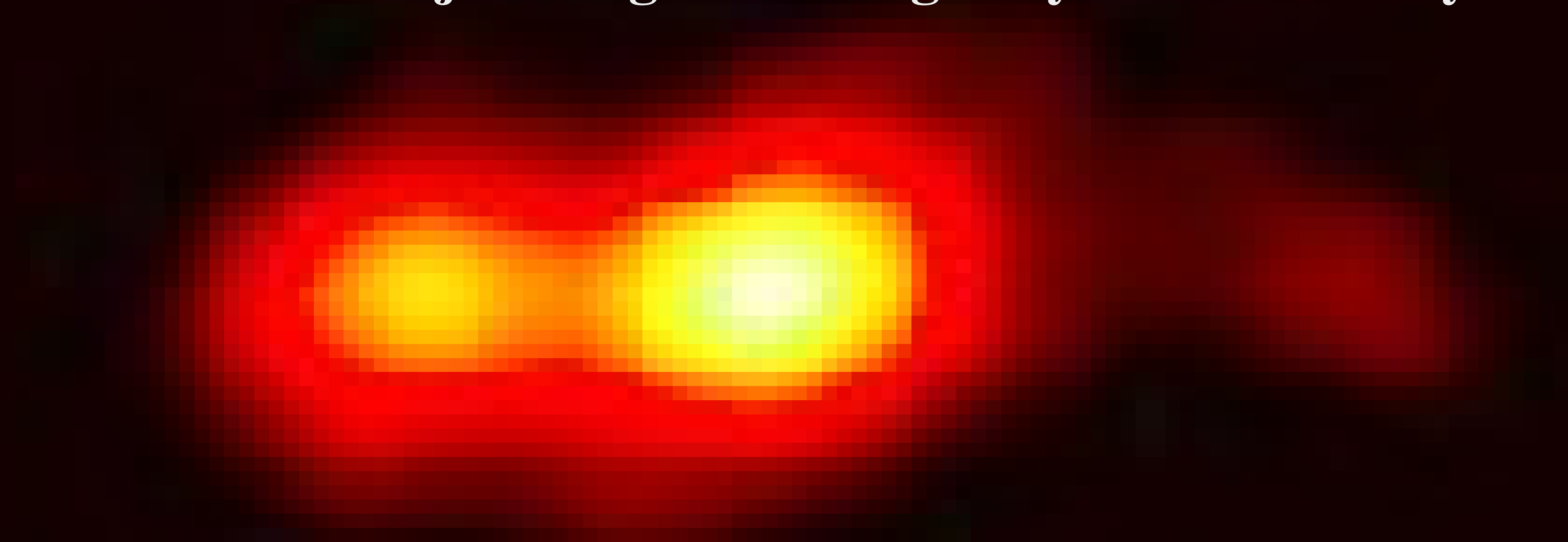
NATIONAL CENTRE FOR NUCLEAR RESEARCH ŚWIERK

The ALMA-ALPINE [CII] survey:
The contribution of major mergers to the galaxy mass-assembly at z~5



Michael Romano[1] & ALPINE collaboration

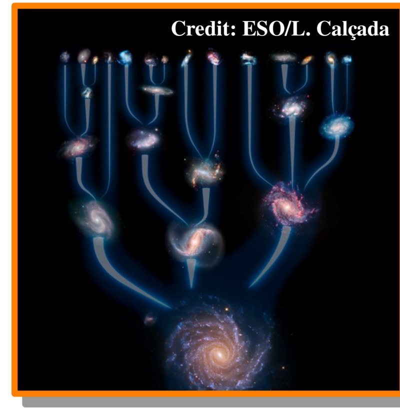
[1]National Centre for Nuclear Research, Warsaw, Poland

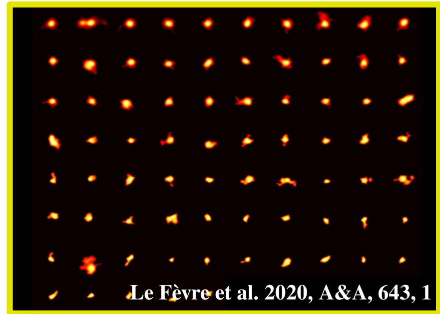
From galaxies to cosmology with deep spectroscopic surveys

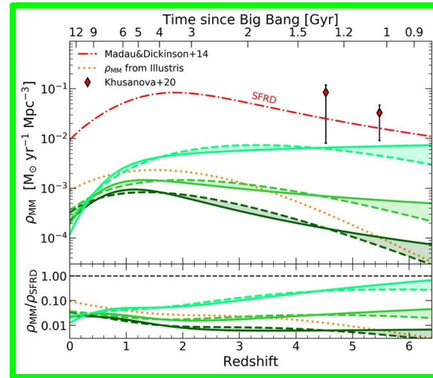
A tribute to Olivier Le Fèvre, 4-8 July 2022, Marseille

Outline

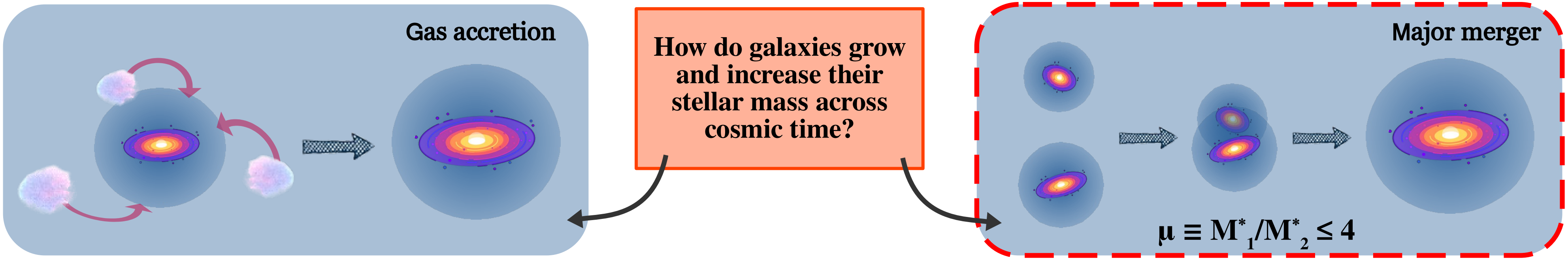
- **Scientific context**
- **The ALPINE survey (in a nutshell)**
- **The role of mergers in the galaxy mass assembly**
    1. Mergers characterization
    2. Major merger fraction
    3. Major merger rate & number of encounters
    4. The contribution of major mergers to the galaxy mass growth
- **Conclusions and prospects**



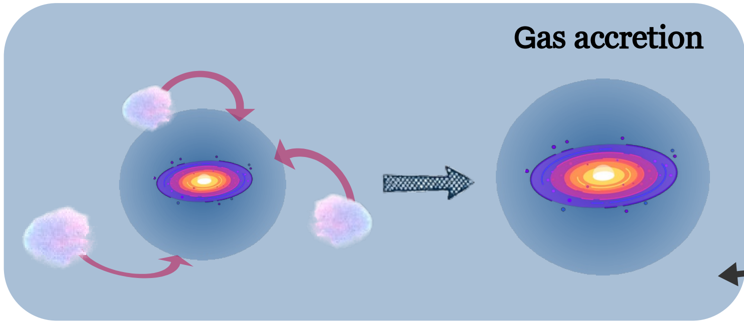




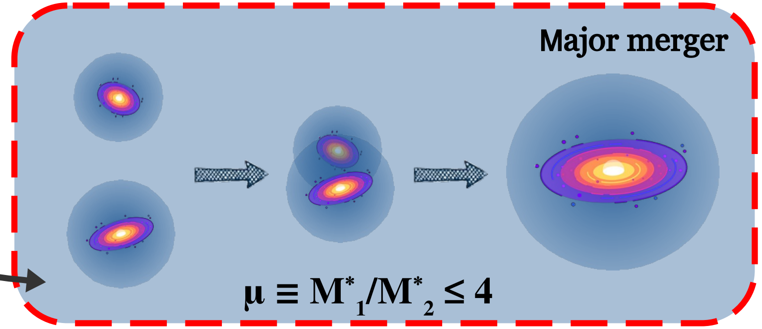
Scientific context



Scientific context



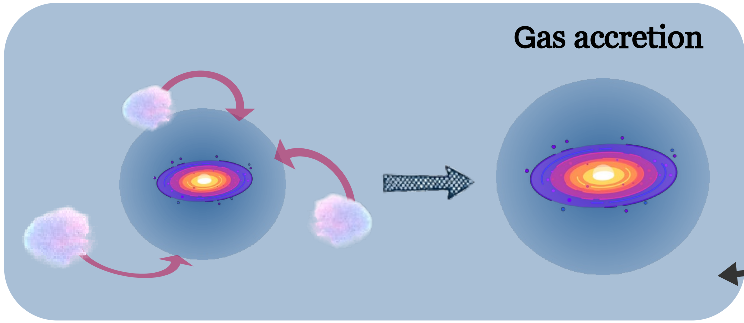
How do galaxies grow and increase their stellar mass across cosmic time?



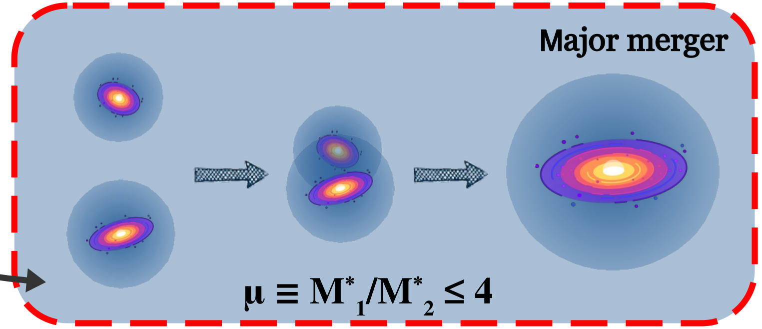
# of galaxies that exist in close pairs

morphological disturbances

Scientific context



How do galaxies grow and increase their stellar mass across cosmic time?

