

ALPINE:

*A Large Survey to Understand
Teenage Galaxies*

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Collage of ALPINE galaxies imaged in C+ at 158 μ m with ALMA
Background: II Zw 40 (similar to high-z galaxies?)

The Big Picture of Galaxy Evolution



The Universe is diverse ...



Star Forming Galaxies
($t = 13.7$ Gyrs; $z = 0$)

The Universe is diverse ...



Quiescent Elliptical
Galaxy
($t = 13.7$ Gyrs; $z = 0$)

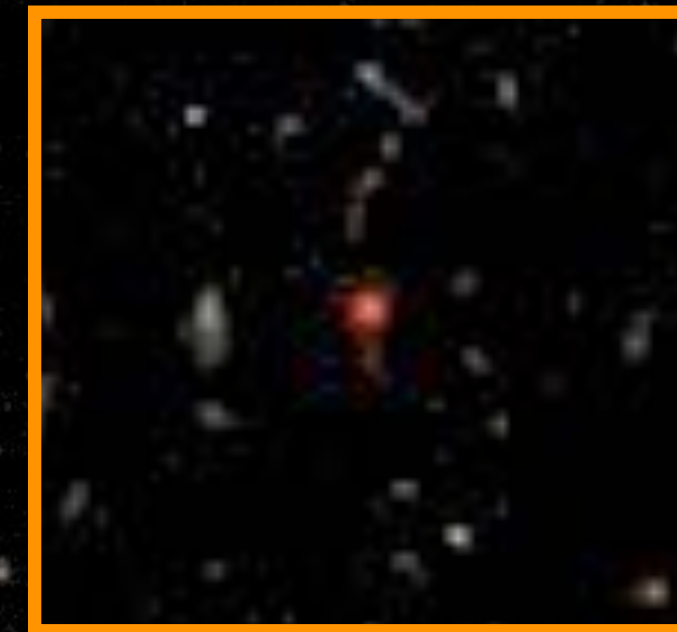
The Universe is diverse ...



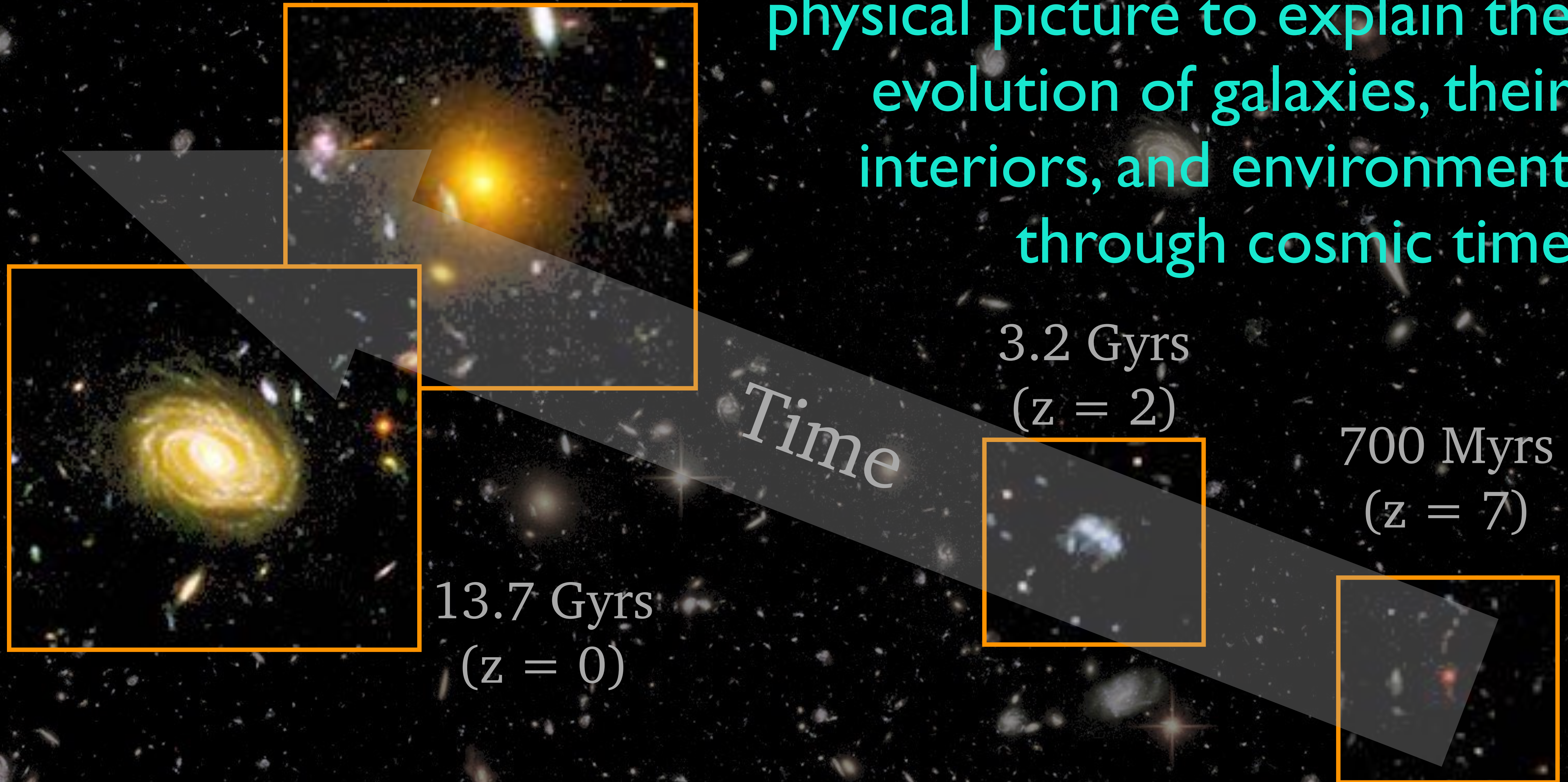
Star Forming Galaxy at
Peak of Cosmic Star Formation
($t = 3.2$ Gyrs, $z = 2$)

