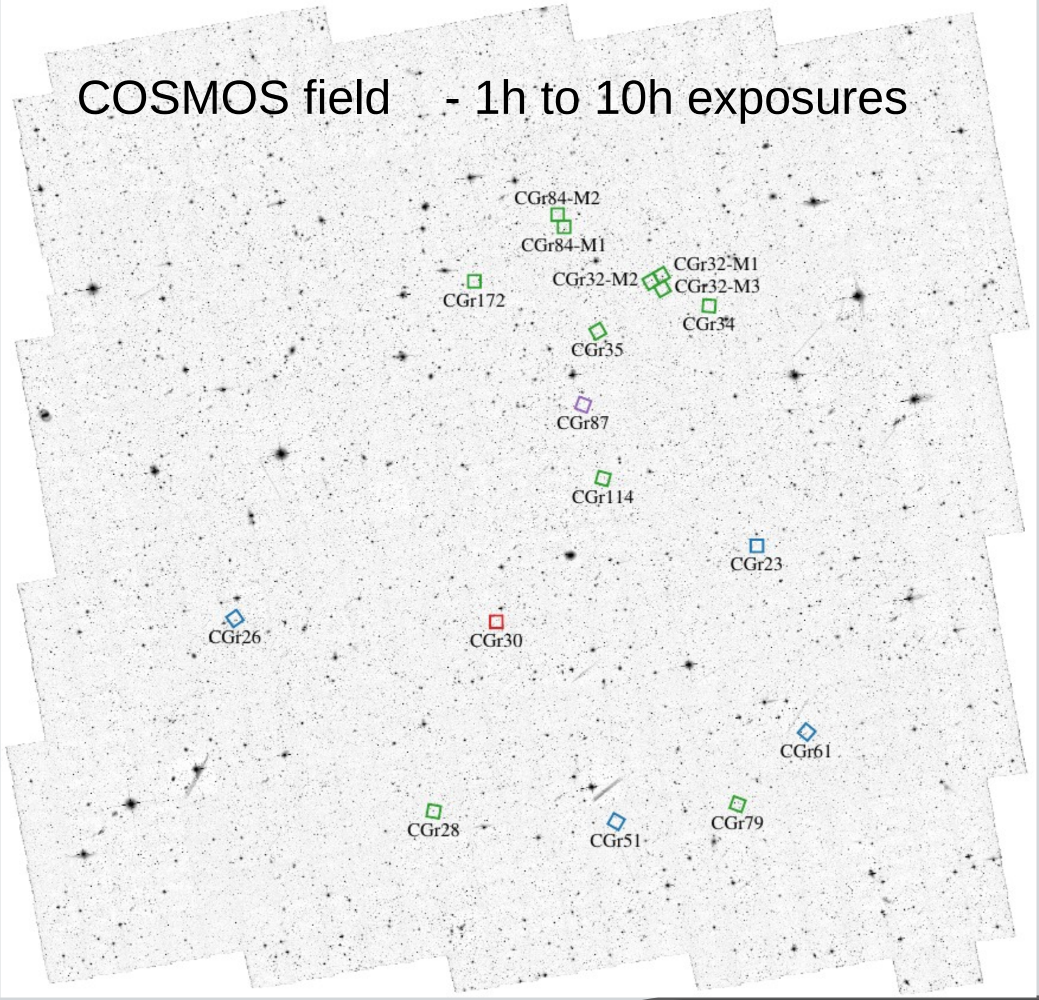
70 h on-source MUSE-GTO survey

14 targeted structures in COSMOS @ z~0.7

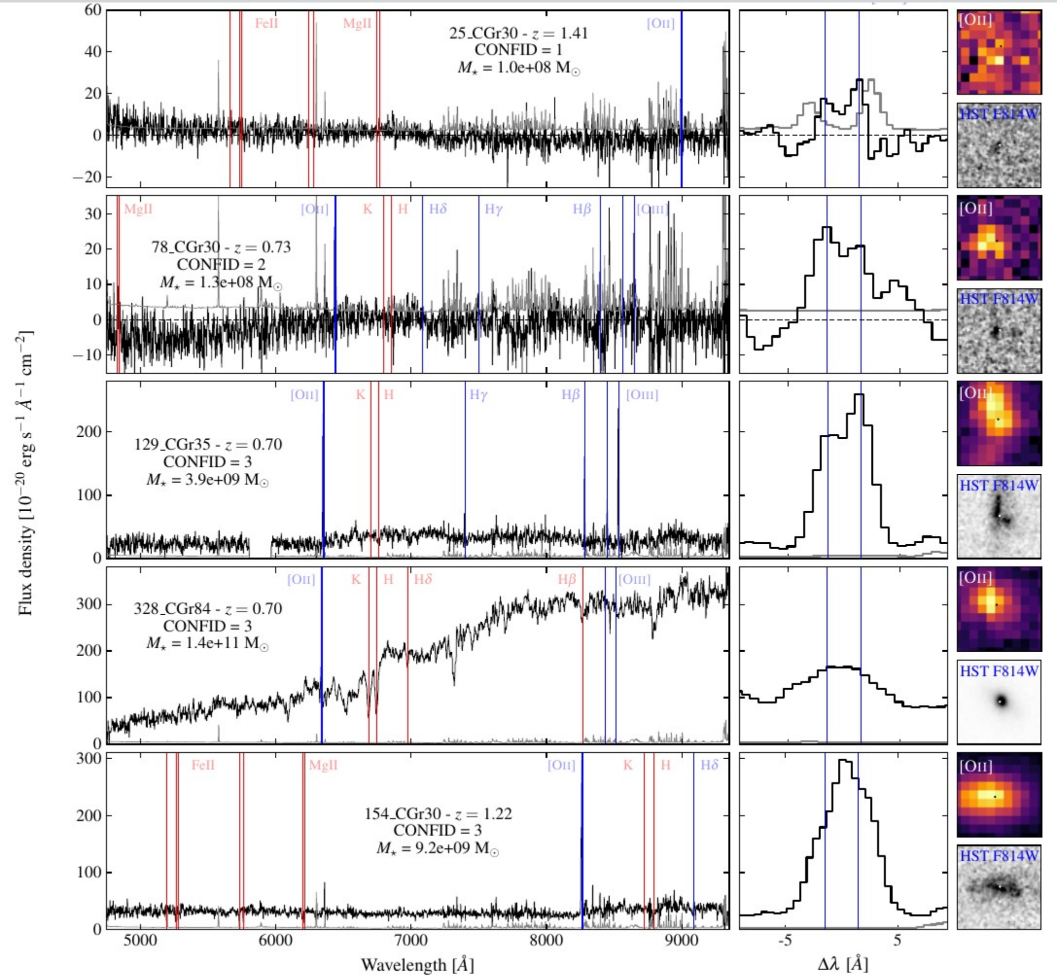
- → 17 MUSE fields
- → CGr32 = mosaic of three FoVs
- → CGr84 = mosaic of two FoVs

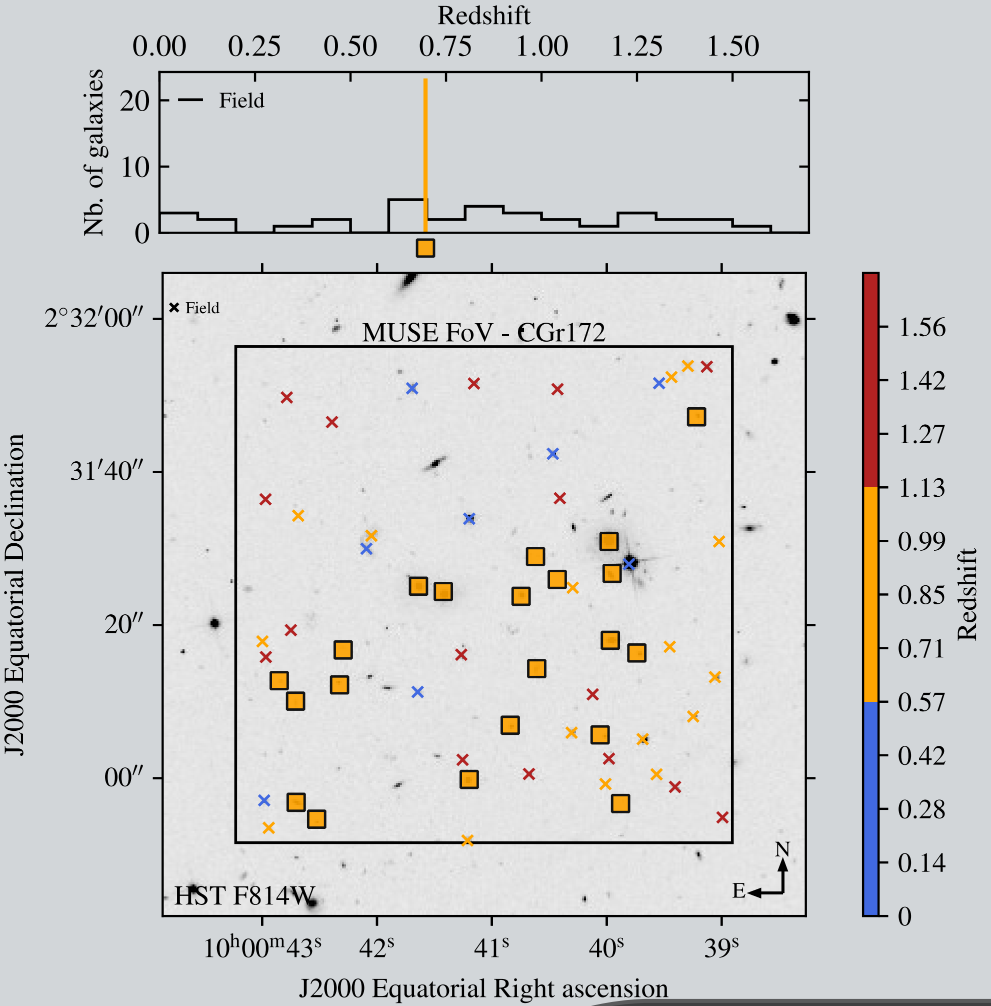
Extensive multi-band photometry (COSMOS2020 catalogue) → SED fitting

FoV: 1’x1’ → ~450 pkpc @ z=0.7
FWHM ~ 0.7’’ → ~5 pkpc @ z=0.7
R ~ 3000 → σ ~ 40 km/s