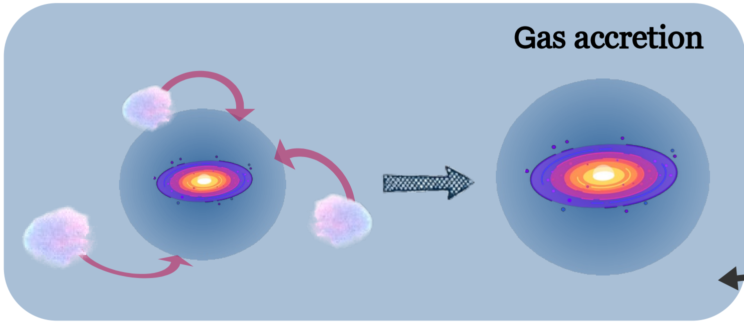


# of galaxies that exist in close pairs → **merger fraction**

morphological disturbances → **merger fraction**

merger fraction → **merger timescale** → **merger rate**

Scientific context



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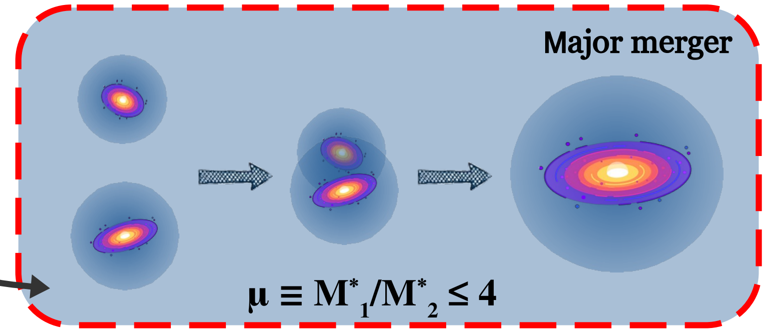


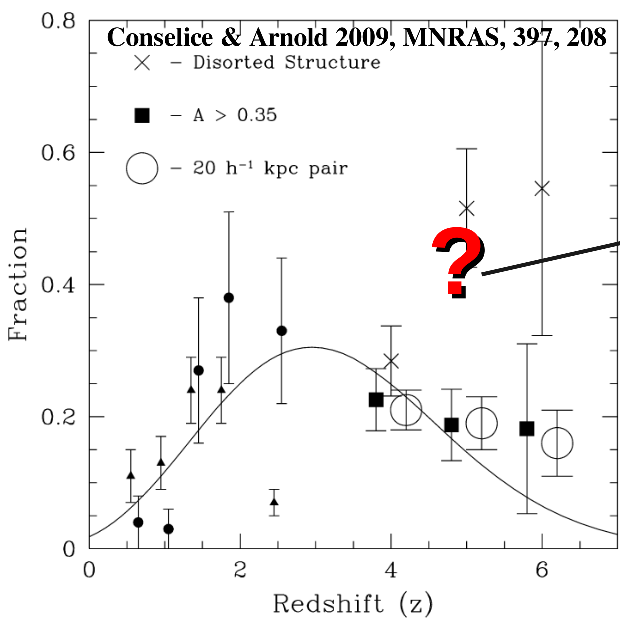
# of galaxies that exist in close pairs

morphological disturbances

merger fraction

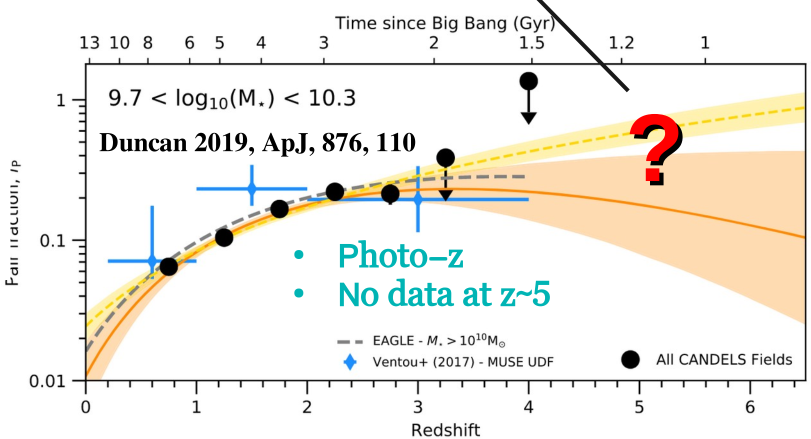
merger timescale

merger rate



- Small sample size
- Photo–z
- No distinction between major and minor

ALPINE

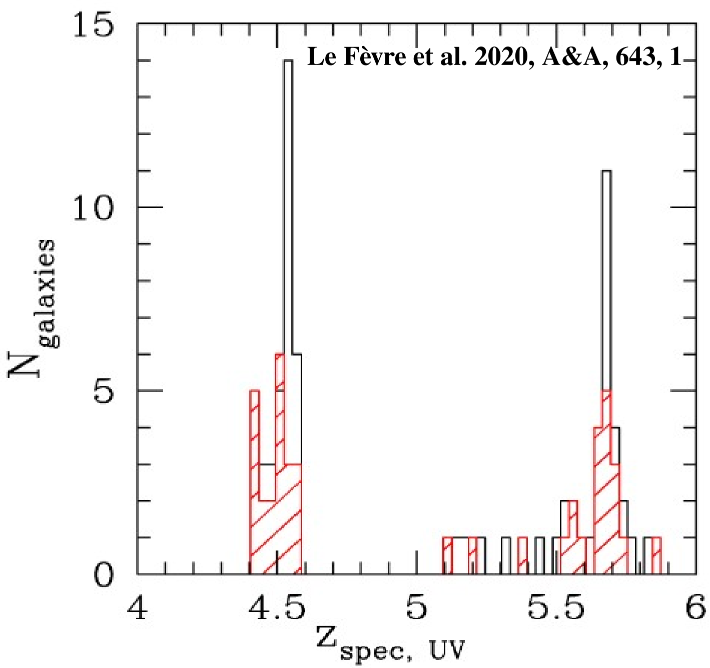


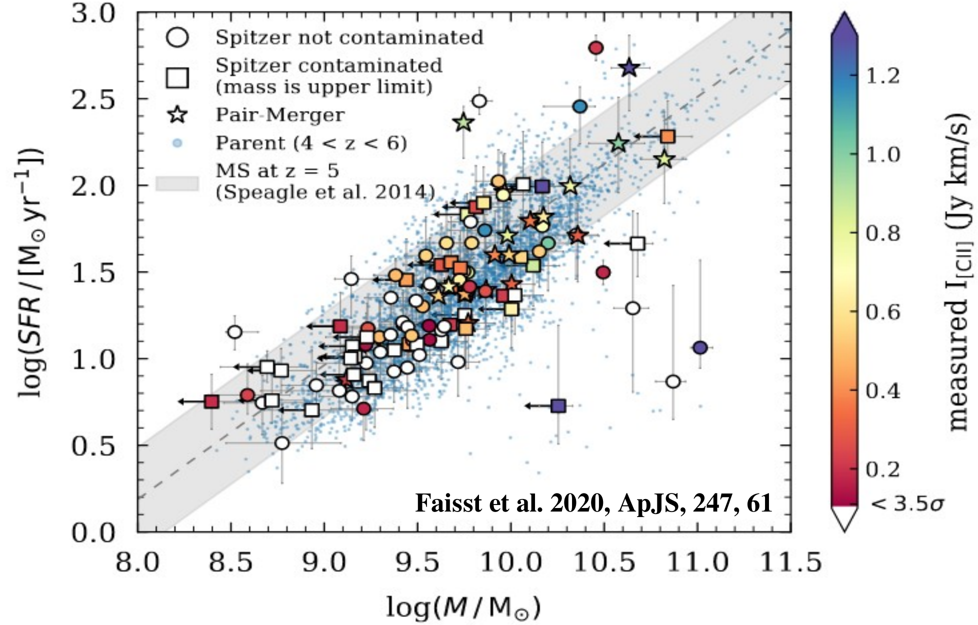
- Photo–z
- No data at z~5

ALPINE: the ALMA Large Program to INvestigate C$^+$ at Early times

- ➔ 70h of [CII] + continuum observations in ALMA Band 7 (PI: Le Fèvre)
- ➔ 118 normal star-forming galaxies (SFGs) drawn from the COSMOS and Extended Chandra Deep Field South (E-CDFS) fields
- ➔ $4.4 < z_{spec} < 5.9$
- • with VUDS and DEIMOS 10K
- ➔ “main-sequence” galaxies
  SFR > 10 $M_\odot$/yr & $9 < \log(M_*/M_\odot) < 11$

See talks by Faisst and Cassata for more!





ALPINE: the ALMA Large Program to INvestigate C⁺ at Early times

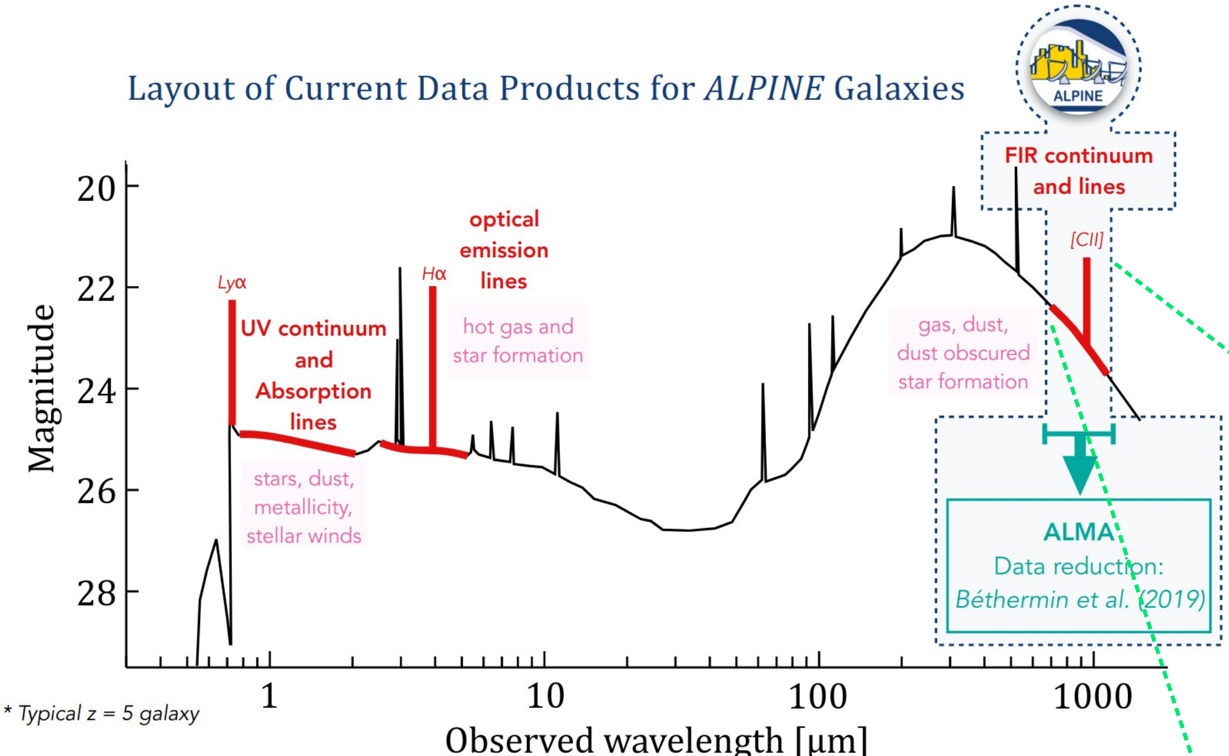
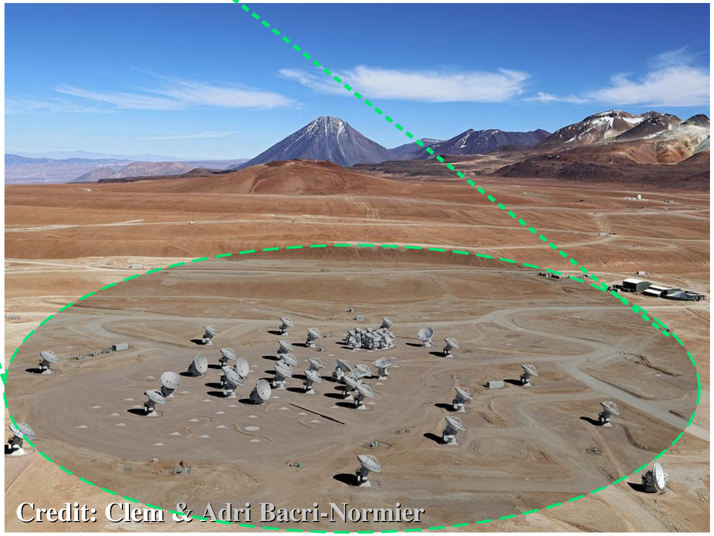


Figure adapted from Faisst et al. 2020, ApJS, 247, 61

[CII] line @ 158 μm rest-frame:

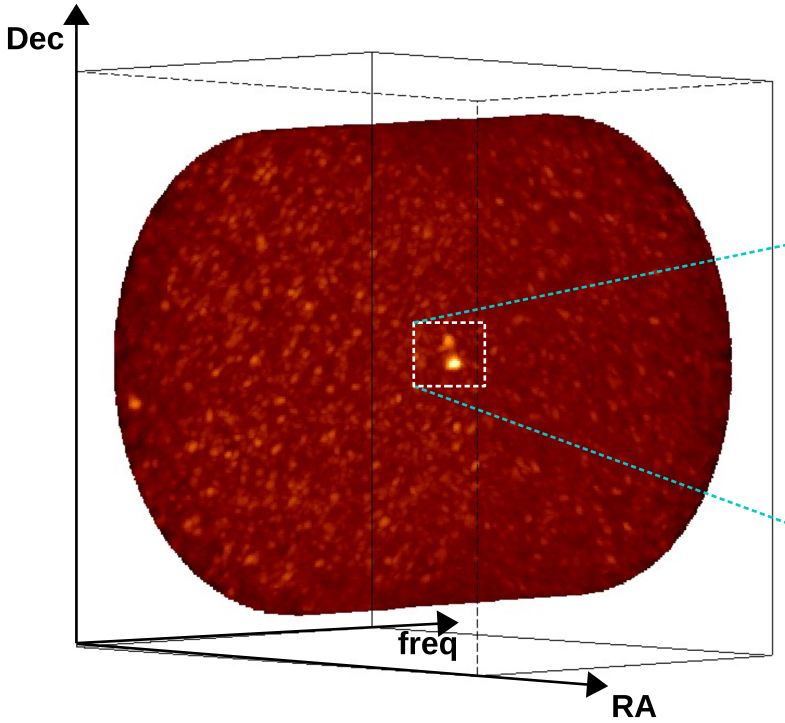
- one of the strongest FIR line;
- mainly excited in photo-dissociation regions (PDRs);
- poorly affected by dust;
- near the peak of FIR emission

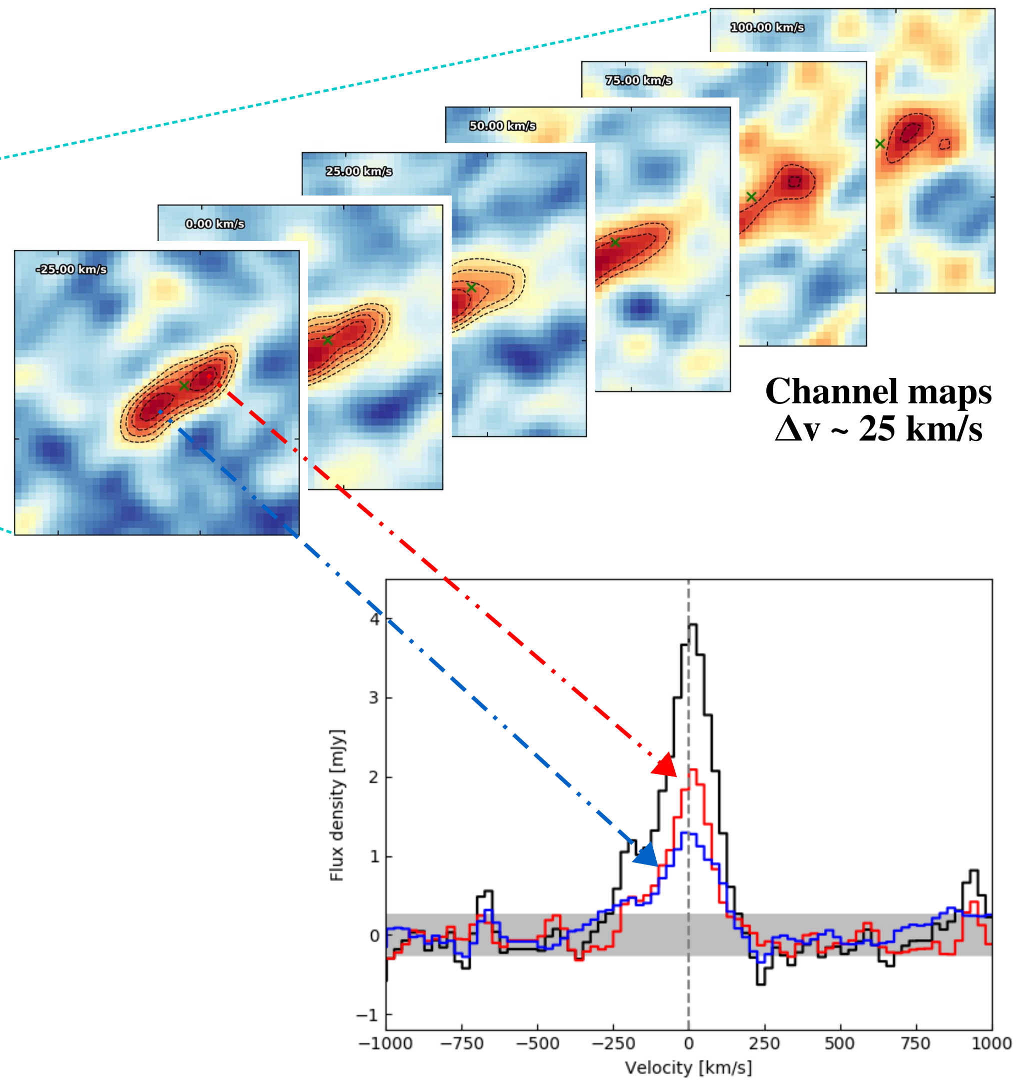


Credit: Clem & Adri Bacri-Normier

Properties of SFGs up to the Reionization epoch in the sub-mm regime

ALPINE: the ALMA Large Program to INvestigate C⁺ at Early times

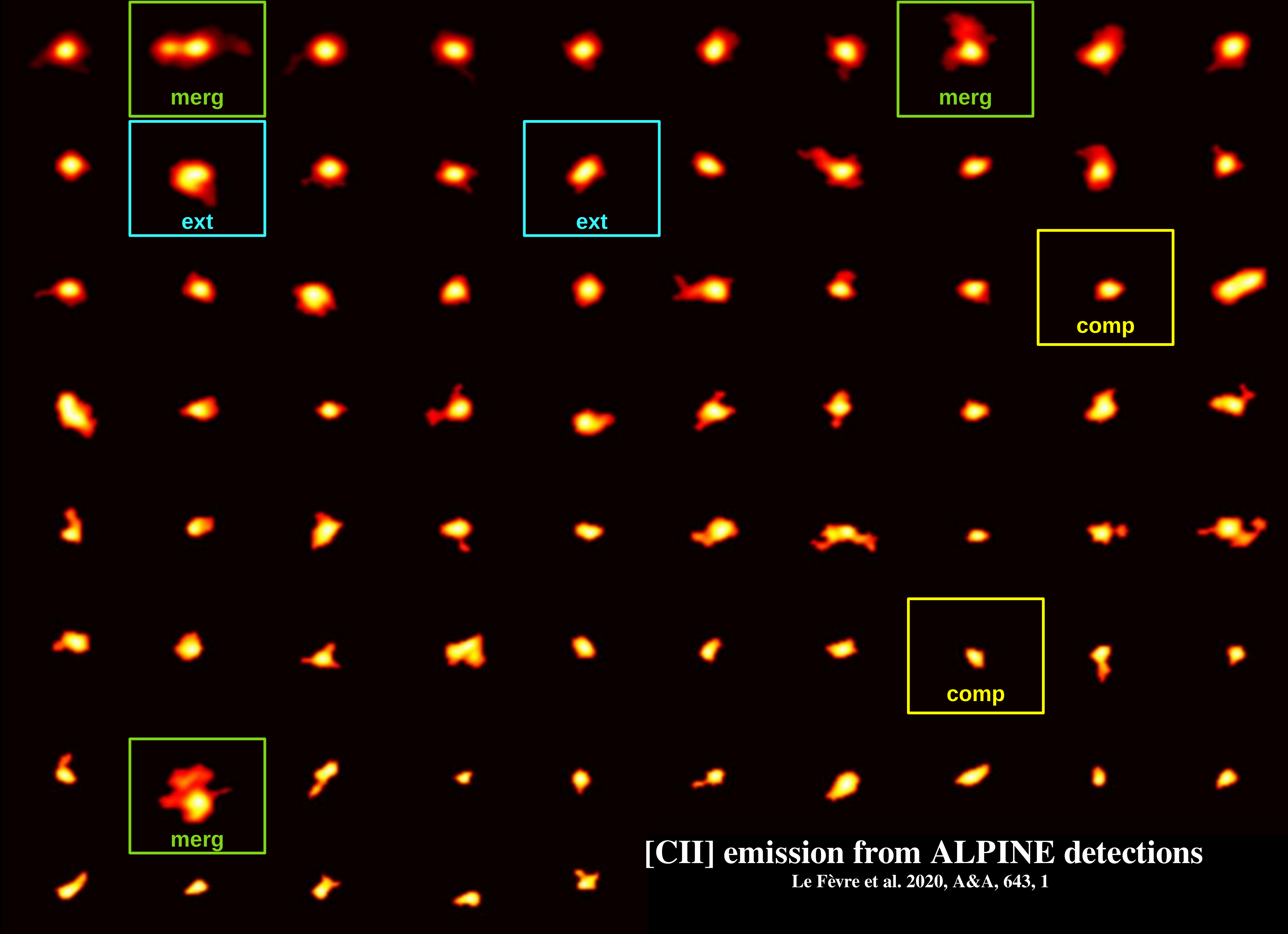




118 ALPINE targets

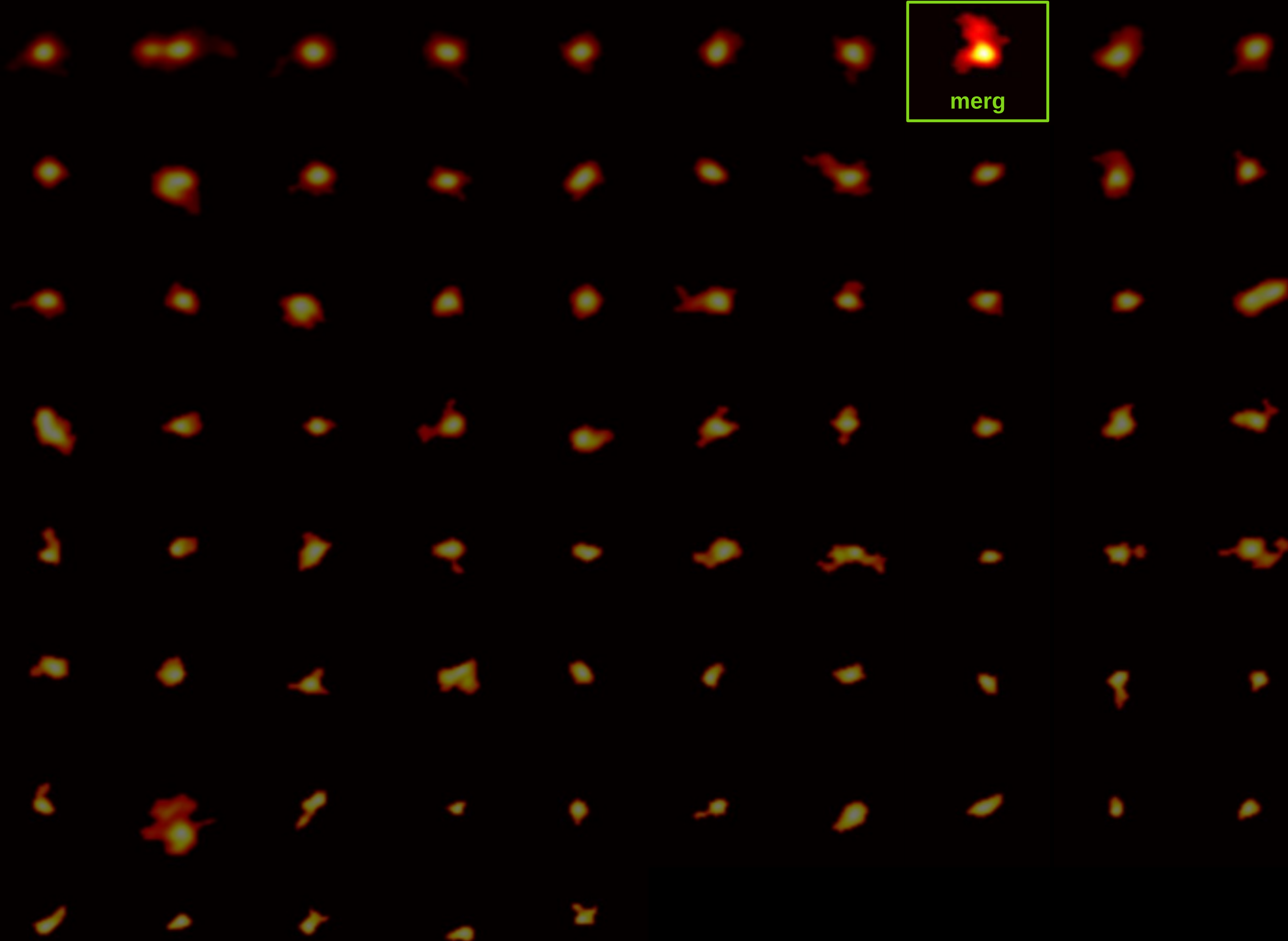
75 [CII] detections (S/N > 3.5)