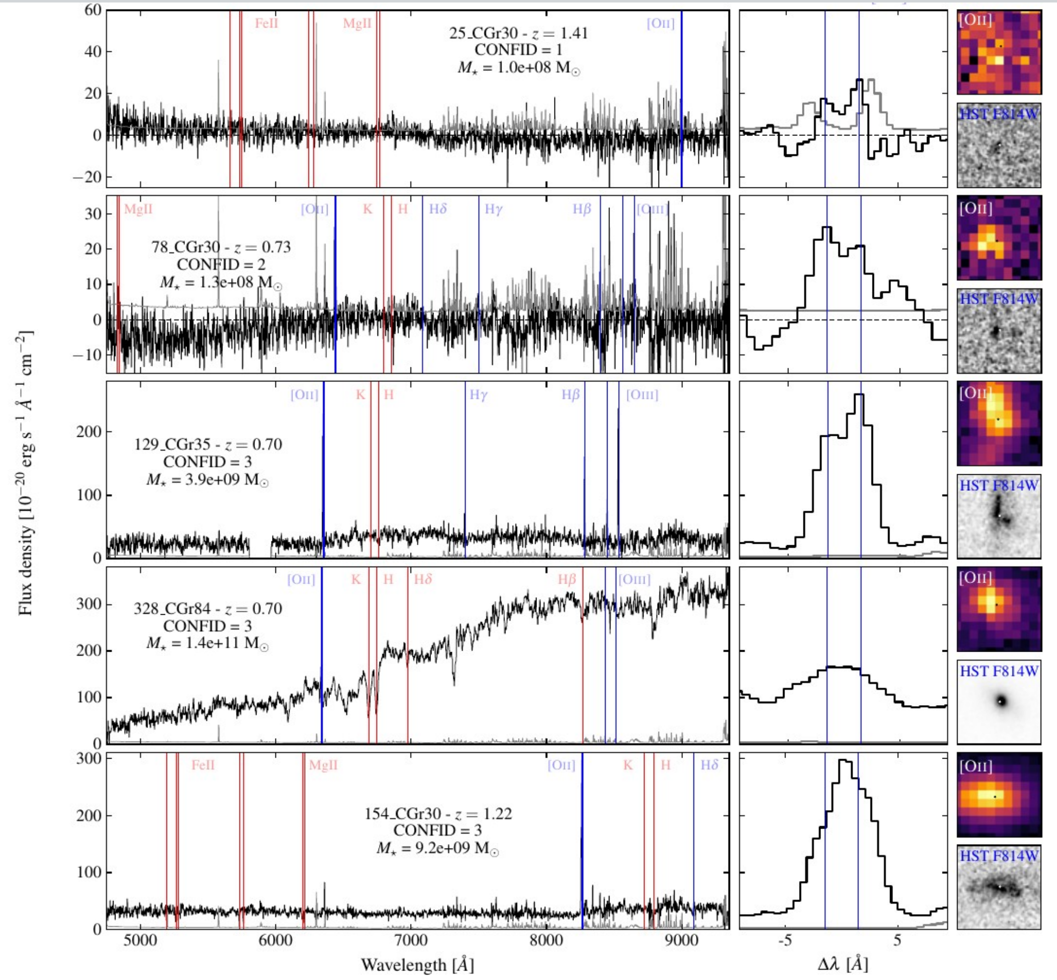


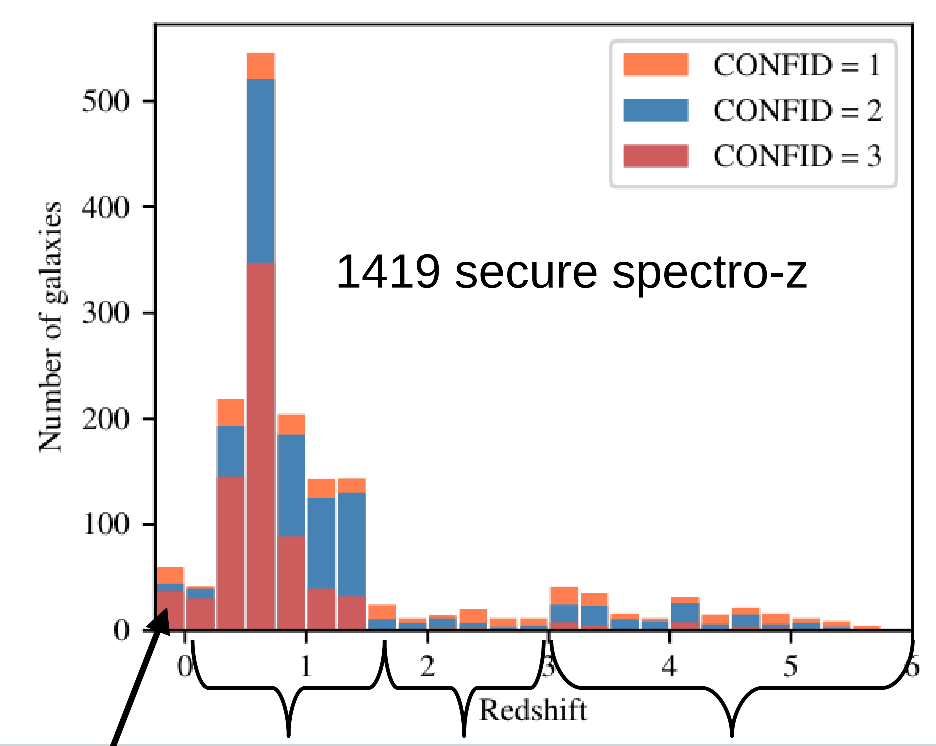
Redshift determination





Redshift determination





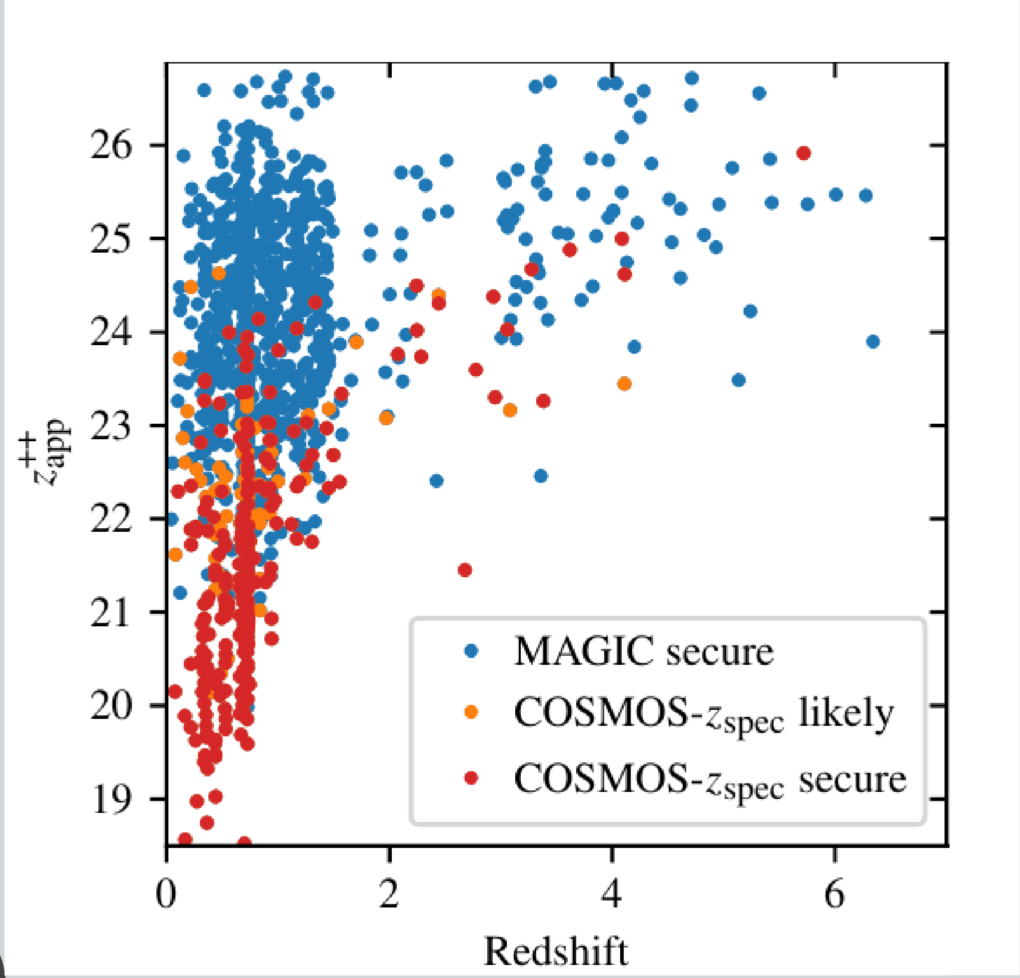
Stars

Nearby & [OII] emitters

Redshift desert

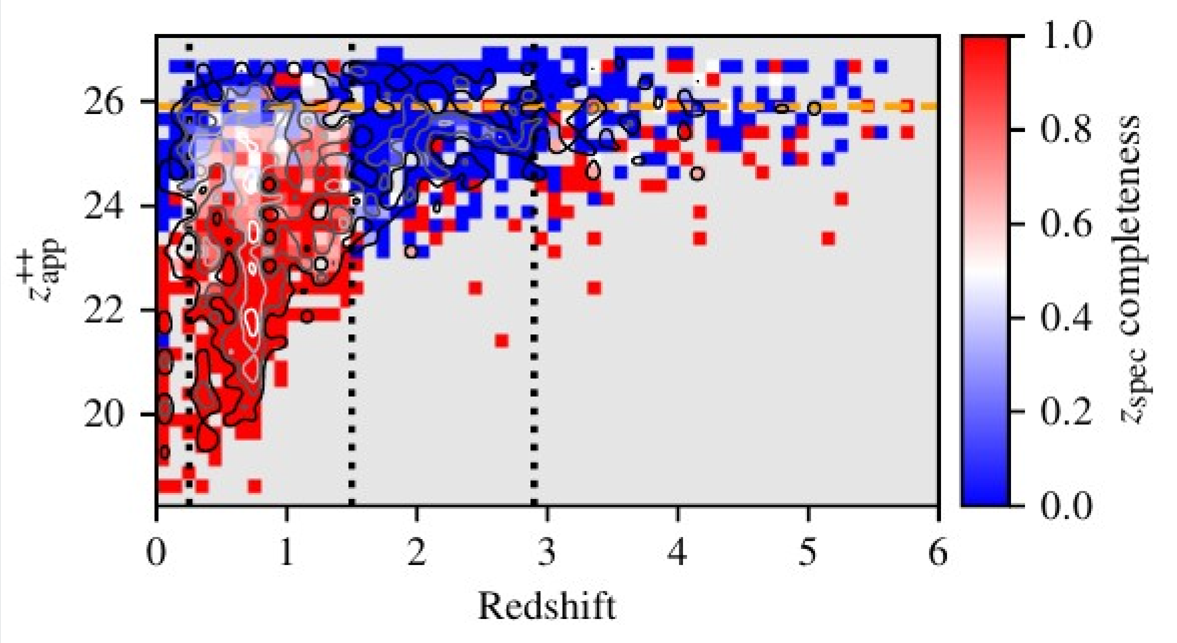
Lyα emitters

Increased density of redshifts



- 1419 secure spectro-z
- Increase by a factor 5
- Magnitude >21.5 galaxies not well sampled previously

MAGIC sample completeness



For 0.25<z<1.5 ([OII] emitters):

- Globally >80% for $z^{++}<25.9$
- Locally >50% for $z^{++}<25.5$

- Locally >90% down to log(M*) = 10
- Locally >70% down to log(M*) = 9
- Locally >60% down to log(M*) = 8

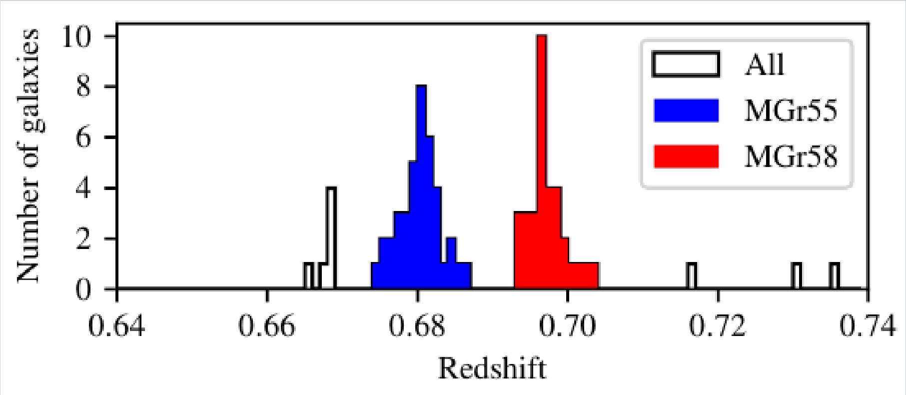
→ Good completeness achieved for the new faint galaxies

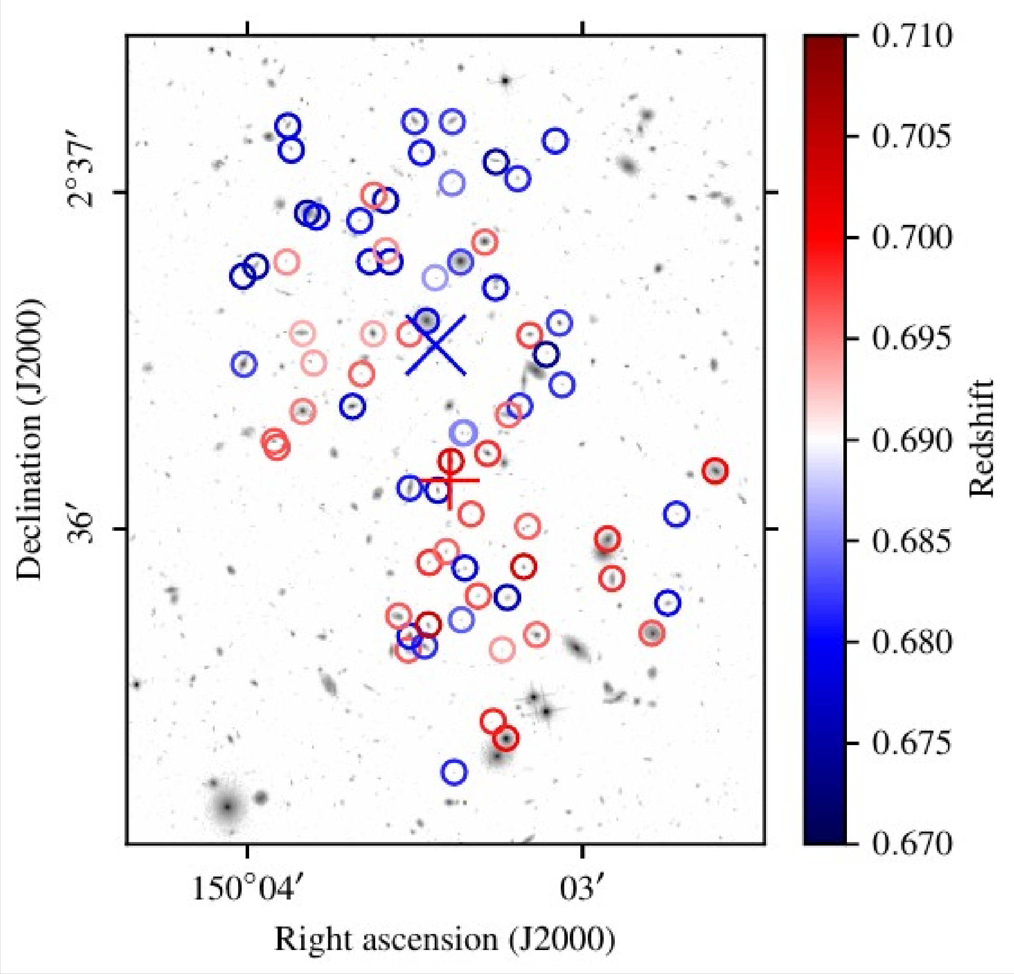
Friends-of-friends group finding algorithm

Constraints on both:

- Angular separation
  → Δr < 375 – 225 pkpc
- Redshift separation
  → Δv < 500 – 300 km/s

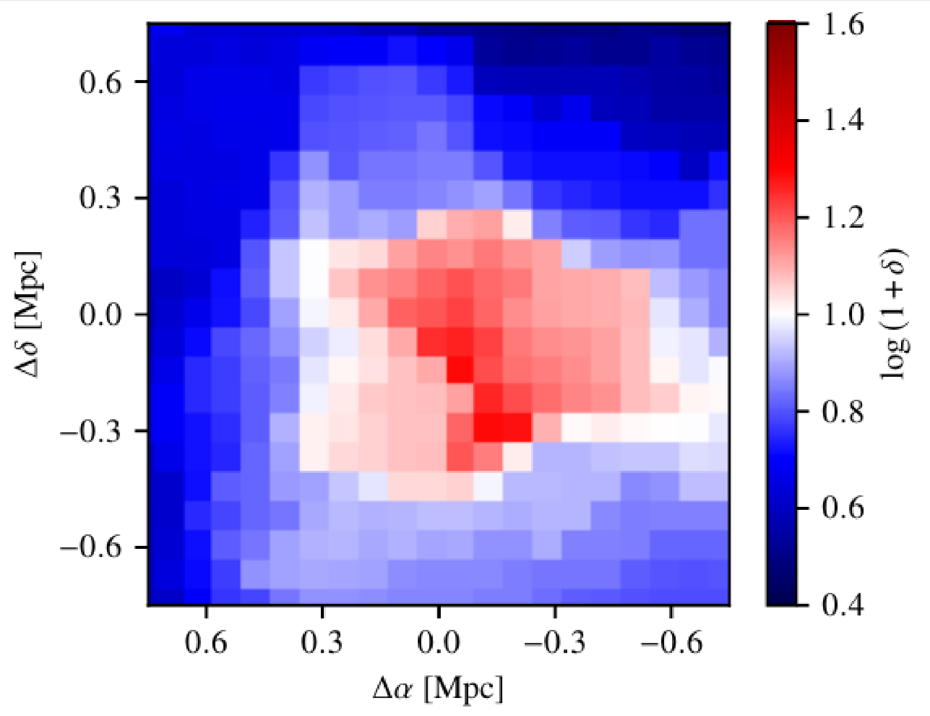
Limits depend on group richness





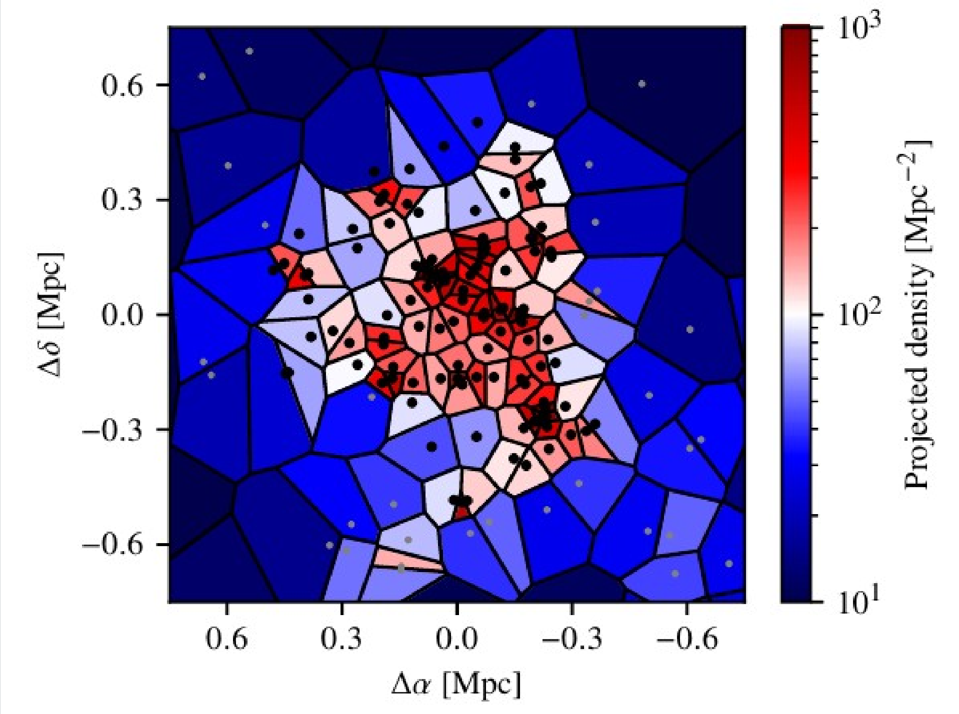
Local environment estimates

Voronoi Monte Carlo (VMC, *Lemaux+22*)