43 [CII] non-detections

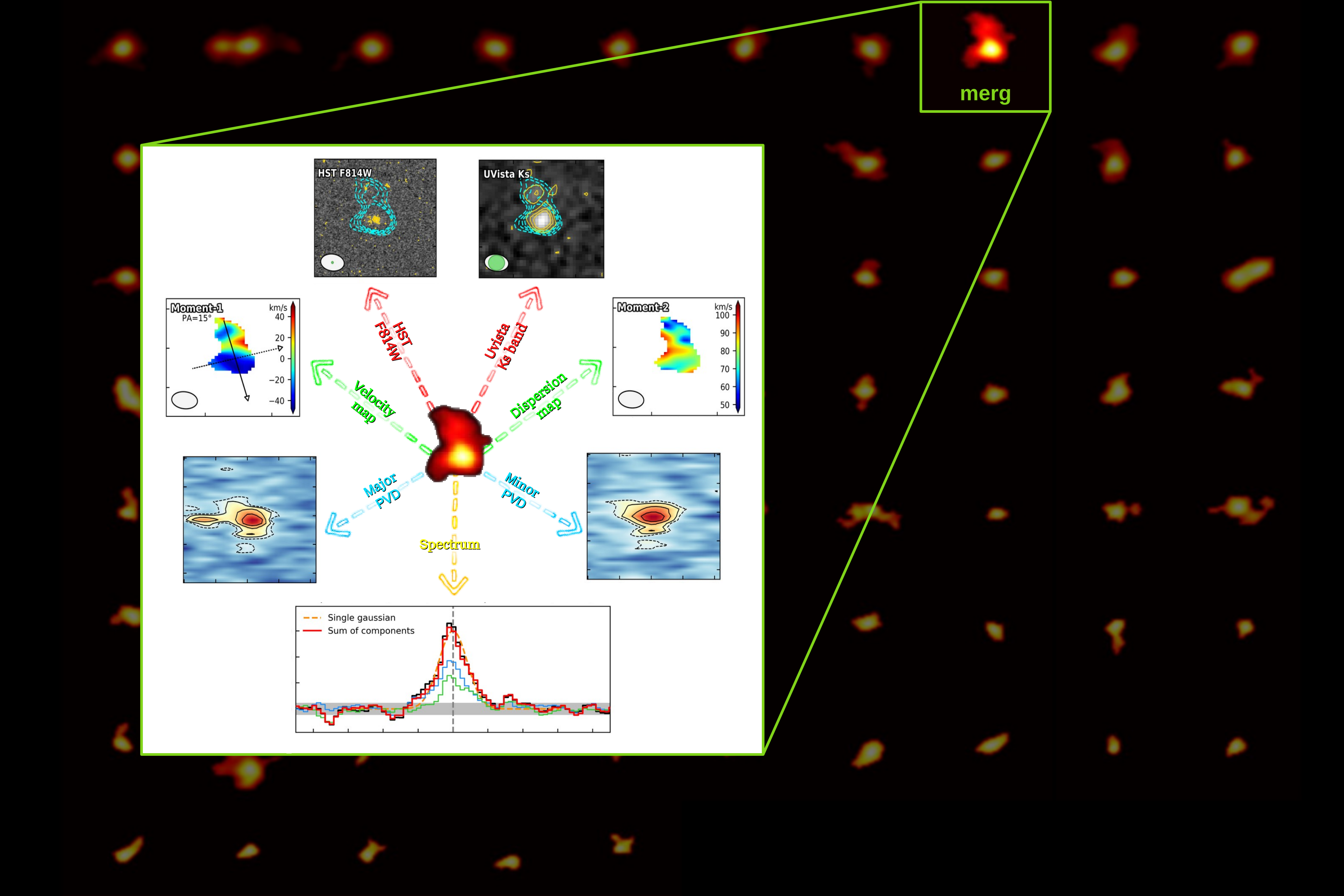


[CII] emission from ALPINE detections

Le Fèvre et al. 2020, A&A, 643, 1



merg



merg
HST F814W
UVista Ks
Moment-1
PA=15°
km/s
Moment-2
HST F814W
Uvista Ks band
Velocity map
Dispersion map
Major PVD
Minor PVD
Spectrum
Single gaussian
Sum of components


Final sample:
23/75 mergers

Major merger fraction

$$f_{MM}(z) = 0.88 \frac{\sum_{j=1}^{N_p} w_{comp}^j}{N_g}$$

# of mergers in the redshift bin

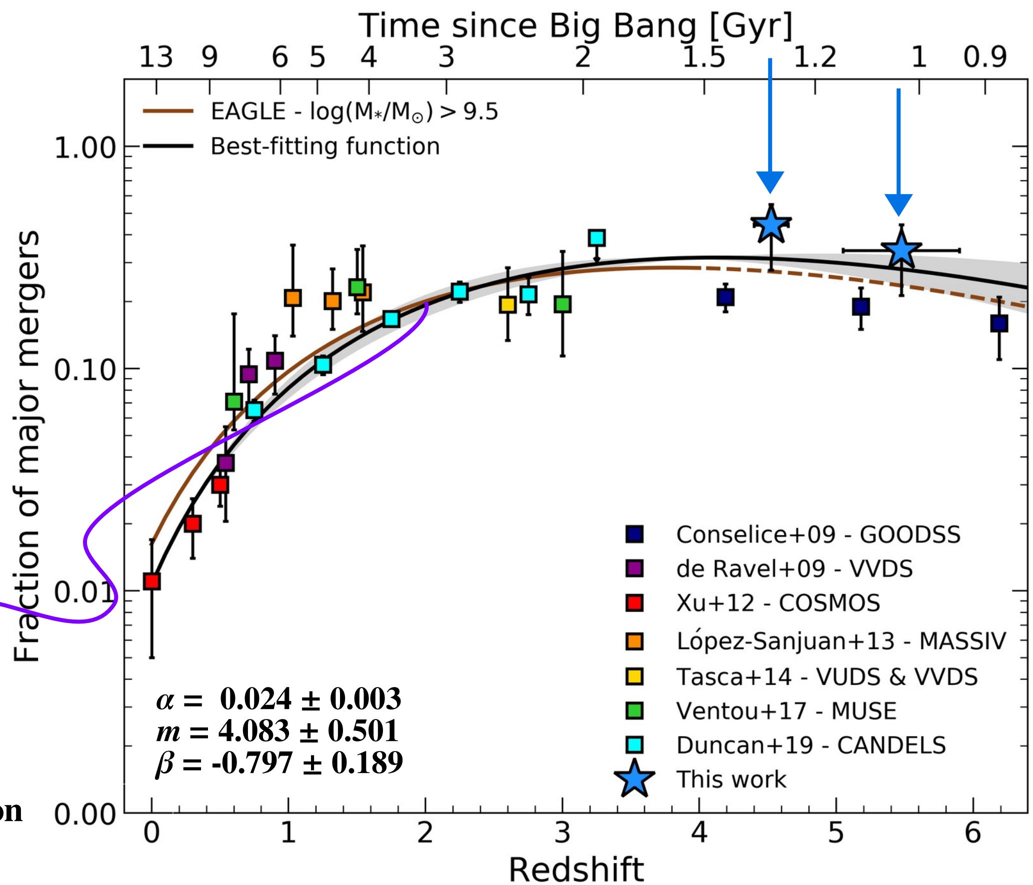
Completeness correction

Uncertainty due to contamination from minor mergers

# of ALPINE galaxies in the redshift bin

$f_{MM}(z \sim 4.5) = 0.44^{+0.11}_{-0.16}$

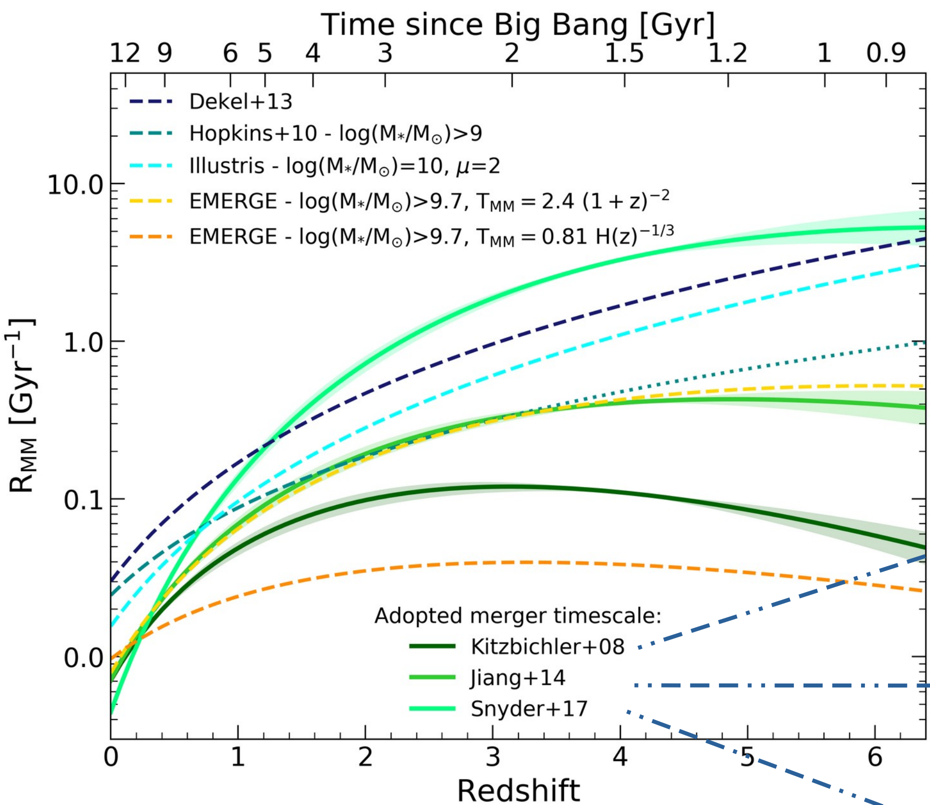
$f_{MM}(z \sim 5.5) = 0.34^{+0.10}_{-0.13}$



$$f_{MM}(z) = \alpha(1+z)^m e^{\beta(1+z)}$$

Cosmic evolution of the major merger fraction

Major merger rate



Cosmic evolution of the major merger rate

Fraction of galaxy pairs that will merge

$$R_{MM}(z) = \frac{C_{merg}\, f_{MM}(z)}{T_{MM}(z)}$$

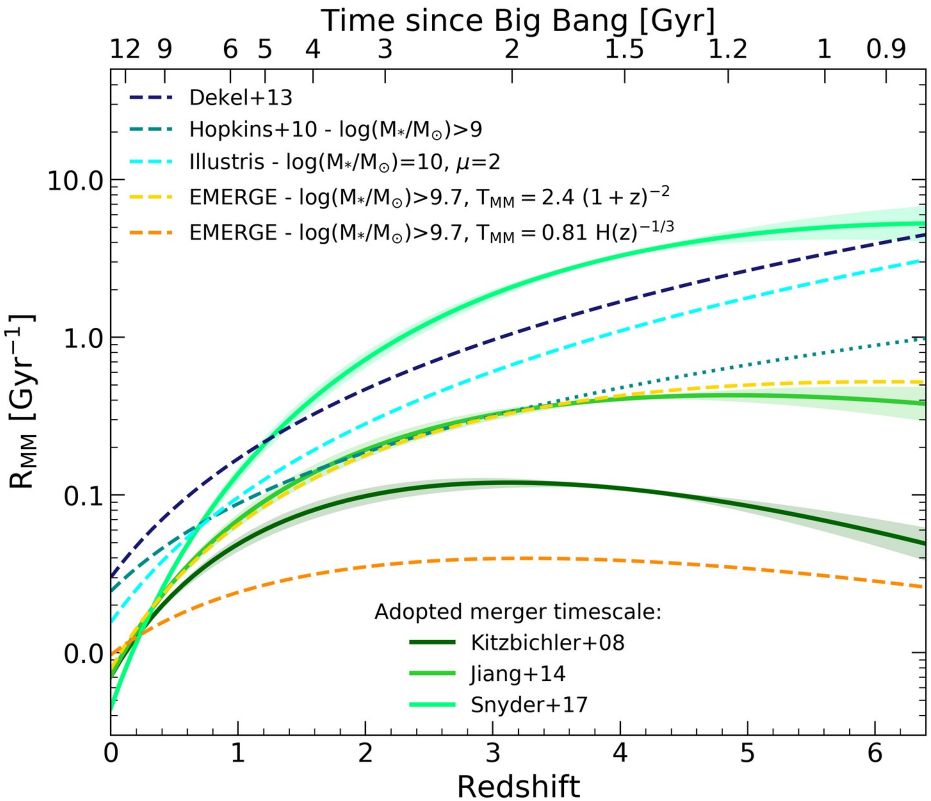
Merger timescale

$T_{MM} \propto z$ **from Millennium simulation**

$T_{MM} \propto H(z)^{-1/3}$ **from N-body simulations**

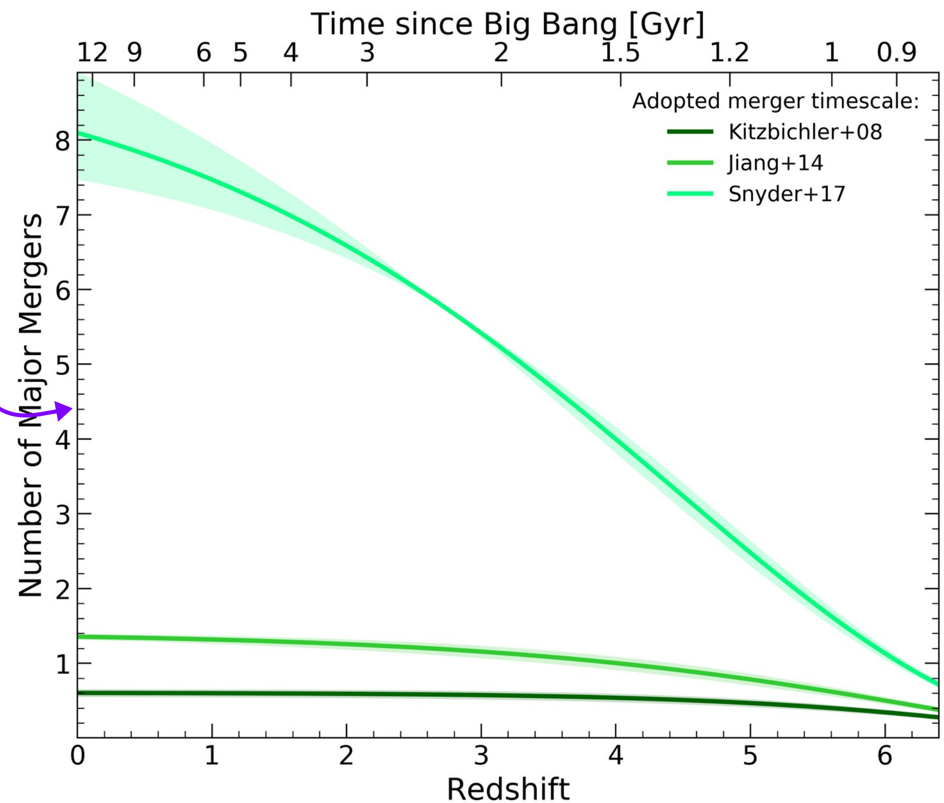
$T_{MM} \propto (1+z)^{-2}$ **from Illustris simulation**

Major merger rate & cumulative number of mergers



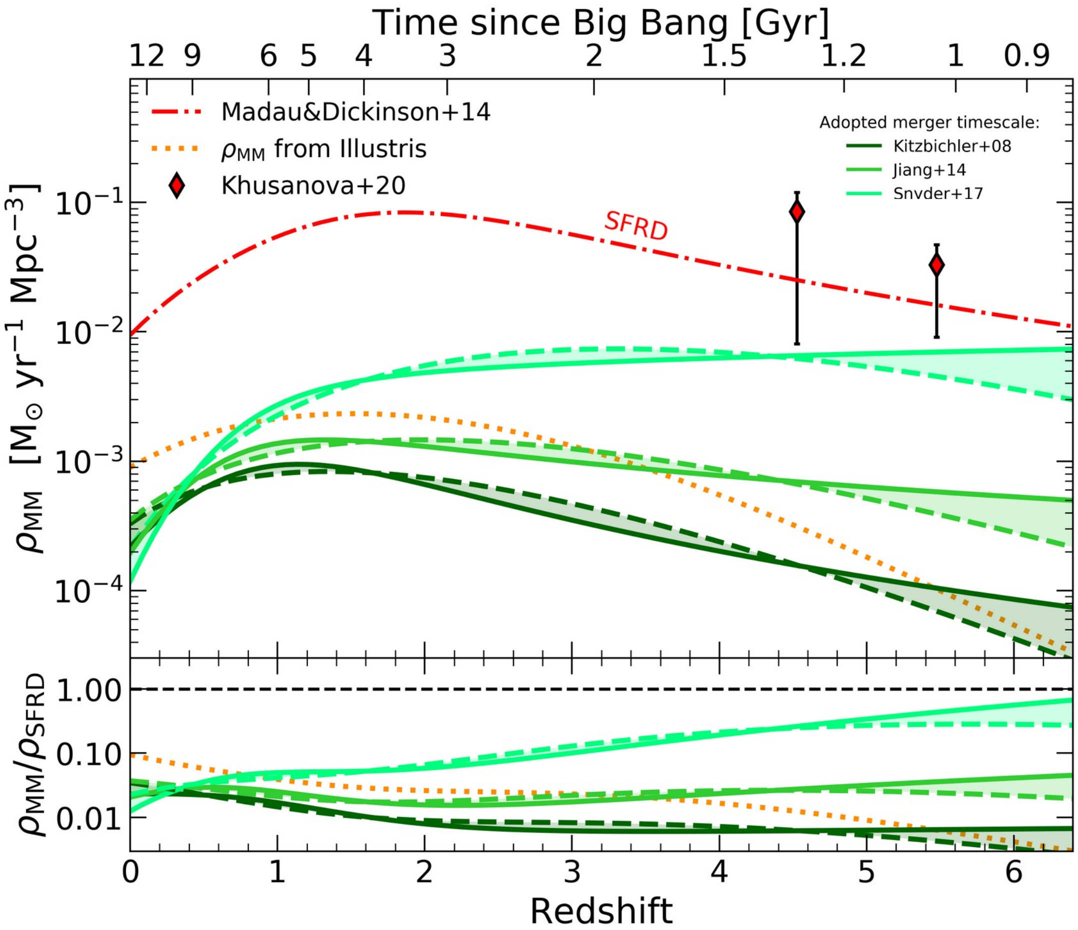
Cosmic evolution of the major merger rate