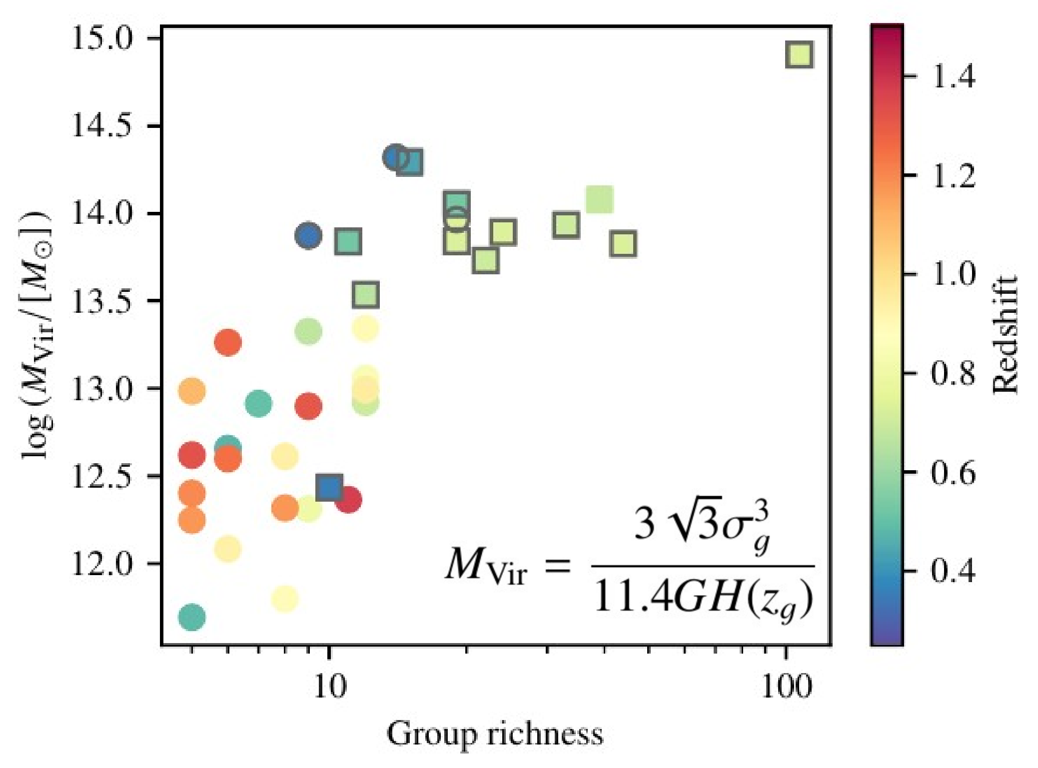
- zCOSMOS spectro-z
  + COSMOS photo-z
- Homogeneous sampling

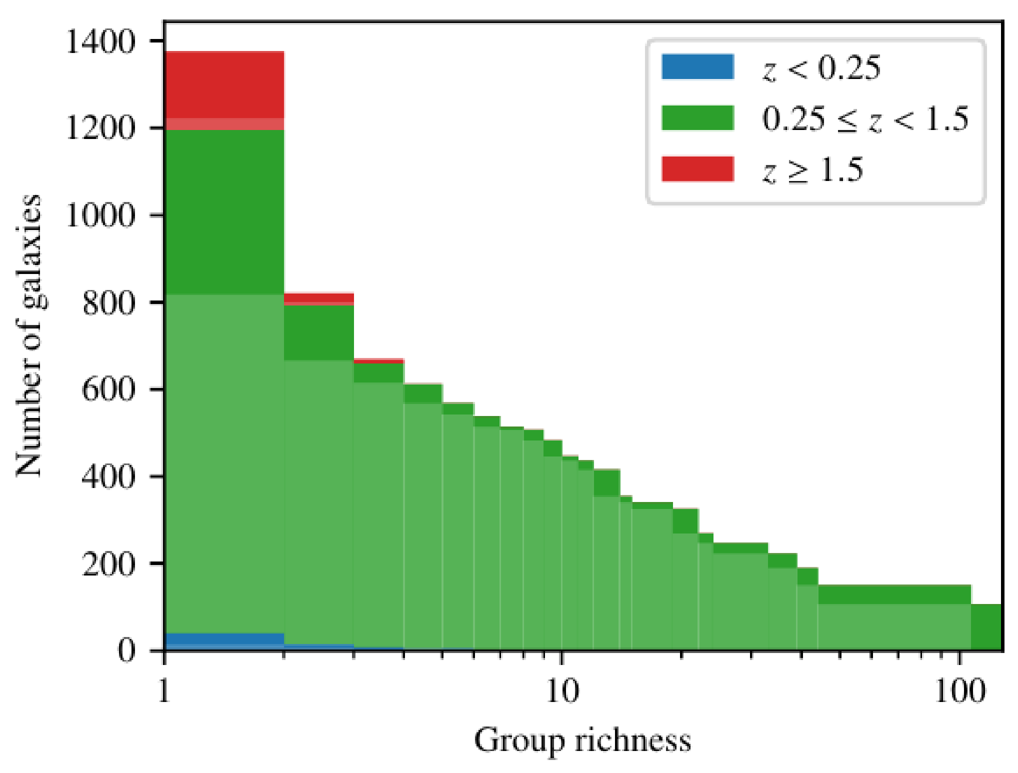
Simple Voronoi tesselations



- MUSE & zCOSMOS spectro-z
- Higher spatial resolution
- But edge effect

Group properties

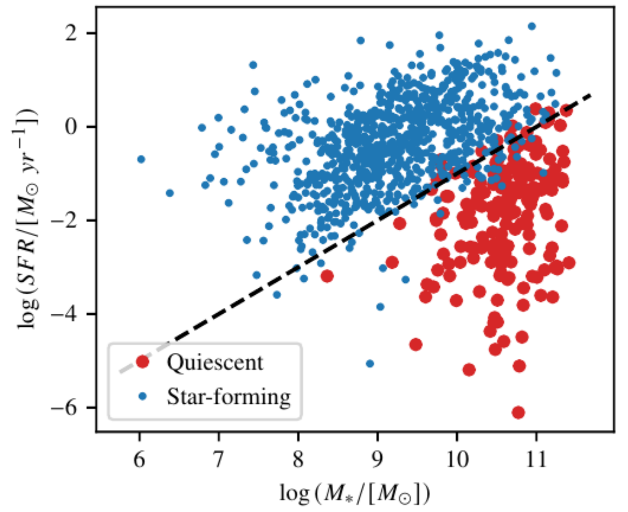




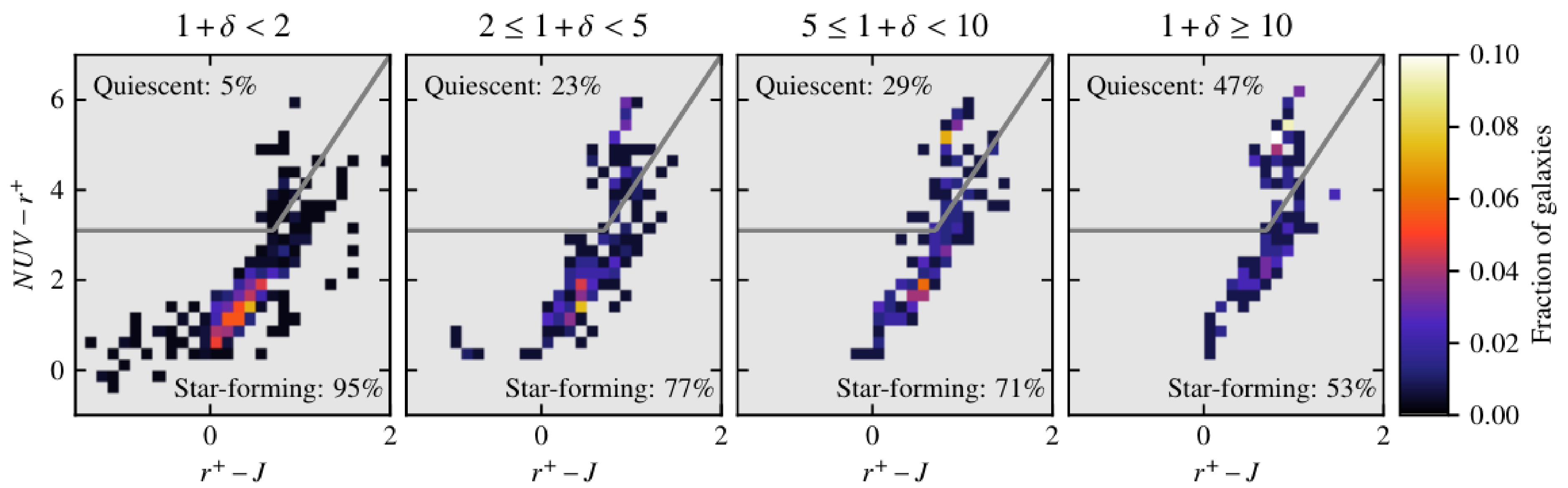
- Correlation between richness and mass
- The 14 targeted groups are among the most massive ones

- 76 pairs, 67 groups, 19 with 10+ members
- Most groups are at intermediate redshift
- Good galaxy statistics for various richness

Red sequence in MAGIC



Red sequence defined using rest-frame color-color diagram
→ colors inferred from SED fitting with CIGALE



Red fraction increases with local density, group mass, richness

Red sequence in MAGIC

Phase-space diagram: location within well defined groups (at least 5 galaxies)

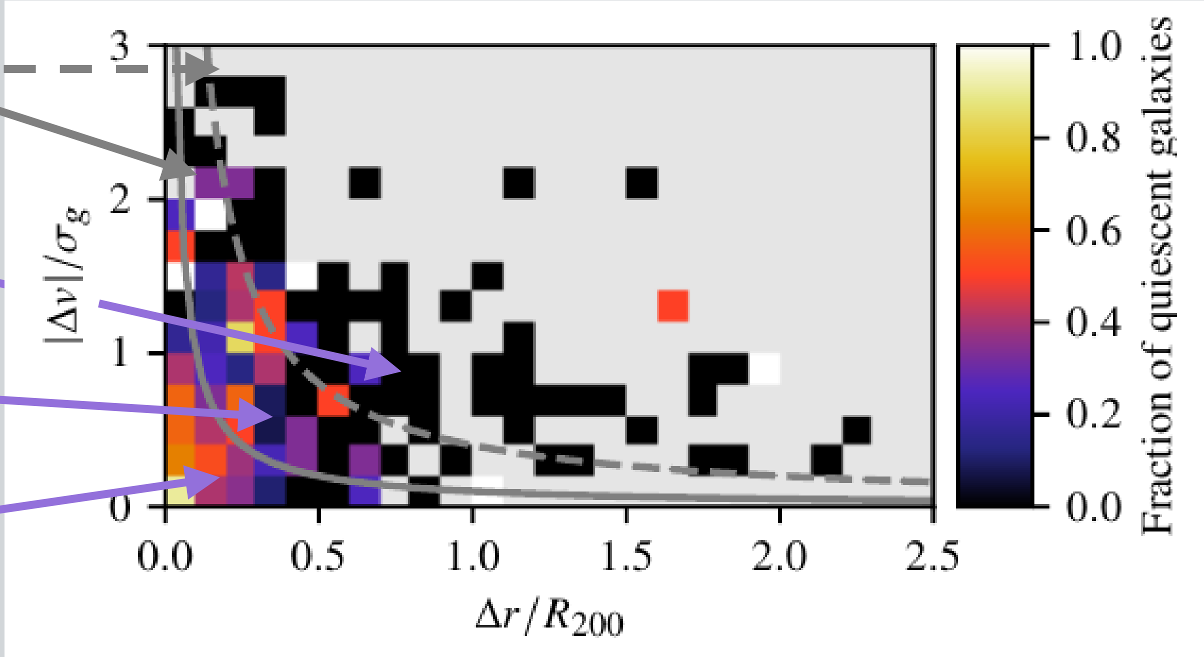
→ global environment, time spent in groups

Constant $\eta = \frac{|\Delta v|}{\sigma_g} \times \frac{\Delta r}{R_{200}}$

Infalling galaxies

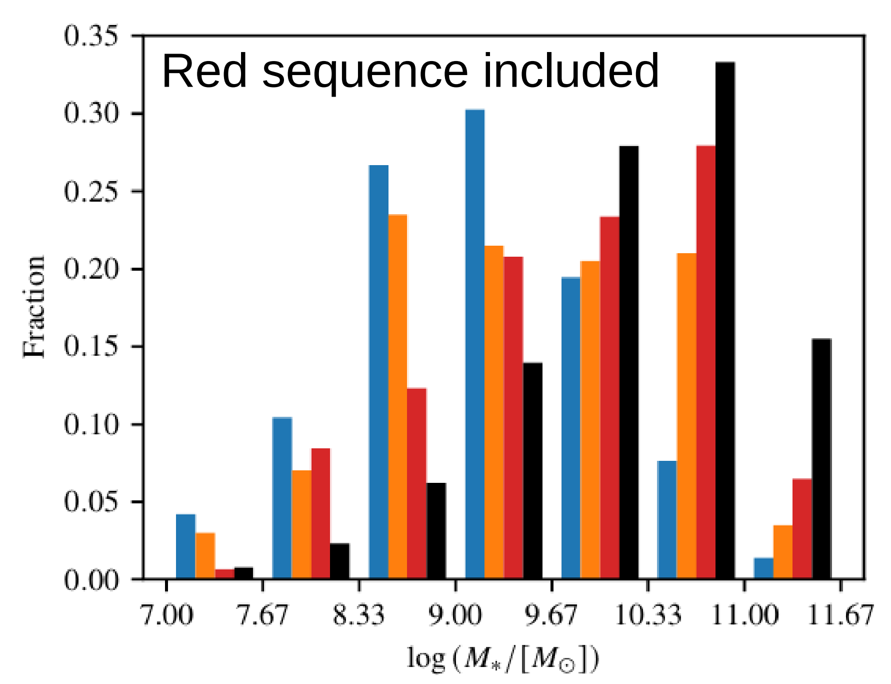
Backsplash galaxies

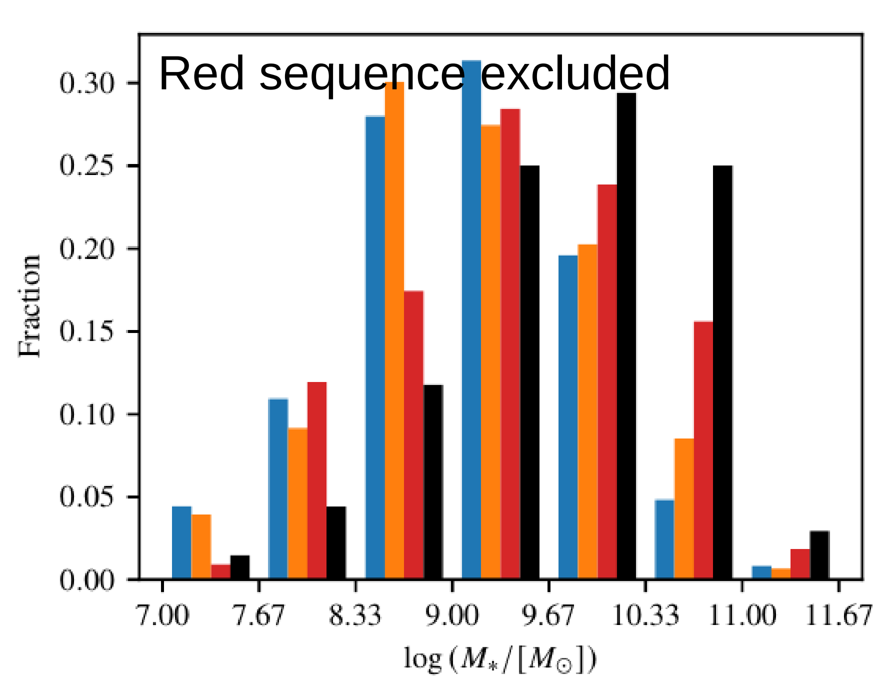
Galaxies accreted early



Red fraction also increases with time spent in structures

Galaxy properties



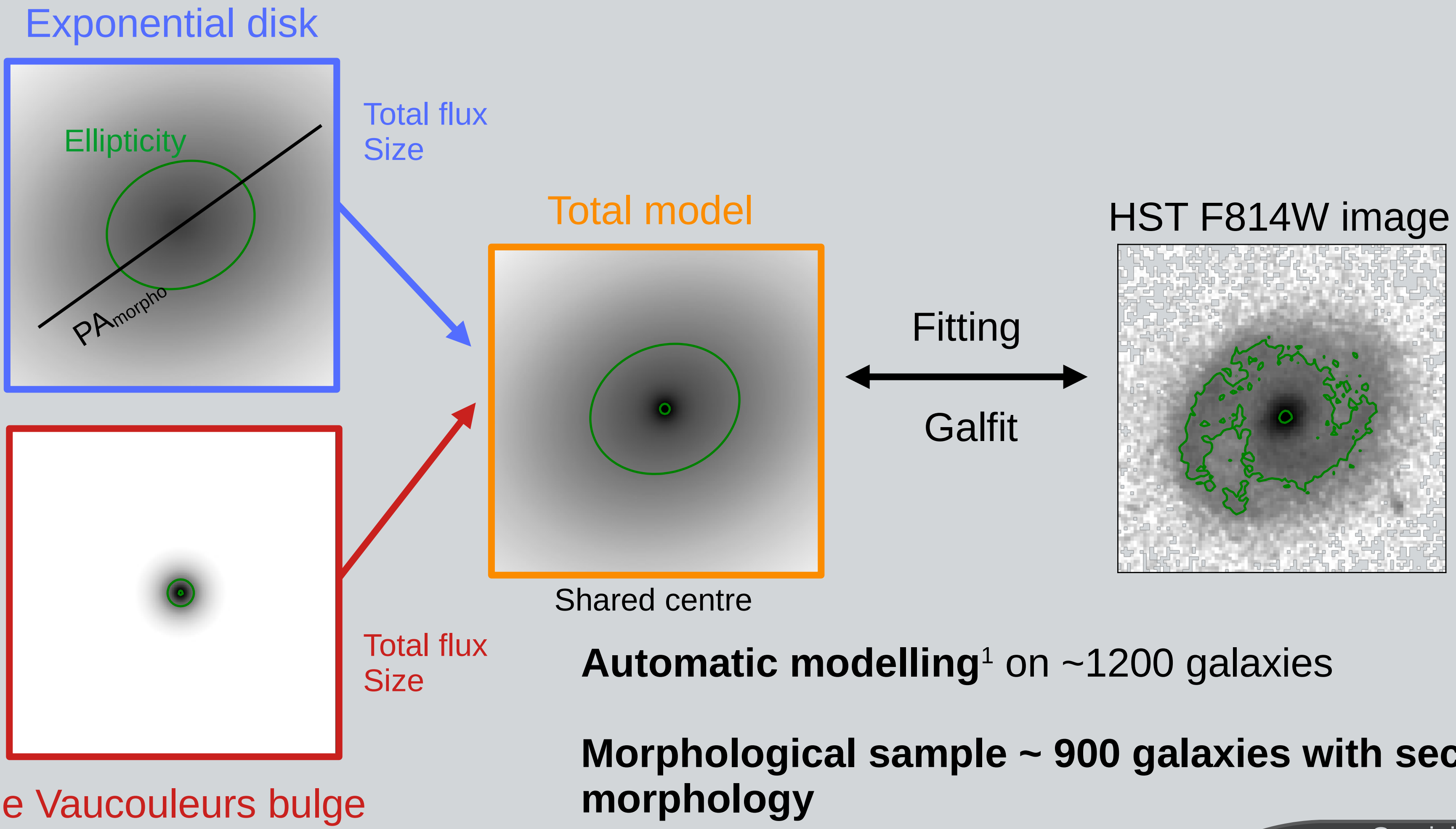


- Fraction of massive galaxies increases with density
- Few low mass galaxies in the densest environments
    - → Small galaxies merged to higher mass galaxies as density increases
    - → Pre-processing in groups of increasing mass

3. Impact of environment on scaling relations

Abril-Melgarejo et al. (2021)
Mercier et al. (2022)
Mercier et al. (2023)

Morphological decomposition

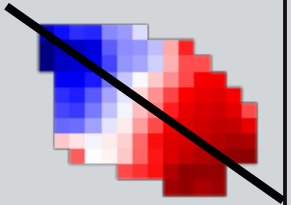


Automatic modelling[1] on ~1200 galaxies

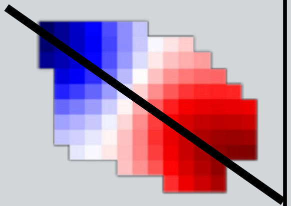
Morphological sample ~ 900 galaxies with secure morphology

Forward kinematics fitting

Velocity field



Best-fit model



Residuals

Free parameters

V_s, PA$_{kinematics}$
Rotation curve parameters

Fixed parameters

PSF parameters (FWHM + β for Moffat)

x_{cen}, y_{cen}, and inclination
Mass, radius, and thickness of the stellar disk
Mass and radius of the stellar bulge

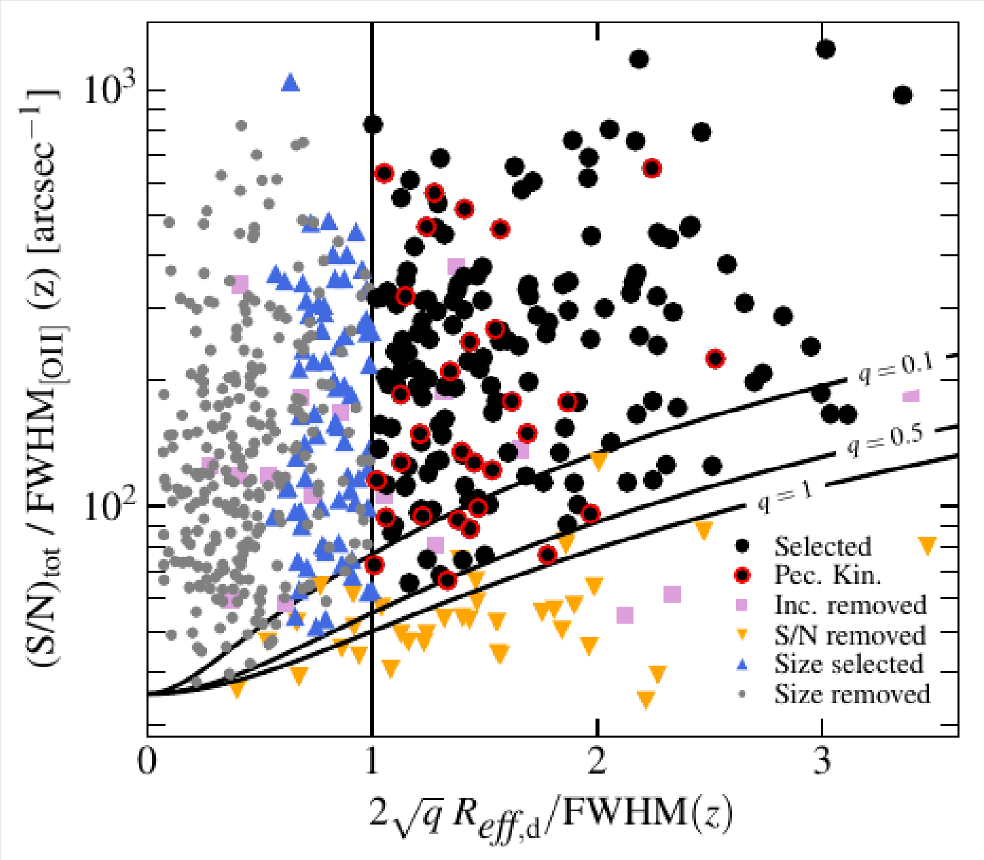
→ Constrained from the morphology

Modelling takes into account:
1. Projection along the line of sight
2. Beam smearing

Measuring V_{22} and σ_V

https://gitlab.lam.fr/bepinat/MocKinG

Sample selection



Mercier et al. (2023)

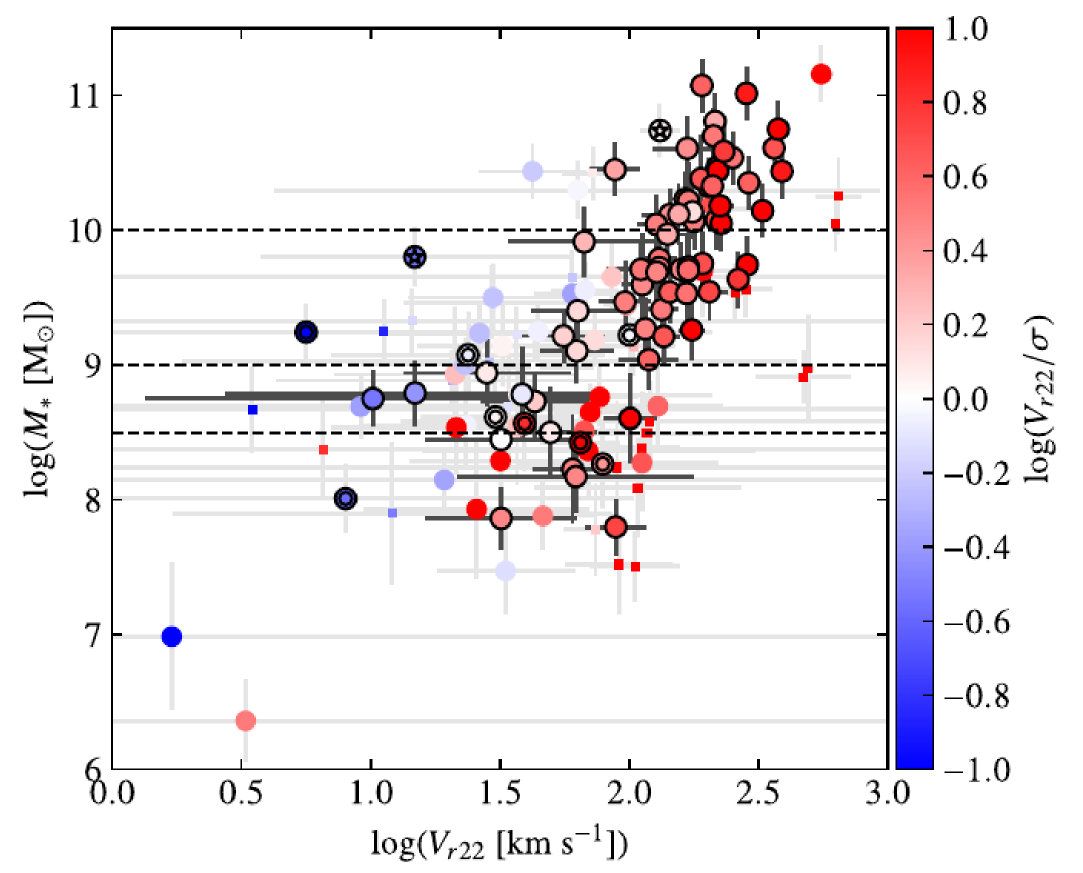
Goals:

1. Focus on star-forming galaxies
2. Remove galaxies with unresolved disks
3. Remove galaxies with too low SNR
4. Remove low inclination systems (deprojection)

First results on the TFR

Abril-Melgarejo et al. (2021)

- Preliminary study on a subsample of 67 galaxies in 8 0.5<z<0.8 groups



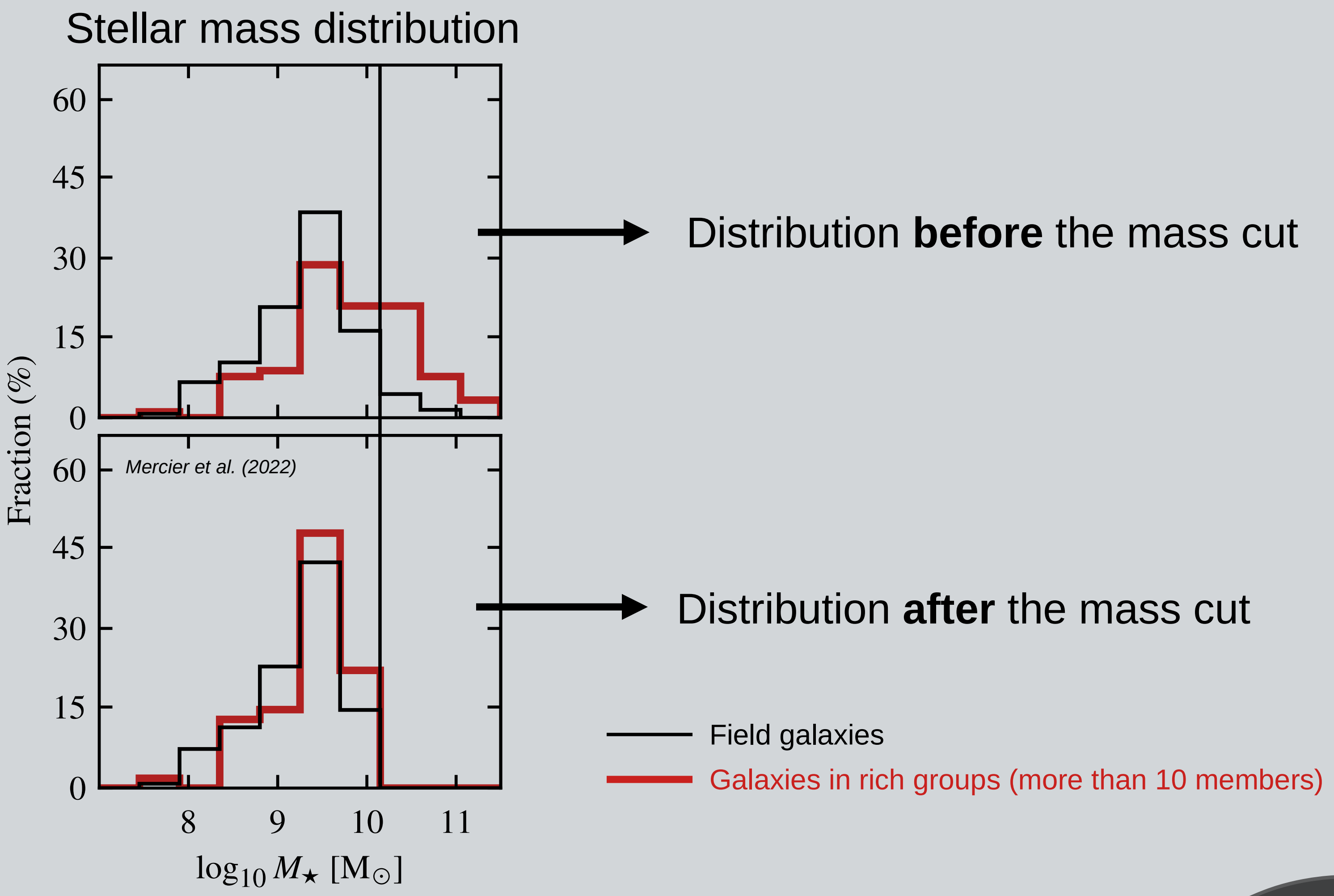
The previous selection enables to exclude

- most of outliers in the TFR

→ most of them are dispersion-dominated systems

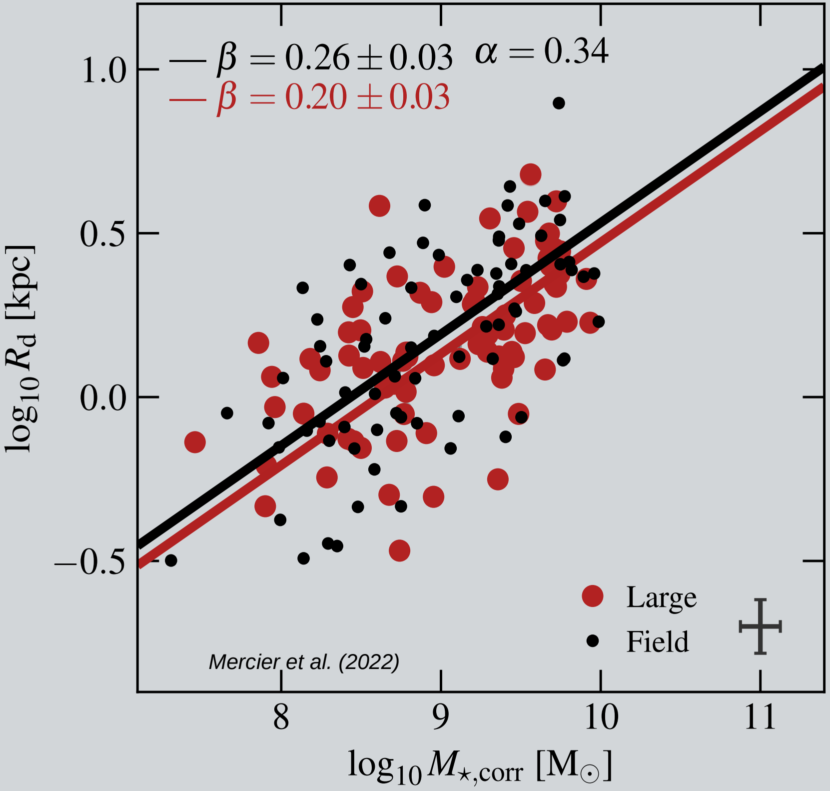
→ low V/σ may be an artifact resulting from observational effect

Importance of a stellar mass cut



Impact on the size-mass relation ?