$$N_{MM}(z) = \int_{z_1}^{z_2} \frac{R_{MM}(z)}{(1+z)H_0 E(z)} dz$$

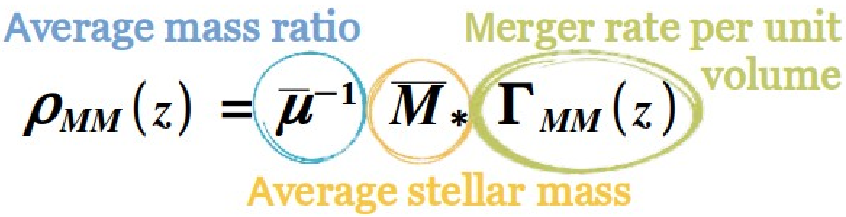


Cumulative number of major mergers per galaxy over cosmic time

The contribution of mergers to the mass assembly

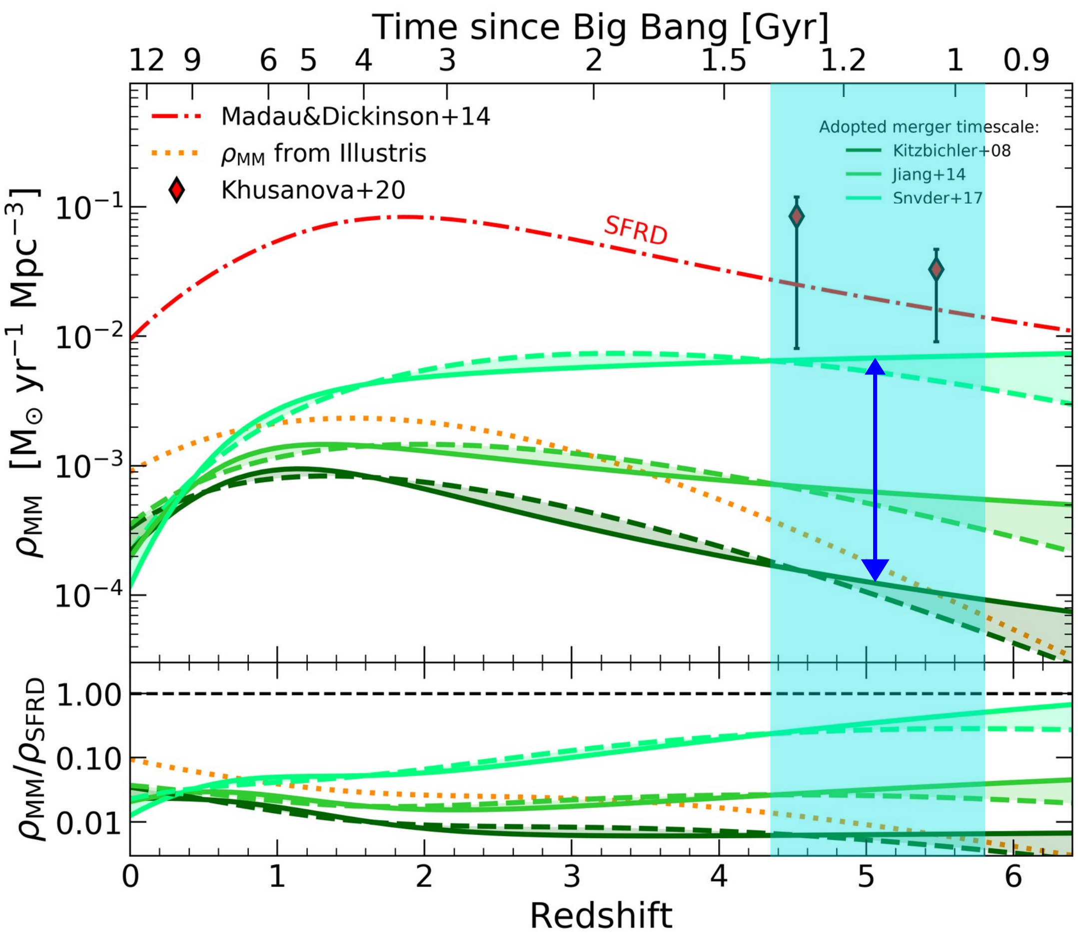


Comparison between mass accretion rate density (ρ_{MM}) and SFRD (ρ_{SFRD})



$$\rho_{MM}(z) = \bar{\mu}^{-1}\,\overline{M}_*\,\Gamma_{MM}(z)$$

The contribution of mergers to the mass assembly



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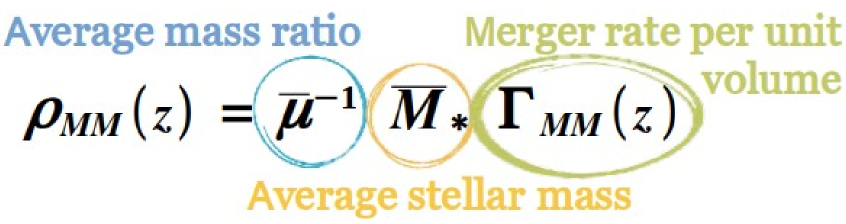


$$\rho_{MM}(z) = \bar{\mu}^{-1}\,\bar{M}_*\,\Gamma_{MM}(z)$$

The merger contribution to the galaxy mass-assembly at high-z strongly depends on the assumed merger timescale

Conclusions

- **First constraint on the major merger fraction at z~5 from [CII] observations**
- **Significant merging activity in the early Universe**
- **Major mergers provide a smaller contribution to the mass assembly than in-situ SFR at all epochs but:**
  - **The two processes could be comparable at z > 5**
  - **Large uncertainties on the merger timescale prevent firm conclusions**

Conclusions and prospects

- First constraint on the major merger fraction at z~5 from [CII] observations
- Significant merging activity in the early Universe
- Major mergers provide a smaller contribution to the mass assembly than in-situ SFR at all epochs but:
  - The two processes could be comparable at z > 5
  - Large uncertainties on the merger timescale prevent firm conclusions

- Increase the statistics
- Increase the resolution
- Go to higher redshift
- Suggestions…?

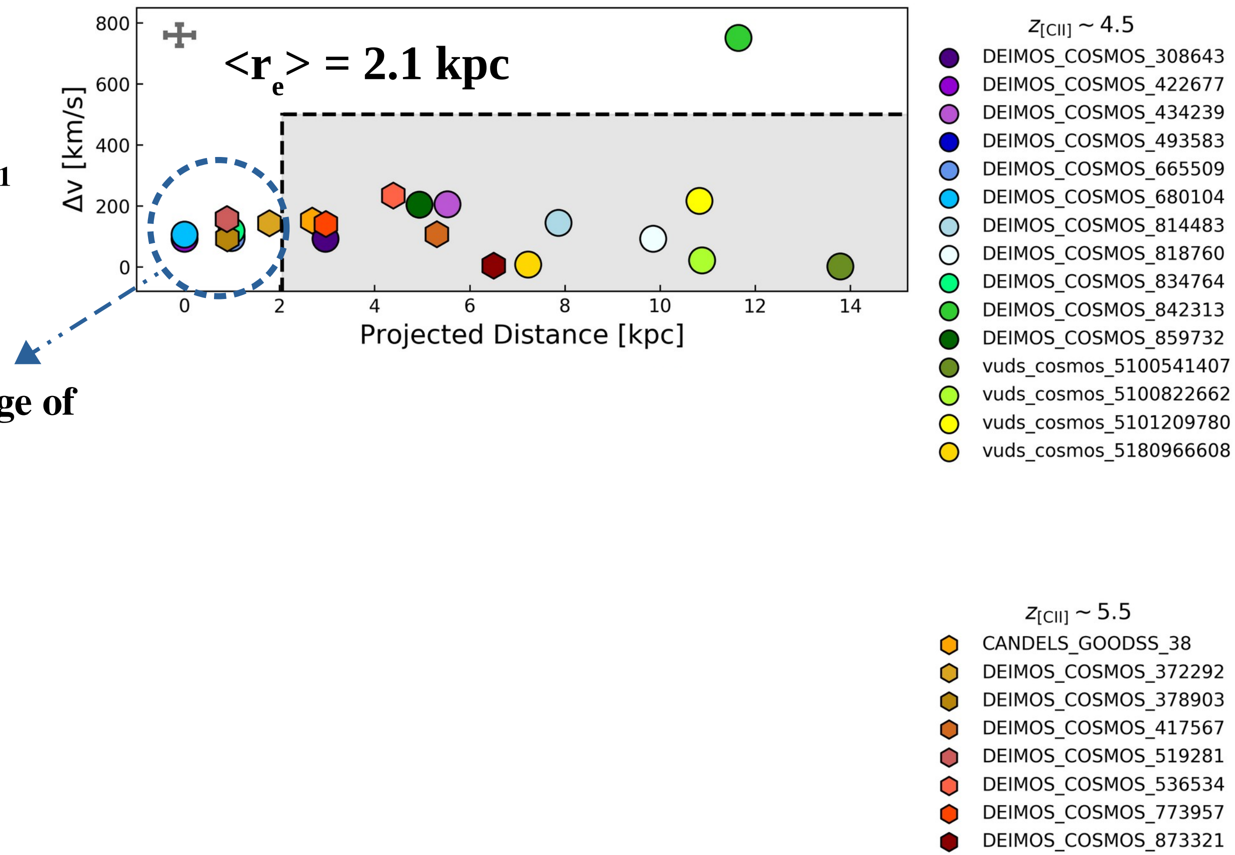

Thanks for the attention!

Extras

The merger sample

r_p > 2.1 kpc

Δv < 500 km s^{-1}



Galaxies in a final stage of merging?

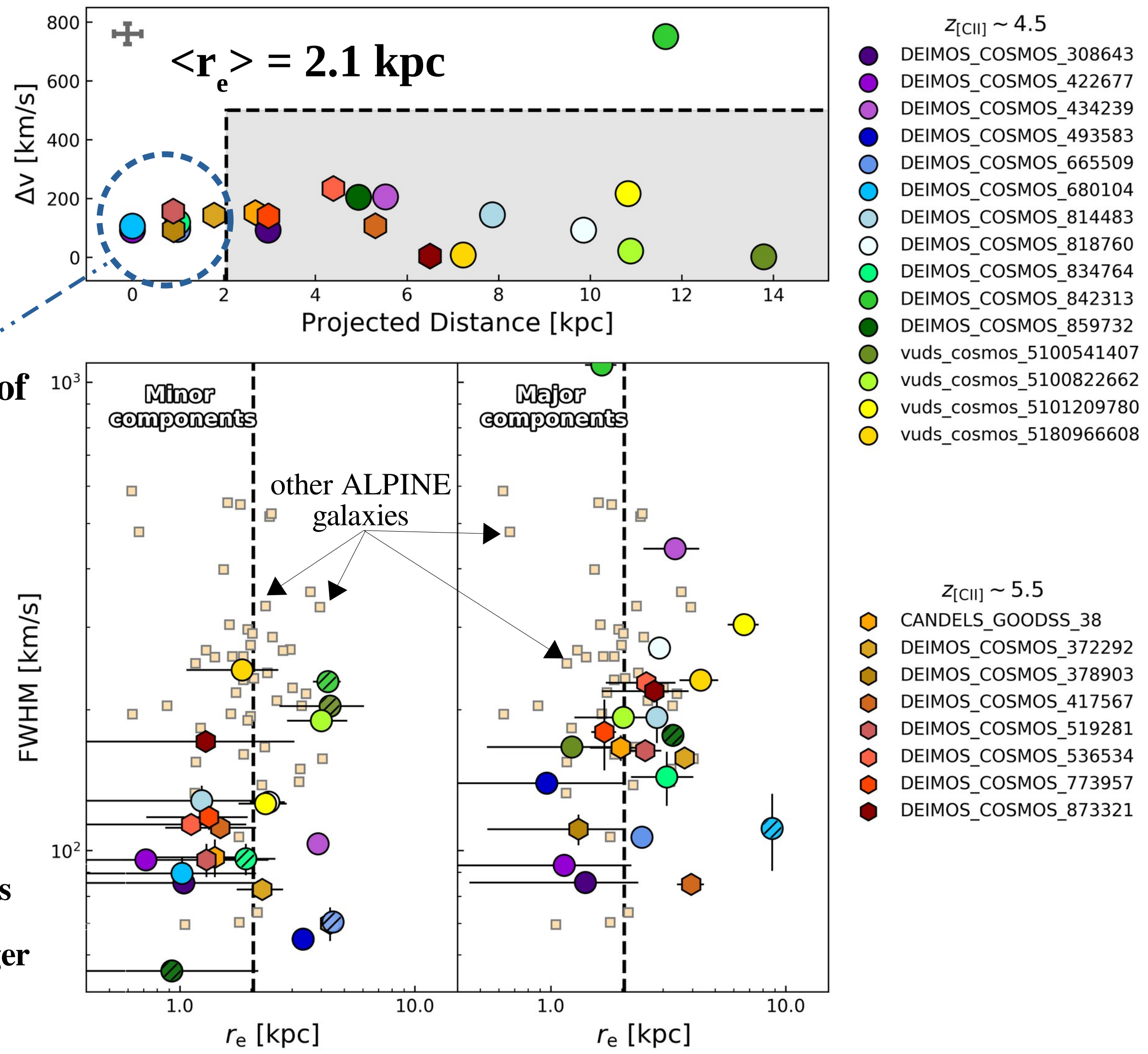
***Top*: Δv vs r_p for the ALPINE mergers**

The merger sample

$r_p > 2.1$ kpc

$\Delta v < 500$ km s^{-1}

Galaxies in a final stage of merging?