Mercier et al. (2022)

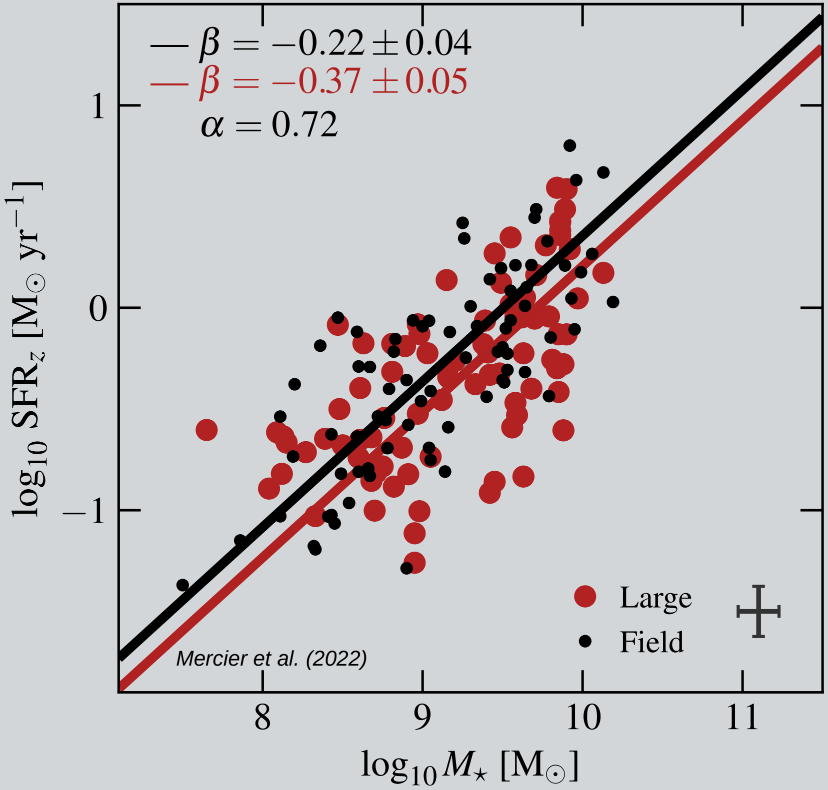


Galaxies in large structures **denser** than those in the field

→ **15% smaller at fixed stellar mass**
→ **Baryon contraction**
→ Similar to Maltby et al. (2010), Kuchner et al. (2017), and Matharu et al. (2019)

Impact on the Main Sequence relation

Mercier et al. (2022)



Lower SFR in large structures with respect to the field

→ **Reduction by a factor ~1.5**

→ Similar to Erfanianfar et al. (2016), Balogh et al. (2020), and Old et al. (2020)

First results on the TFR

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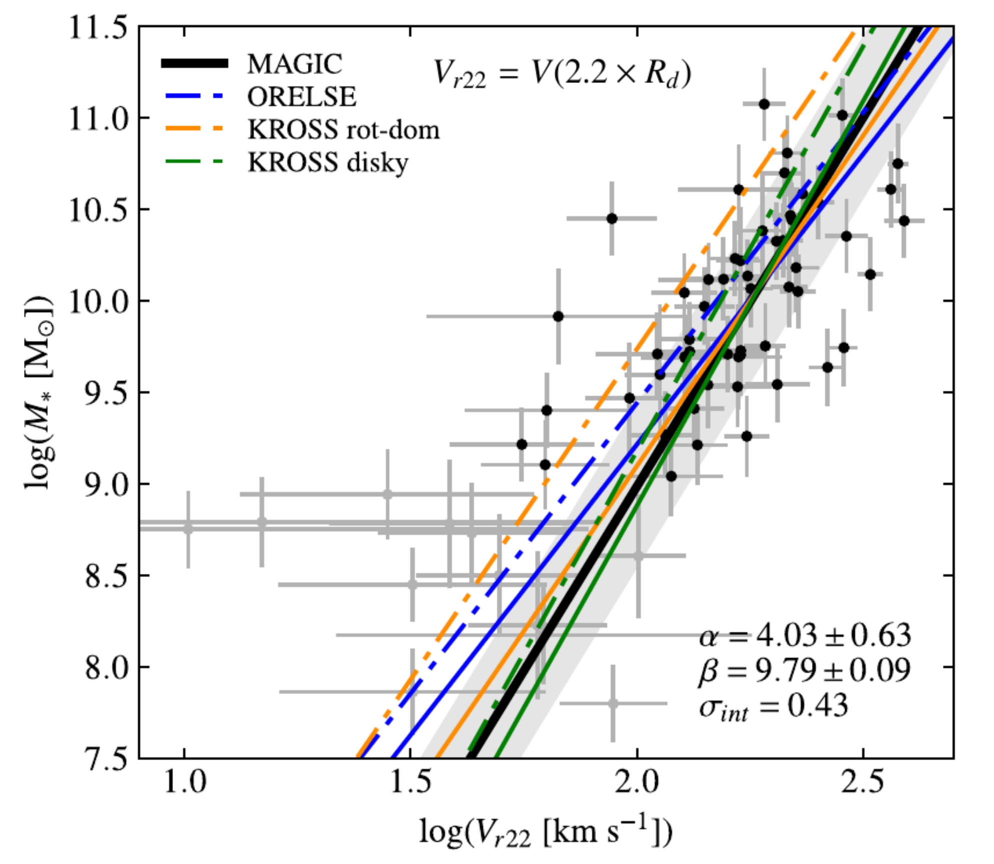
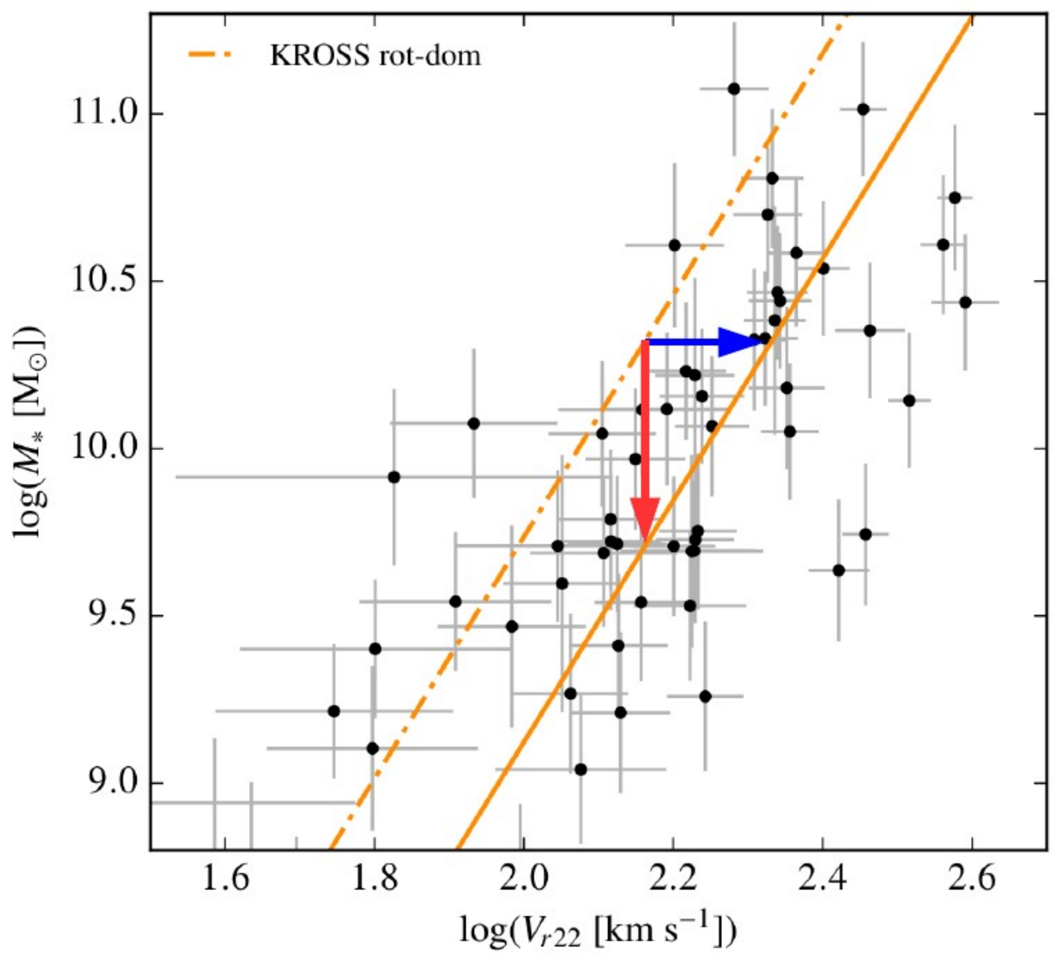


Offset of the zero-point (~0.2 dex) compared to other samples at z~0.9:

- IFS samples: KMOS3D *(Übler et al. 2017)* & KROSS *(Tiley et al. 2019)*
- Long-slit spectroscopy sample: ORELSE *(Pelliccia et al. 2019)*

First results on the TFR

Abril-Melgarejo et al. (2021)



Quenching $\Delta(\log M_*) \sim 0.2$ dex

- V traces DMH mass

→ Less stars/baryons at a given DMH mass

- Decrease of SF by ~0.3 dex *(Tomczak et al. 2019)*

→ Quenching timescale

$$\Delta T = \frac{\Delta(\log M_*)}{\alpha \times \Delta(\log \mathrm{SFR})} = 1 - 3\ \mathrm{Gyr}$$

Contraction $\Delta(\log V) \sim 0.04$ dex

- V traces mass within R_{22}: $M_{\mathrm{dyn}}(r) = \frac{rV(r)^2}{G}$
- Contraction of distribution by ~0.05 dex:

$$\Delta(\log V) = -0.5\Delta(\log R_{22}) \sim 0.025\ \mathrm{dex}$$

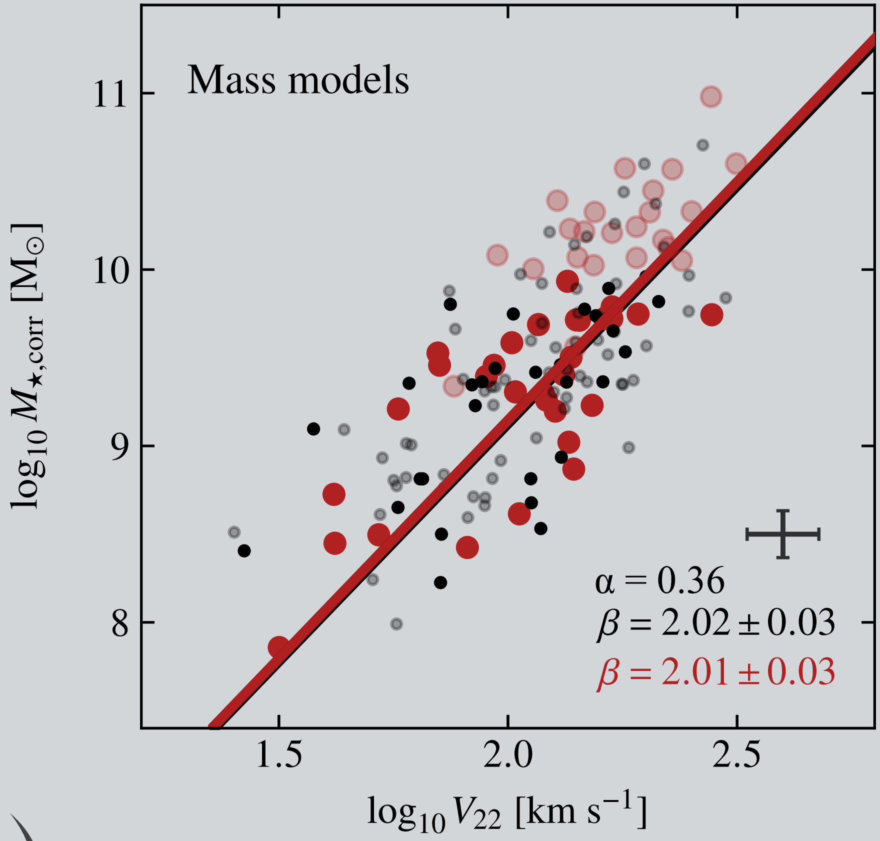
→ Explains part of the offset

→ **Combination of both effects?**

→ **Methodological bias?**

Impact on the Tully Fisher relation ?

Mercier et al. (2022)

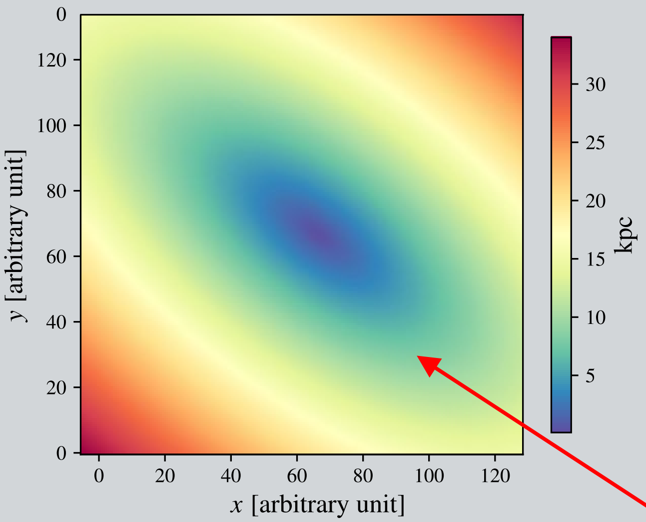


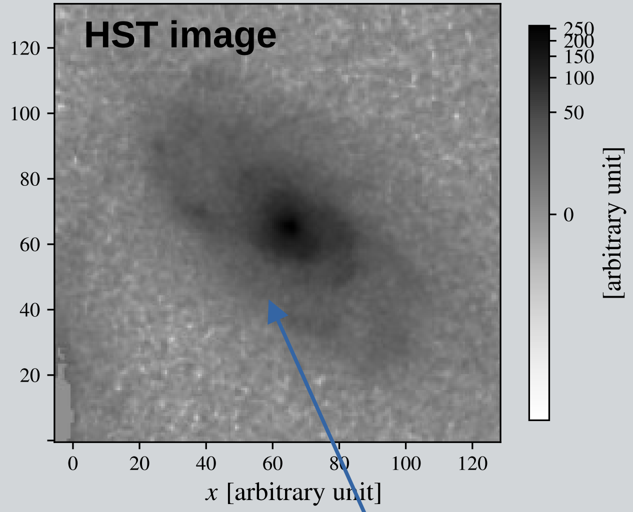
First self-consistent analysis of the TFR as a function of environment

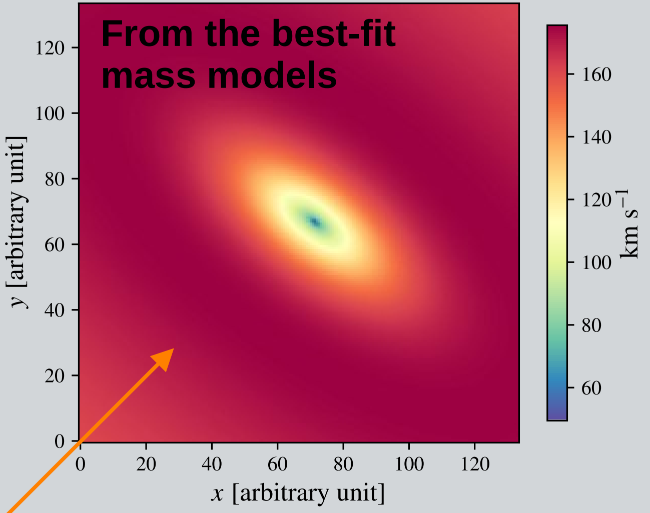
No clear effect of environment at z~0.7

→ result in Abril-Melgarejo+21 seems to be induced by systematics

Deriving precise angular momentum values







Stellar mass distribution

Stellar velocity

$$j_\star = \int_{x,y} dx dy \, R \, \Sigma_\star(x,y) V_{\theta\star}(R) / M_\star$$