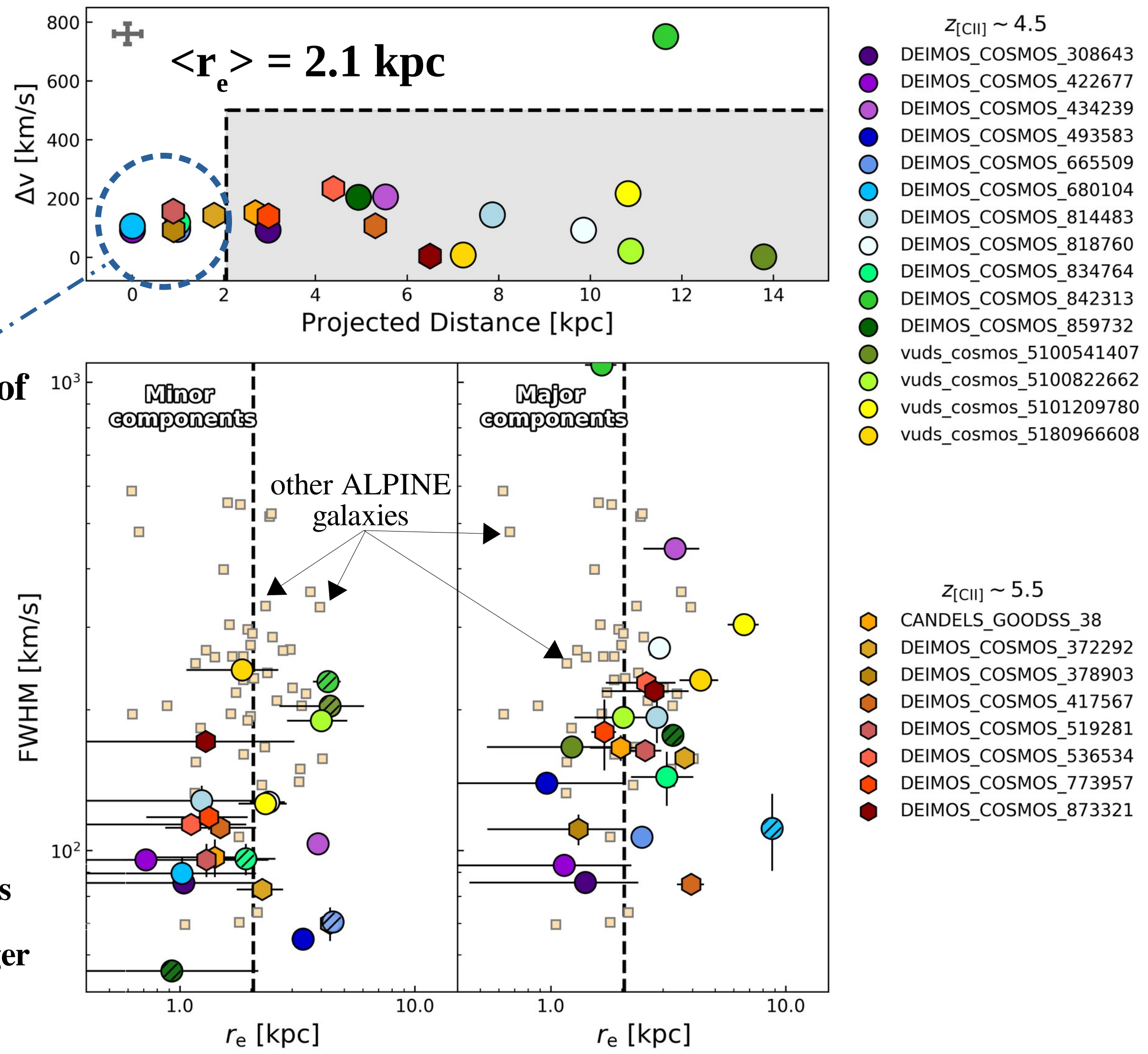
Top: Δv vs r_p for the ALPINE mergers

Bottom: FWHM vs size for each merger component

The merger sample

r_p > 2.1 kpc

Δv < 500 km s^{-1}



Galaxies in a final stage of merging?

Final sample: 23/75 mergers

***Top*: Δv vs r_p for the ALPINE mergers**

***Bottom*: FWHM vs size for each merger component**

Completeness correction

Luminosity of the secondary component assuming μ=4

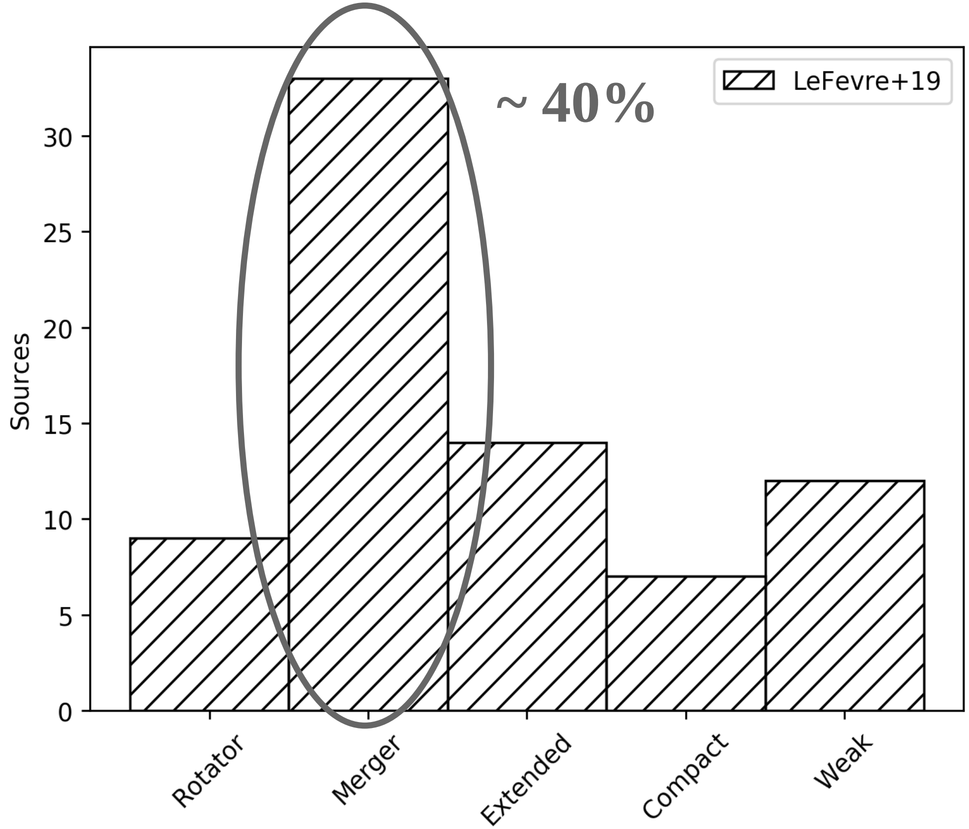
Luminosity of the primary component

[CII] luminosity function from ALPINE

$$w_{comp}(L,z) = \frac{\int_{L2}^{L1} \Phi(L,z)\, dL}{\int_{Llim}^{L1} \Phi(L,z)\, dL}$$

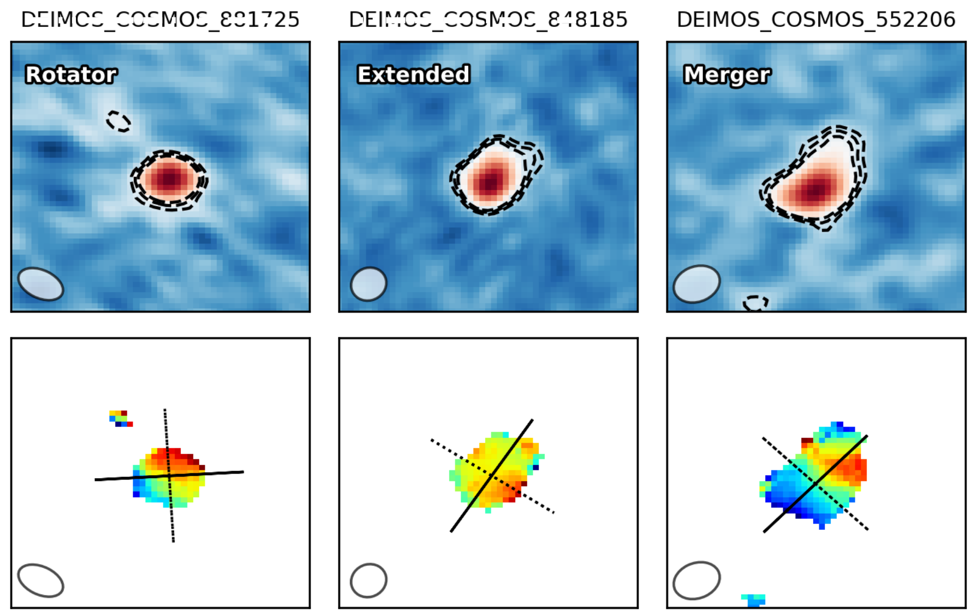
Limiting luminosity of each ALPINE pointing

Morpho-kinematic classification by Le Fèvre



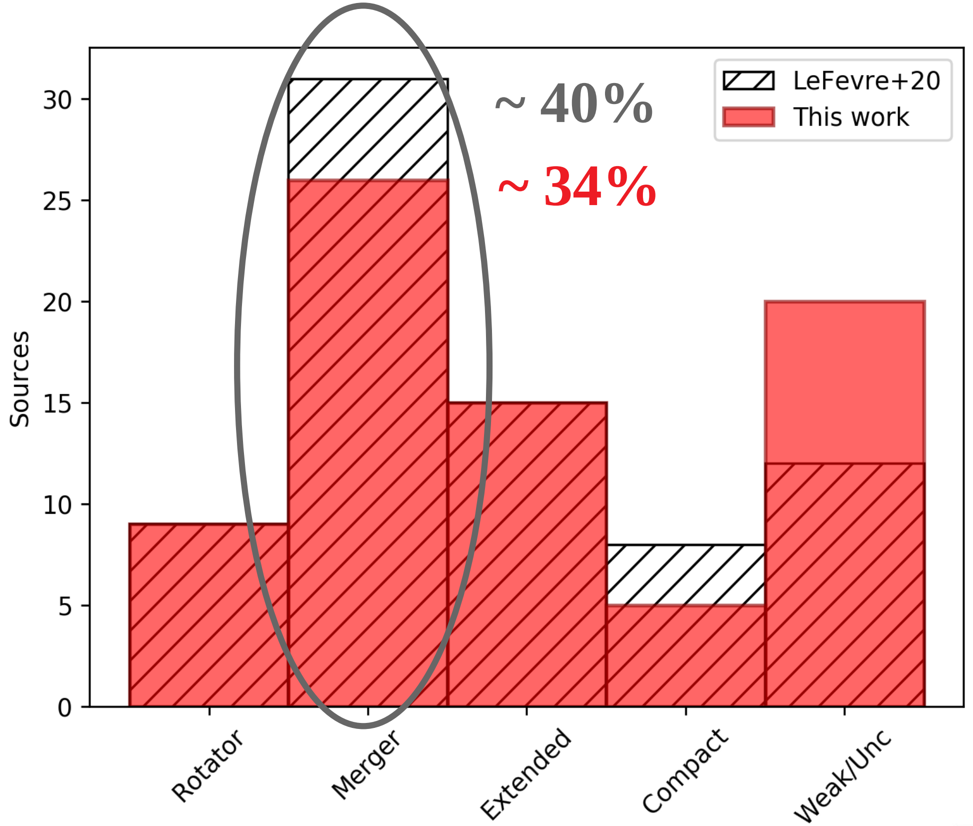
Distribution of morpho-kinematic classes in the ALPINE sample as obtained by Le Fèvre et al. 2020

Rotating discs:	**13.3 %**
Mergers:	**40 %**
Extended:	**20 %**
Compact:	**10.7 %**
Too weak:	**16 %**