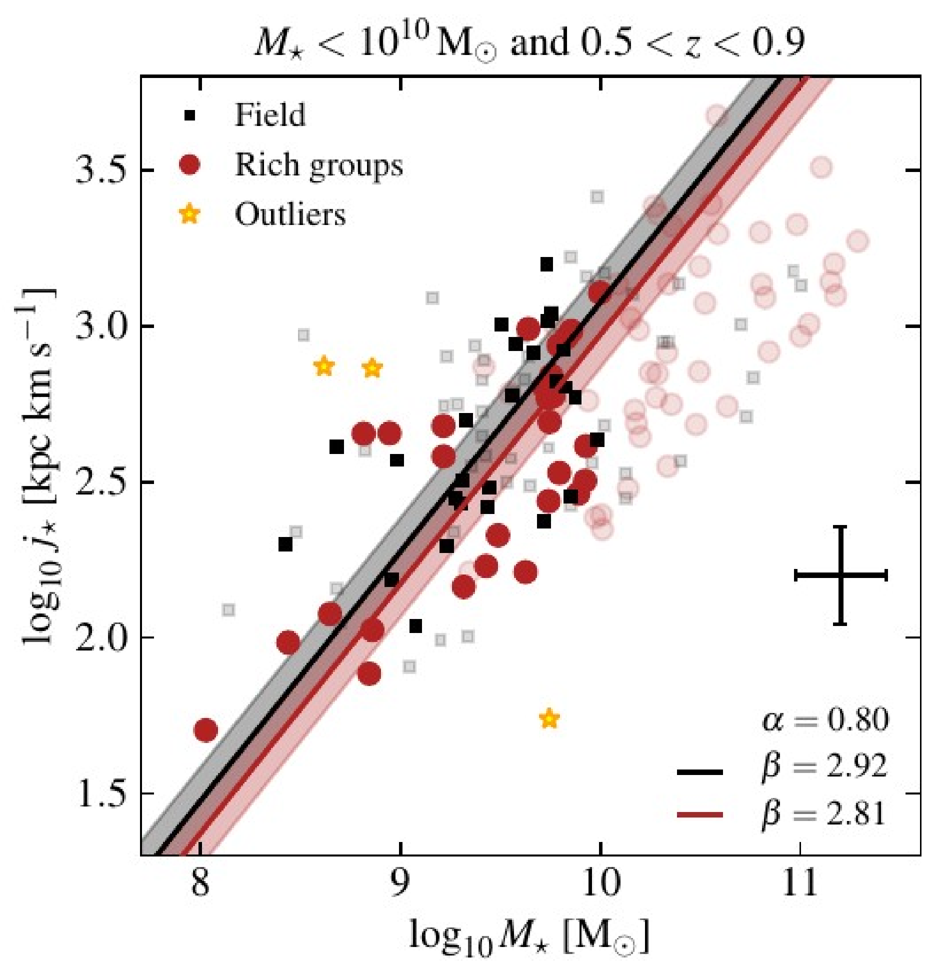
Distance to centre

Constrained from projection parameters (centre, inc, and PA)

Assume co-rotation between the gas and stellar **disks**

Sample of ~200 galaxies

Impact of environment on the Fall relation



Mercier et al. (2023)

- **Depletion of angular momentum in dense environments:**
  - 0.12 dex
  → 2σ significant

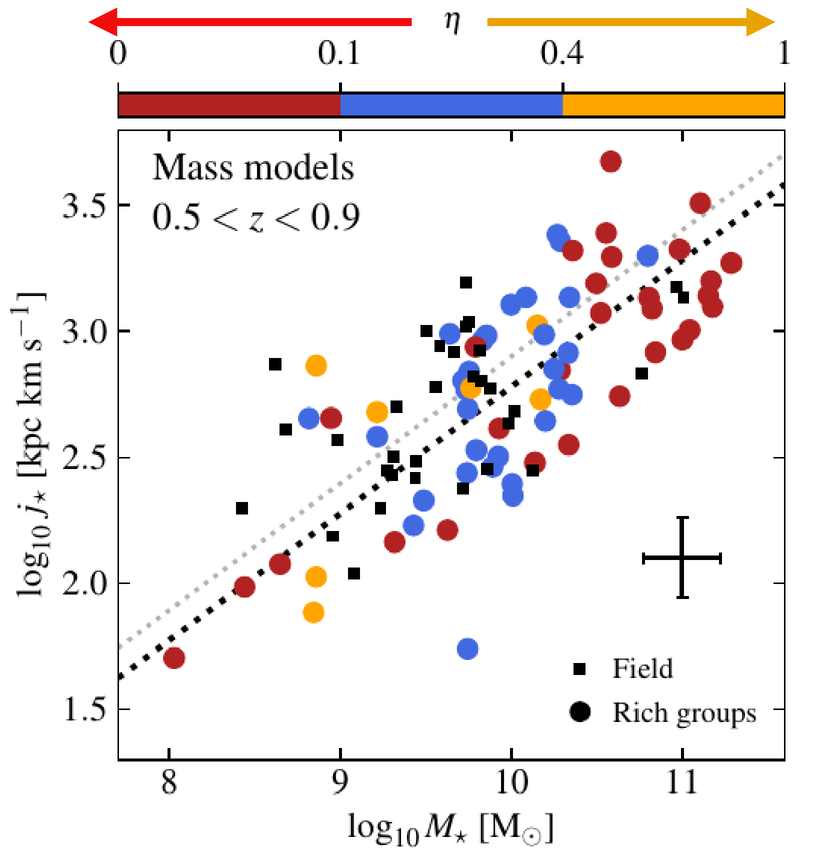
- Massive galaxies systematically below the Fall relation found at the low-mass end (bending)

Impact of environment on the Fall relation

High density

Low density

Mercier et al. (2023)

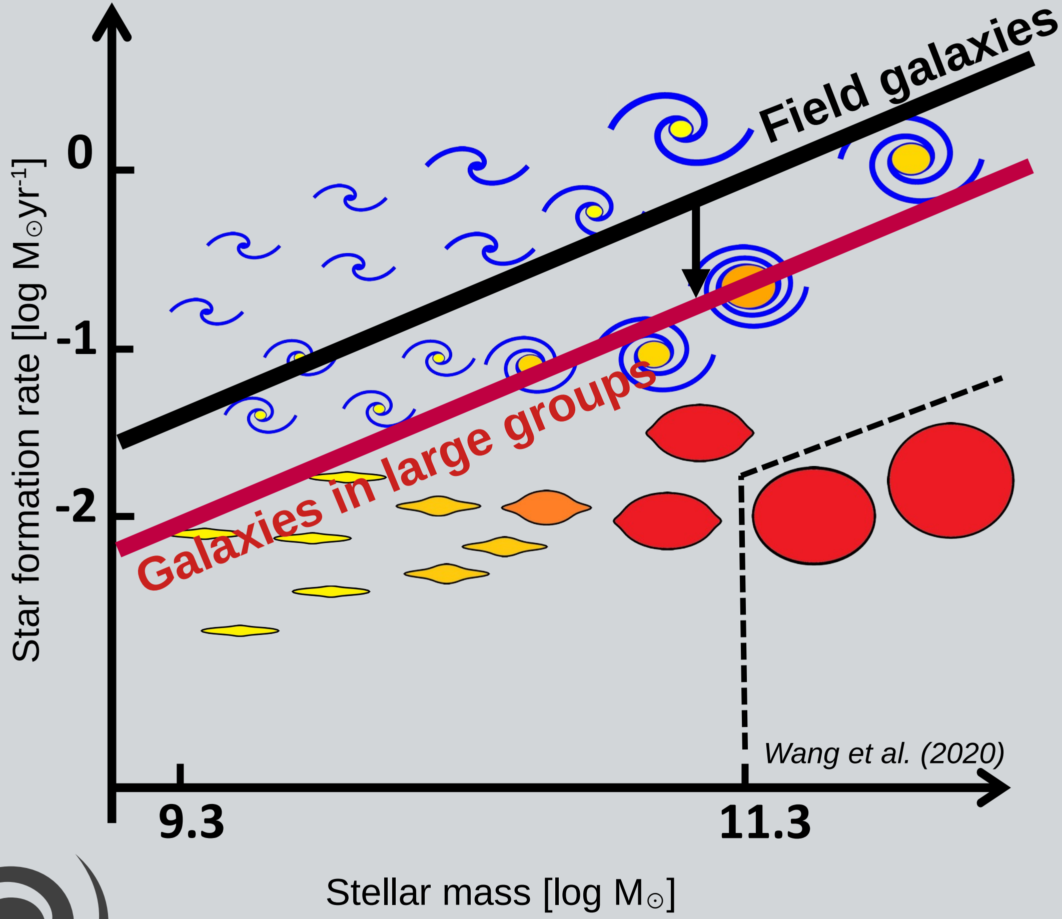


Strong impact seen at the highest masses:

- Massive galaxies systematically below the Fall relation found at the low-mass end (bending)
- Correlated with high-density global environments

But we lack massive field galaxies to discriminate between an **environment-** or a **mass-driven effect**

Physical interpretation

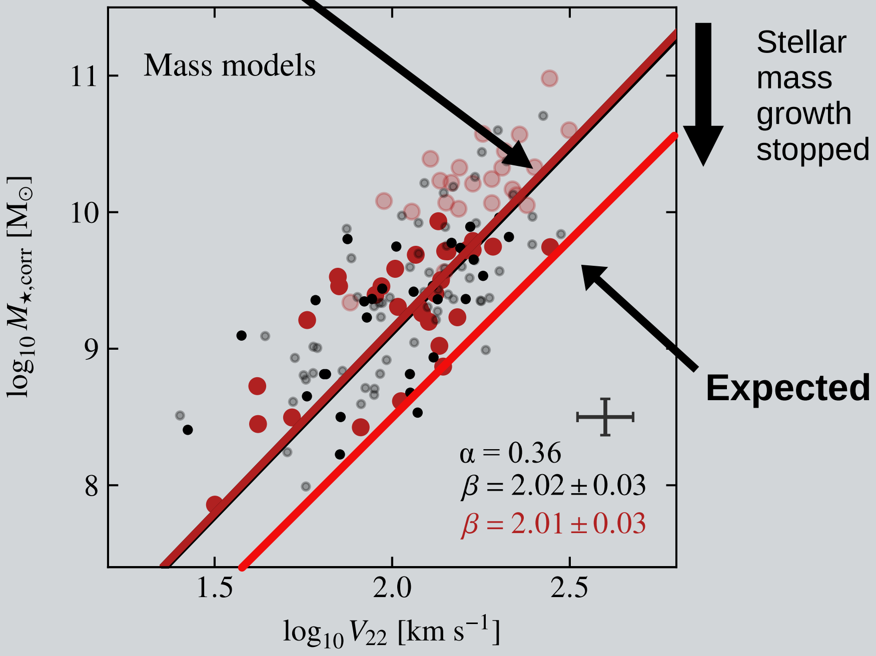


Mercier et al. (2023)

Quenching probed on **short timescales**

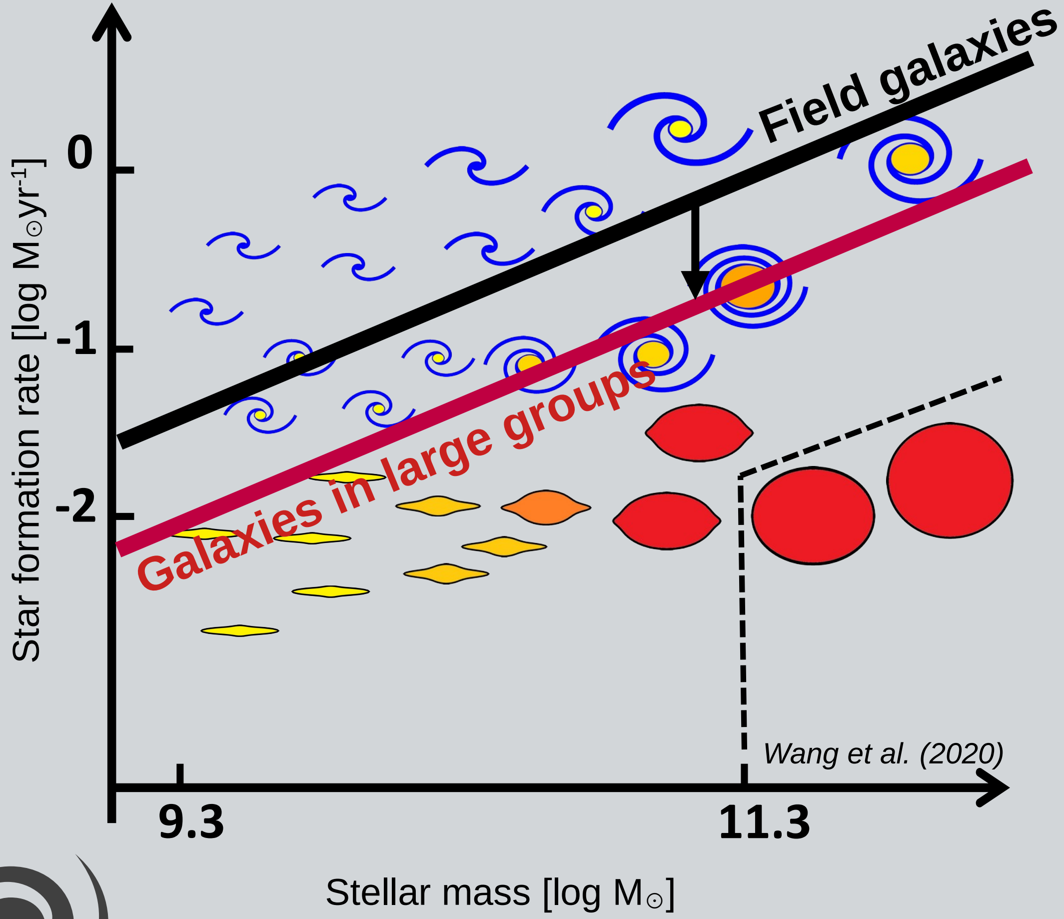
→ probes **~10-100 Myr timescale** ≪ 7Gyr of prior galaxy evolution

+ no impact on the TFR at *z*~0.7



Physical interpretation

Mercier et al. (2023)



Quenching probed on **small timescales** + **no impact on the TFR at *z*~0.7**

↓

Recent accretion into the structures at most **between 700 Myr and 1.5 Gyr**

Galaxies **undergoing** their **morpho-physical transformation**

- **shape of RC**
- **redistribution of baryons**

4. Extended nebulae in dense environments

Giant ionized gas structure at z~0.7

Epinat et al. (2018)

Massive group: M ~ 5 x 10^{13} M_{sun}

SB([OII]) > 2 x 10^{-18} erg/s/cm^2/arcsec^2

Source of ionization

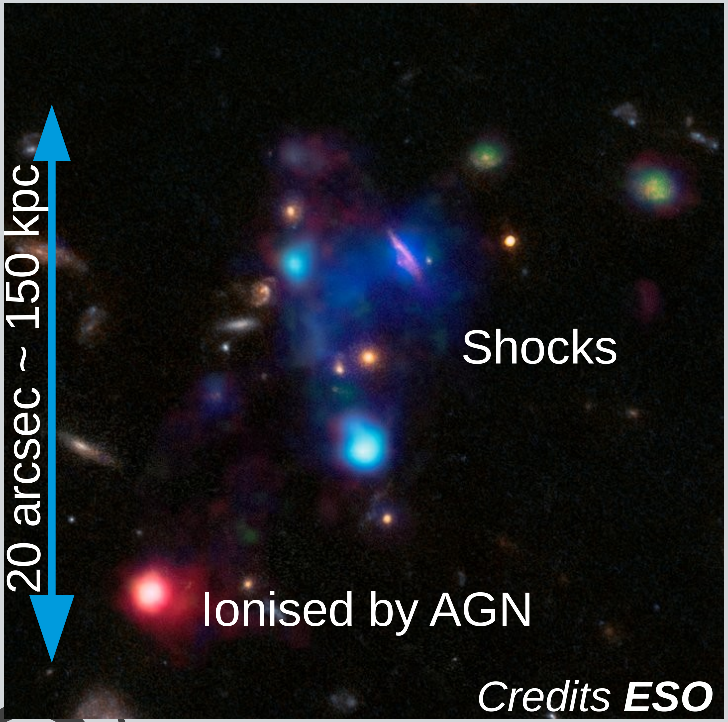
- SF in tidal interaction tails
- Shocks: extended vs galactic gas
- AGN power (jet-like feature)

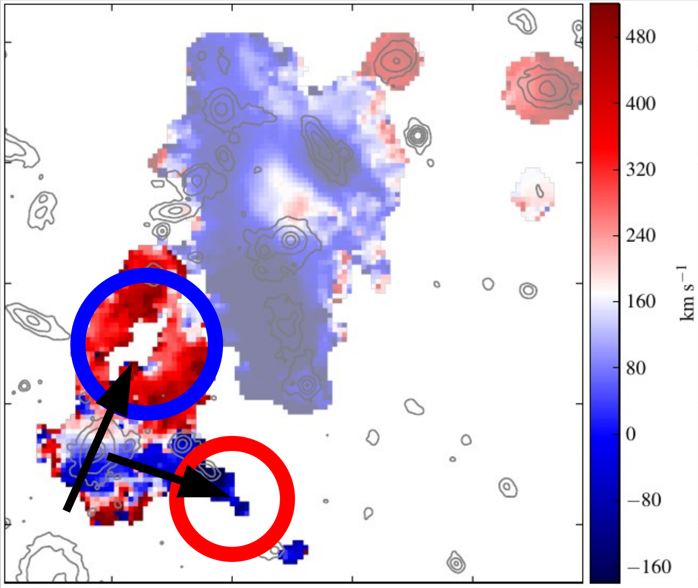
Gas settled in a disk around the most massive galaxy

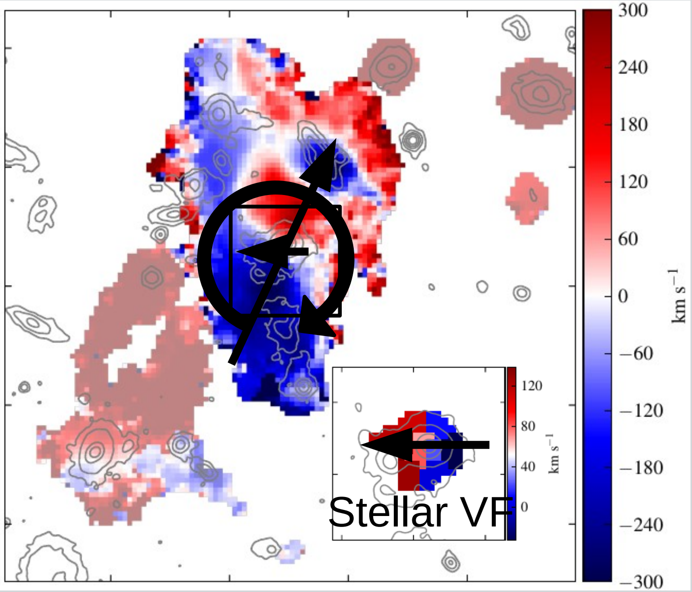
→ Gas extracted from galaxies during interactions?

→ Gas expelled from AGN?

→ Disk rebuiding?







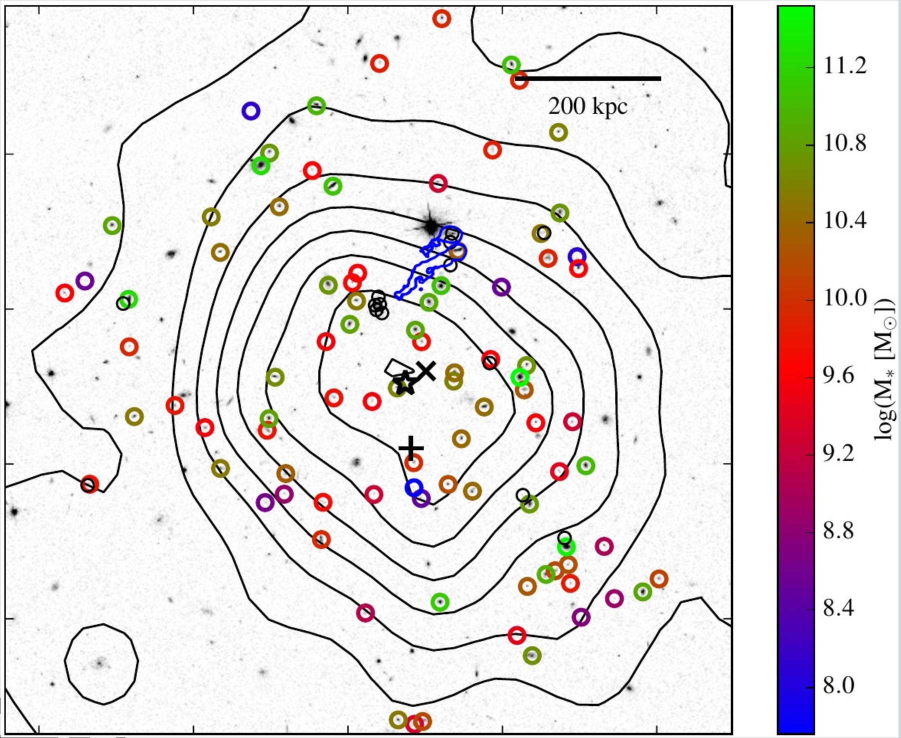
Ram-pressure stripping at z~0.7

Boselli et al. (2019)

Cluster with group infall

$M_{200} = 2.3 \times 10^{14}\ M_{sun}$

$R_{200} = 1$ Mpc



Main galaxy

- $M^* \sim 2 \times 10^{10}\ M_{sun}$
- SFR ~ 40 M_{sun}/yr
- $M_{gas} \sim 1\text{-}4 \times 10^{10}\ M_{sun}$

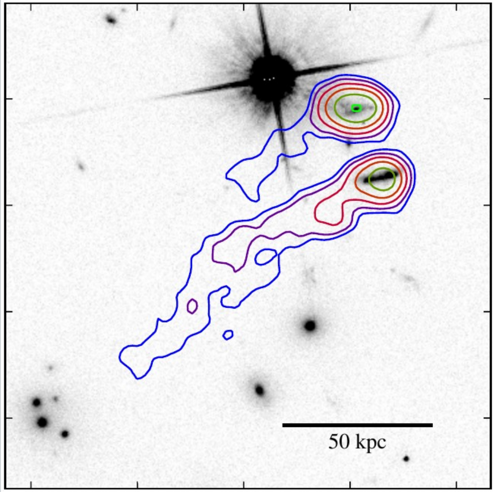
Main tail (in [OII])

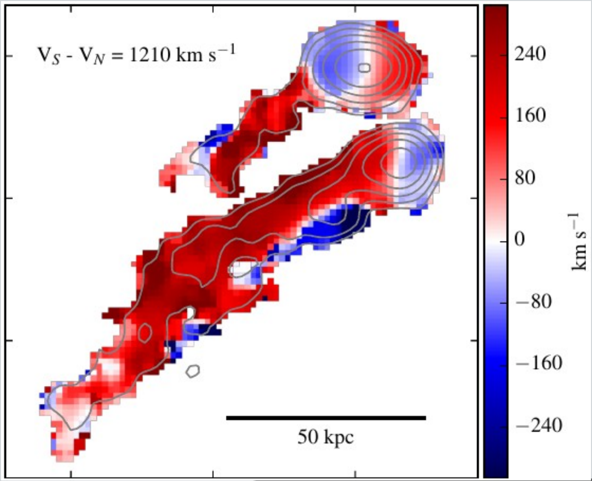
- **SB > 1.5 x 10^{-18} erg/s/cm²/arcsec²**
- Dimensions ~ 100 x 20 kpc²
- Flux ~ 10^{-16} erg/s/cm²

- **First evidence for (edge-on) stripping at z~0.7**

→ no optical counterpart

→ gas is decelerated in tails

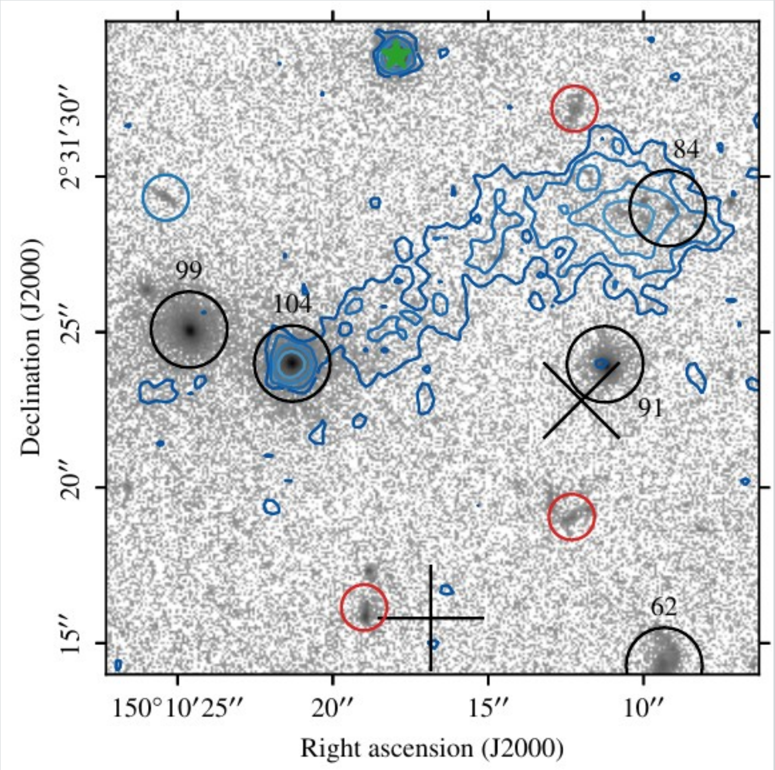




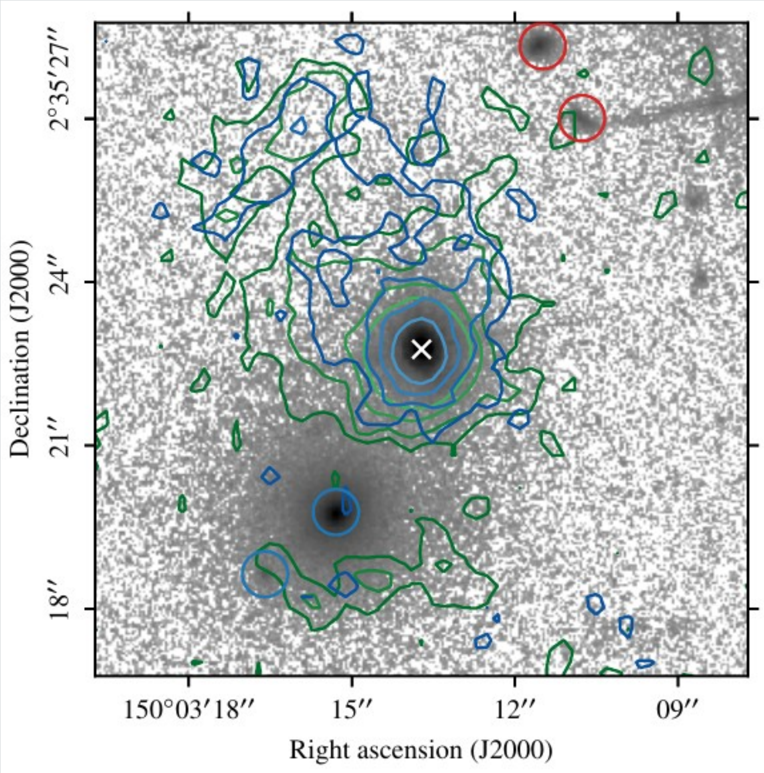
More large ionized nebulae in MAGIC!

Epinat et al. (2024)

Extended ionized gas nebula in CGr172
- stripped gas?
- interaction?



Extended [OII] and [OIII] ionized gas nebula around QSO in CGr84



5. Conclusions

Conclusions

Sample features

- Access to low mass galaxies with good completeness
- Diversity of environments
- Red sequence continuously growing when environment gets dense + when reaching the central regions of massive groups
- Low mass galaxies less present in massive groups

  → pre-processing in small groups

Impact of environment on scaling relations:

- Noticeable evolution of size-mass relation
- Noticeable evolution of SFR-mass relation
- No noticeable evolution fo the TFR
- Noticeable evolution of the Fall relation (angular momentum)

  → scenario in which environment impact morphology and rotation curve shape

Conclusions

→ **New selection and methodologies introduced to avoid methodological biases**

Very rich MAGIC dataset with unexpected extended ionized nebulae associated to

- Ram-pressure stripping
- AGN/QSO activity
- Shocks
- Galaxy interactions

MAGIC data release

- Catalogs (galaxies, groups):

https://vizier.cds.unistra.fr/viz-bin/VizieR-3?-source=J/A%2bA/683/A205/galaxy

- Datacubes:

https://www.eso.org/sci/observing/phase3/news.html#magic

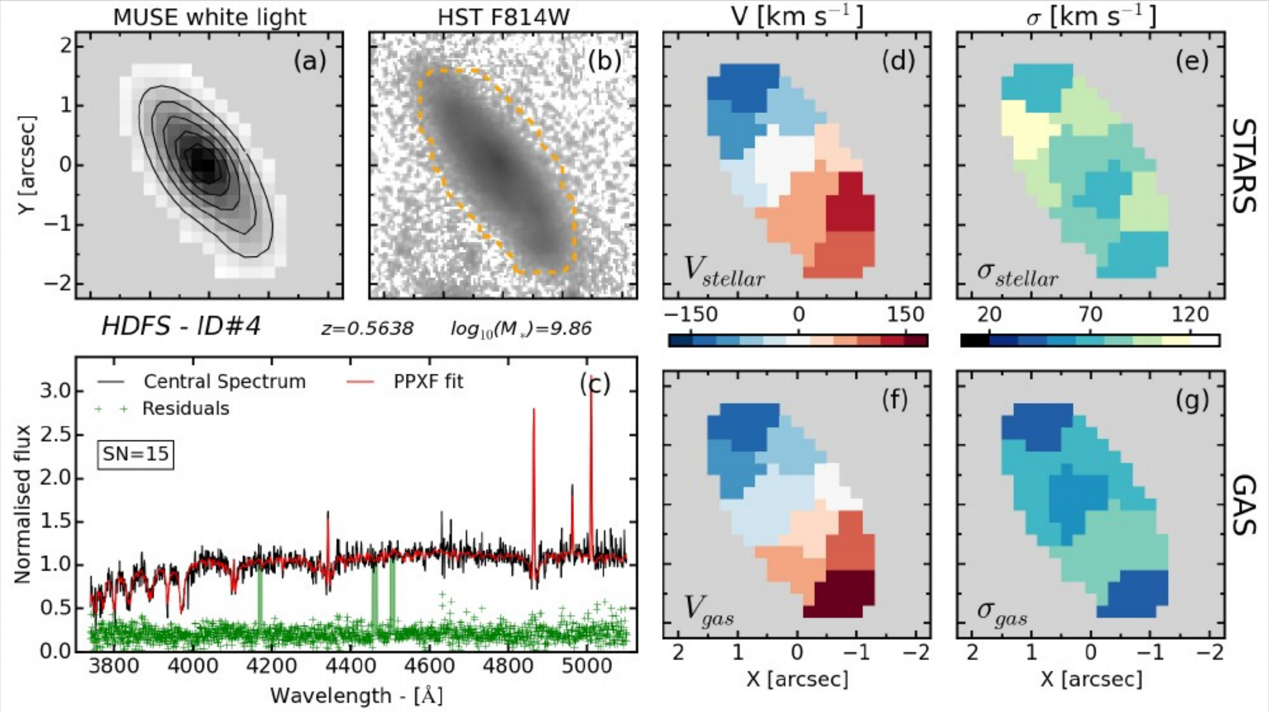
WHAT IS NEXT?