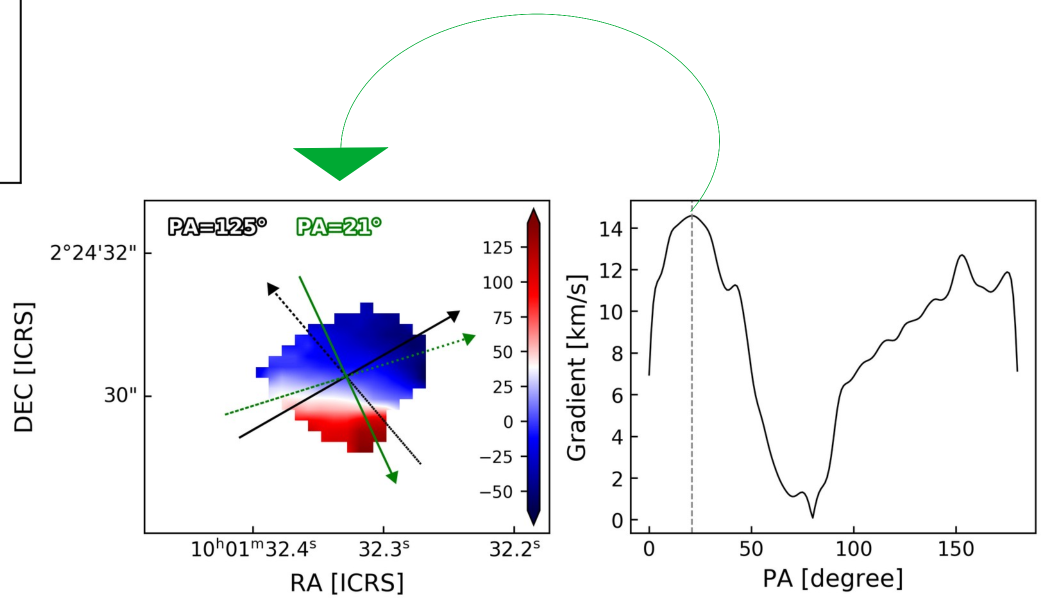
Example of ALPINE galaxies showing different [CII] morphology and kinematics

New morpho-kinematic classification

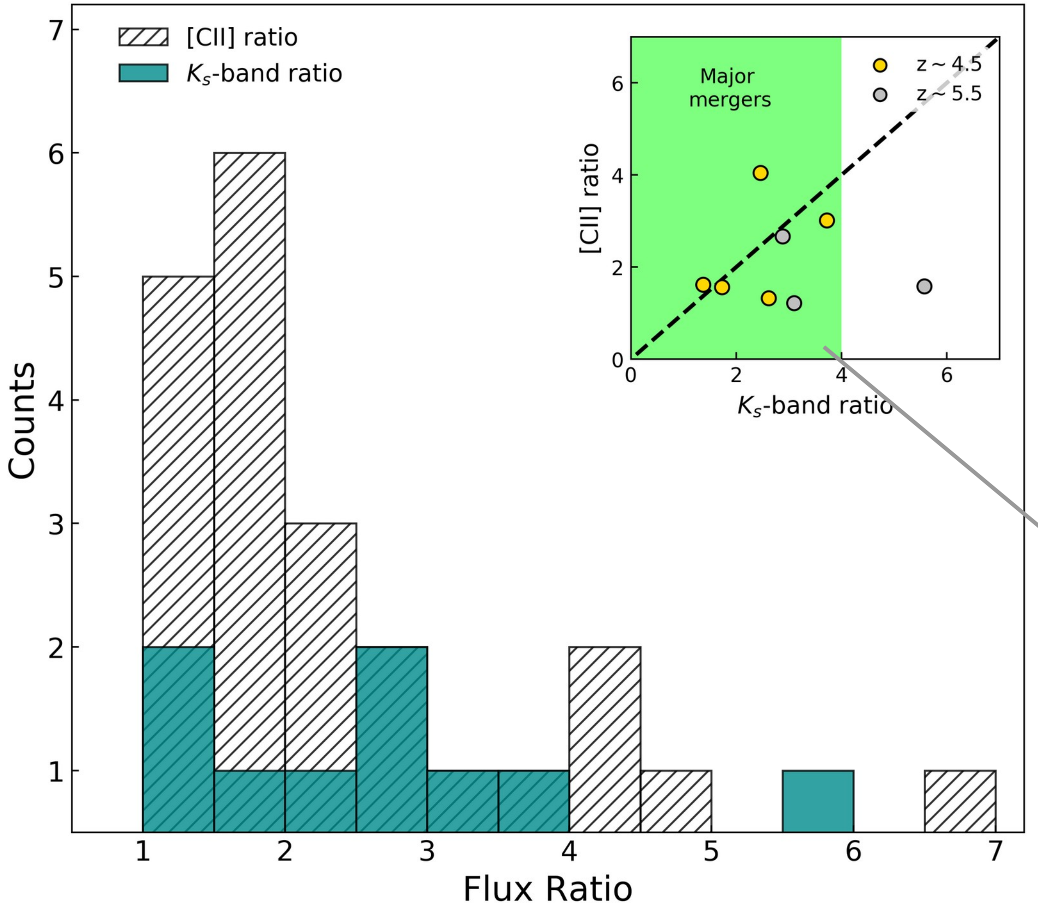


Some differences:

1. **All pixels above 3x(average rms)**
2. **Major axis along the major velocity gradient**
3. **Only sources with minor component having S/N>3**



Distinction between major and minor mergers



Distribution of Ks-band and [CII] flux ratios

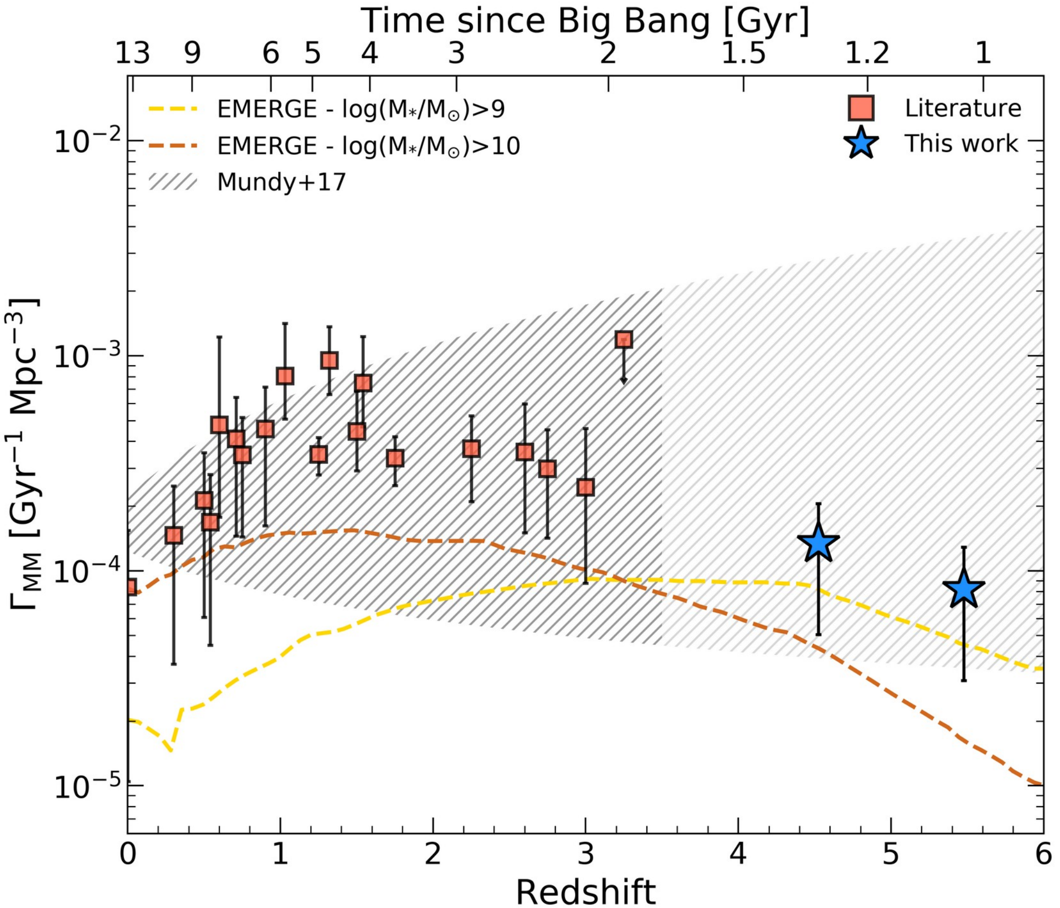
$1 \leq \mu_K \leq 4 \rightarrow$ Major merger

$\mu_K > 4 \rightarrow$ Minor merger

88% of sub-sample having both μ_K and $\mu_{[CII]} < 4$

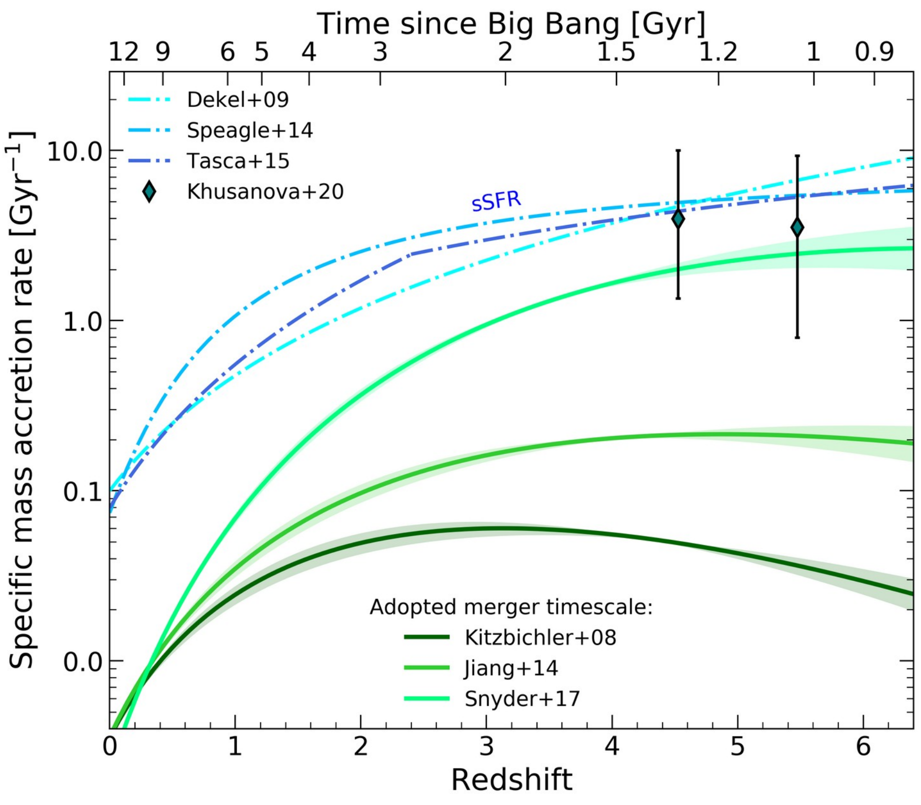
Merger rate density

$$\Gamma_{MM}(z) = \frac{f_{MM}(z)\, n(z)}{T_{MM}(z)}$$



Merger rate density as a function of redshift

The contribution of mergers to the mass assembly



Comparison between specific mass accretion rate (sMAR) and specific star-formation rate (sSFR)

$$sMAR(z) = R_{MM}(z)\,\mu^{-1}$$