What is next?

Better understand evolution of angular momentum

- Taking advantage the mass distribution of MAGIC (Mercier et al. in prep)
- Studying the impact of environment on quiescent galaxies from stellar dynamics

Impact of environment on quiescent galaxies



Spatially resolved stellar kinematics

→ 17 star forming galaxies 0.3 < z < 0.8 in HDFS & HUDF 30h fields (*Guérou+17*)

→ 106 massive galaxies 0.1 < z < 0.8 in CANDELS fields (Muñoz López+24)

→ no impact of environment

→ not enough environment diversity

→ >**80 galaxies** @ z < 0.8 with $M_*>10^{10}$ Msun in **MAGIC**

- Strong red sequence

Integrated stellar kinematics

→ **~150** galaxies in MAGIC (Muñoz López et at. In prep)

What is next?

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- Studying the impact of environment on quiescent galaxies from stellar dynamics

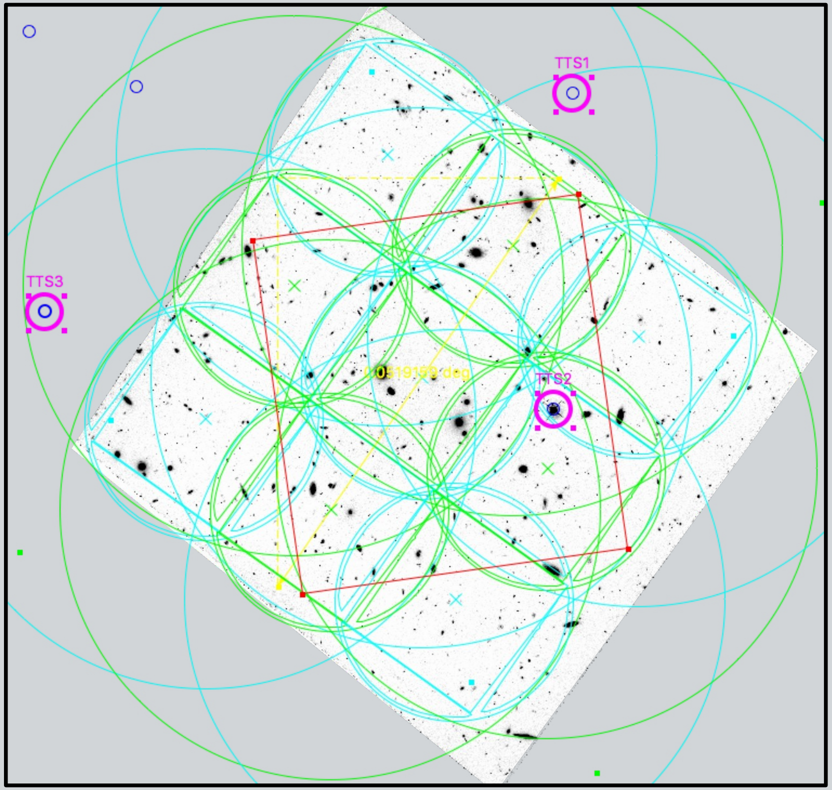
Statistical analysis of extended nebulae to constrain the rate of quenching processes (RPS, galaxy interactions, etc…) at intermediate redshift

Pursuing analysis of the environmental impact

Improved analysis with additional MUSE surveys:

- MUSE-Wide, HDFS, HUDF, MXDF, etc.
- **MUSCATEL**
  → Hubble Frontier Fields (parallel fields)
  → **36 shallow** (~2h), **16 deep** (~5h), and **4 very deep** (~25h) **fields**
  → Large volume implies **access to massive field galaxies**

MUSCATEL observing strategy



What is next?

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- Taking advantage the mass distribution of MAGIC (Mercier et al. in prep)
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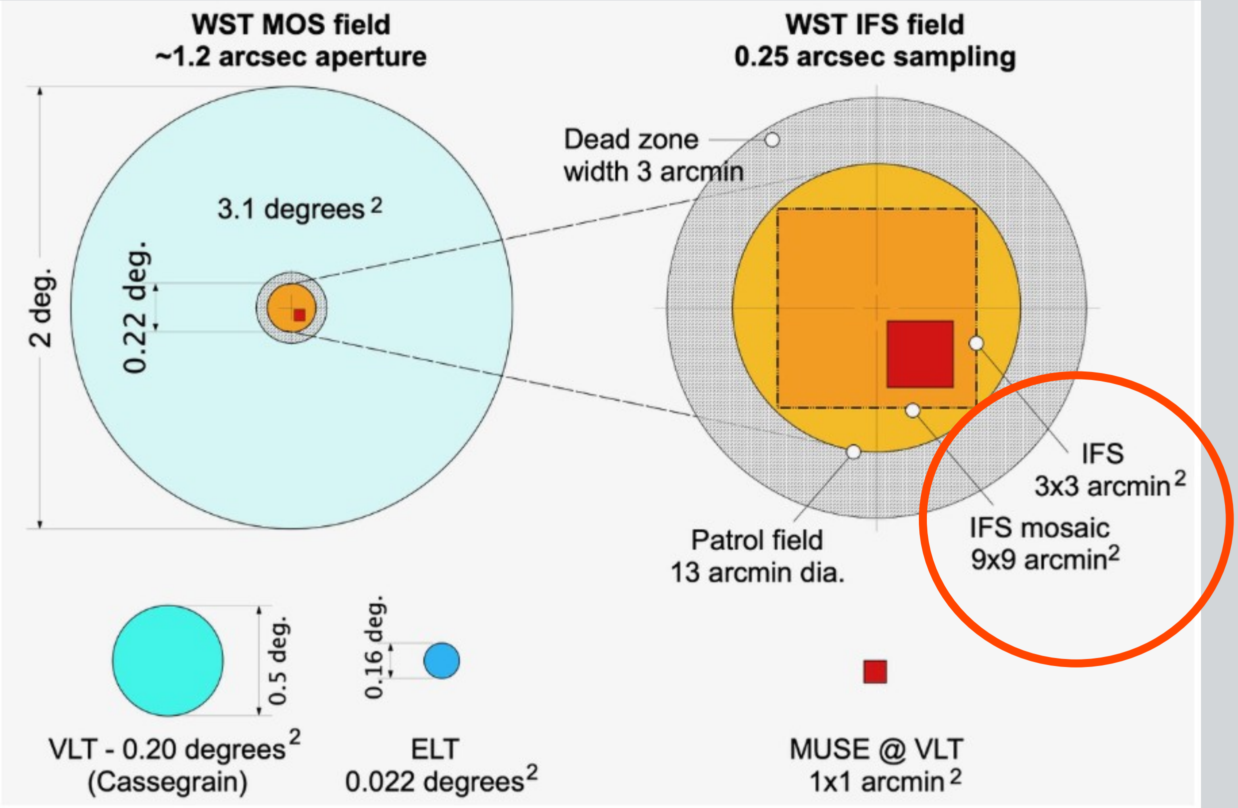
Better statistics with other MUSE fields

Longer term

- Better statistics: larger IFUs to map cosmic web at intermediate redshift
  - → BlueMUSE (white paper: https://arxiv.org/abs/1906.01657)
  - → WST (white paper: https://arxiv.org/abs/2403.05398)

What is next?

WST white paper: https://arxiv.org/abs/2403.05398



In the meantime: large IFUs already exist!

SITELLE, a Current large IFU at CFHT

CFHT is located on Maunakea, land of the kānaka maoli people, and a mountain of considerable cultural, natural, and ecological significance to the indigenous Hawaiian people.

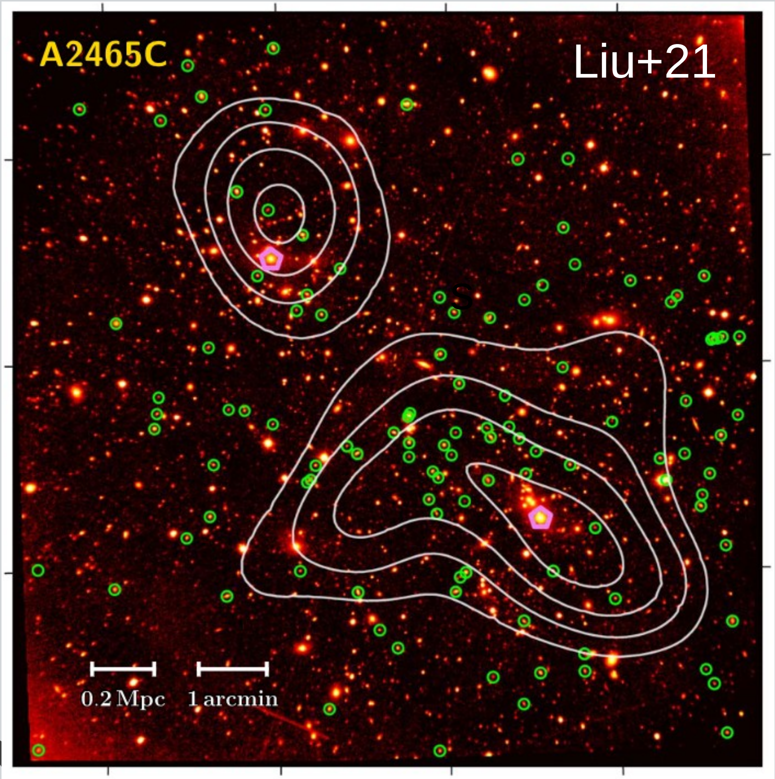
iFTS: imaging Fourier Transform Spectrograph

- Whole detector used for imaging
- Sampling: 0.32”/pixel
- FoV: 11’x11’ (MUSE@VLT is only 1’x1’)
- Tunable R <15000 (MUSE@VLT R~3000)
- Spectral range: 300 – 1000 nm split with dedicated filters

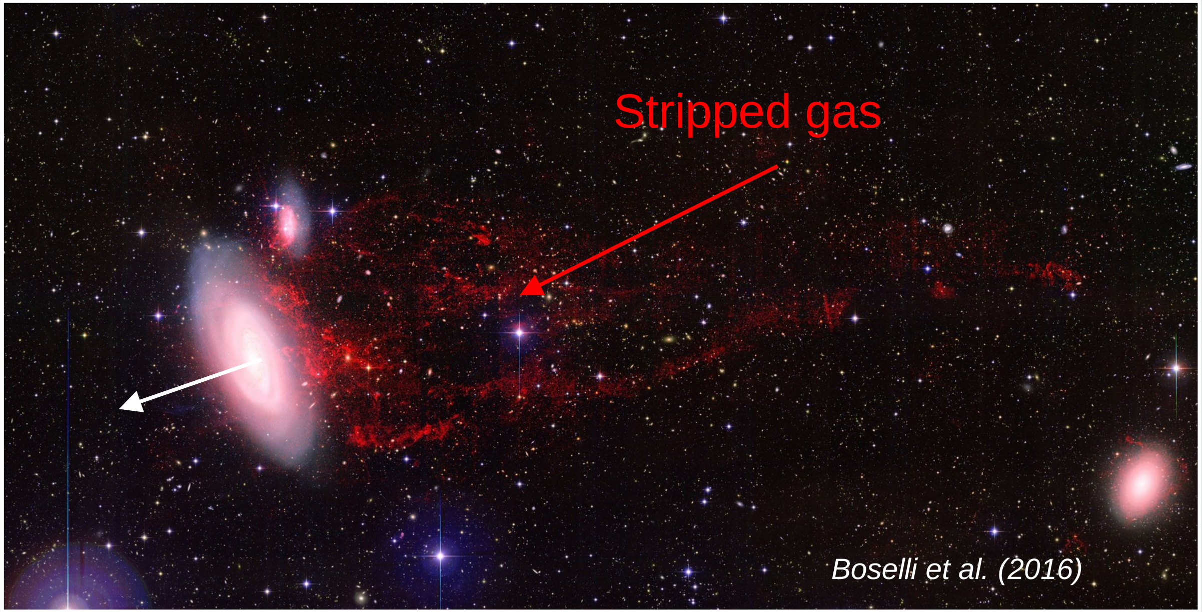
SITELLE, a Current large IFU at CFHT

New narrow band (~10 nm) filters → optimize S/N for faint objects

z> 0.1 clusters



Interactions in local clusters (e.g. RPS)

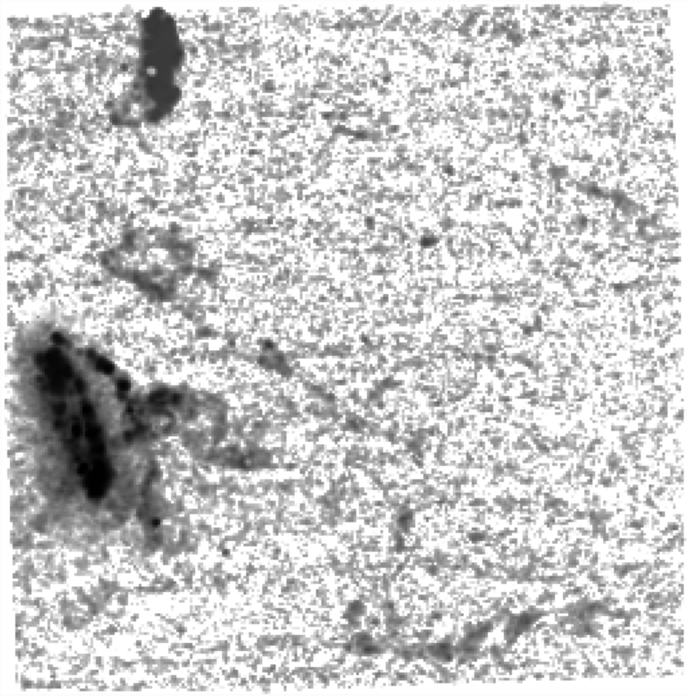


SITELLE, a Current large IFU at CFHT

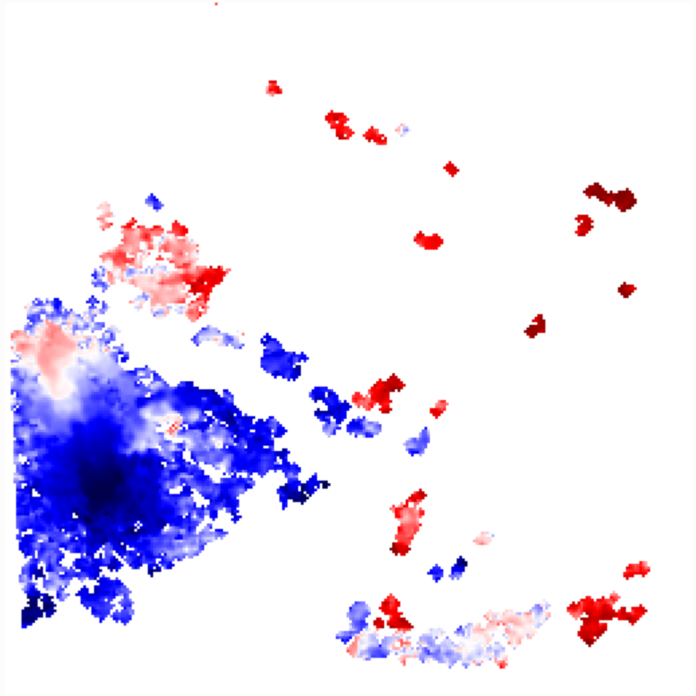
Commissioning data of the new filter (February 2024), 5h exposure, R=3000

Boselli et al. (2016)

Line detection map



Velocity map



Thank you ! Questions ?

MAGIC data release
- Catalogs (galaxies, groups):
https://vizier.cds.unistra.fr/viz-bin/VizieR-3?-source=J/A%2bA/683/A205/galaxy
- Datacubes:
https://www.eso.org/sci/observing/phase3/news.html#magic