The Universe is diverse ...

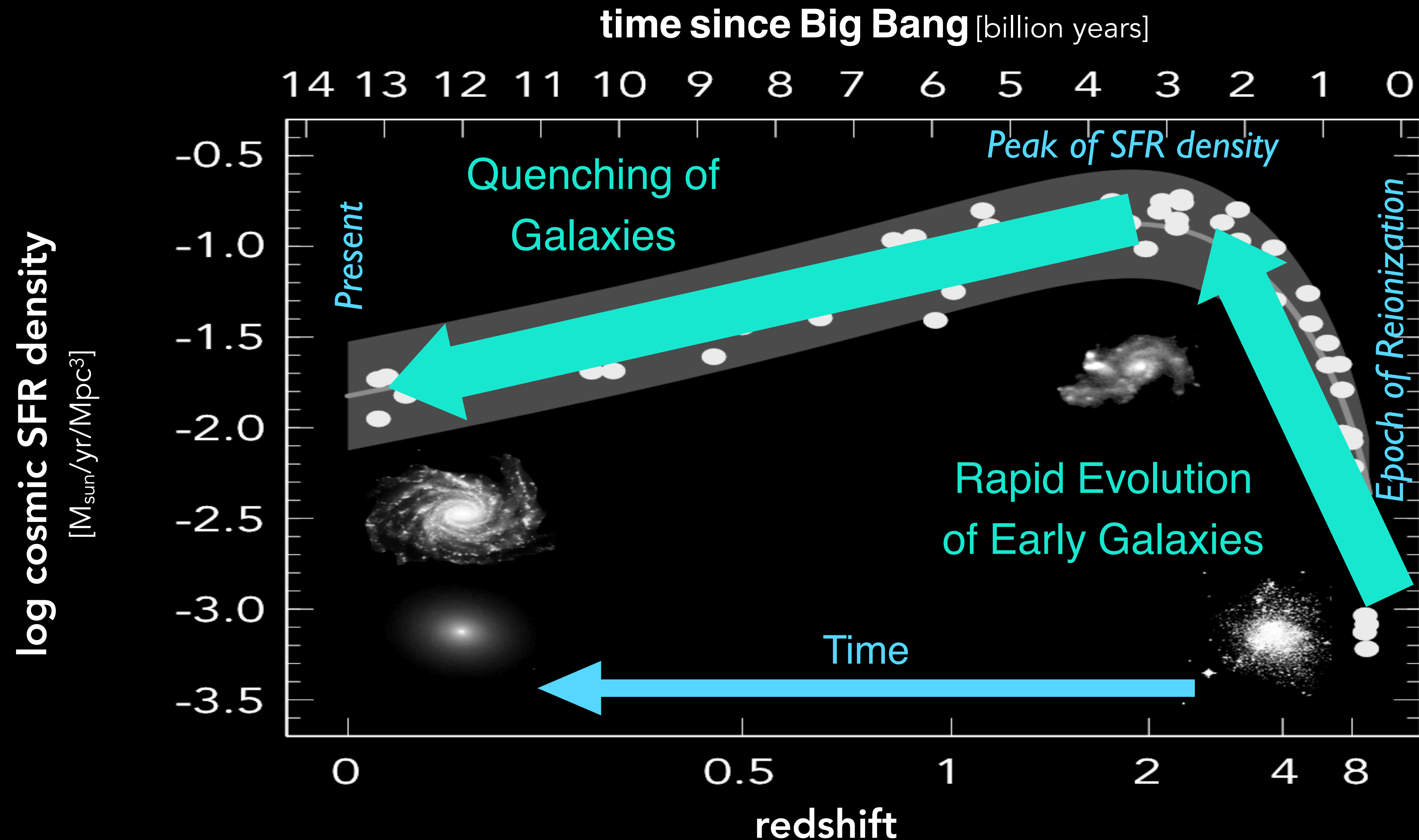
Primordial Galaxy in
the Early Universe
($t = 700$ Myrs; $z = 7$)



Goal: Find a Coherent physical picture to explain the evolution of galaxies, their interiors, and environment through cosmic time



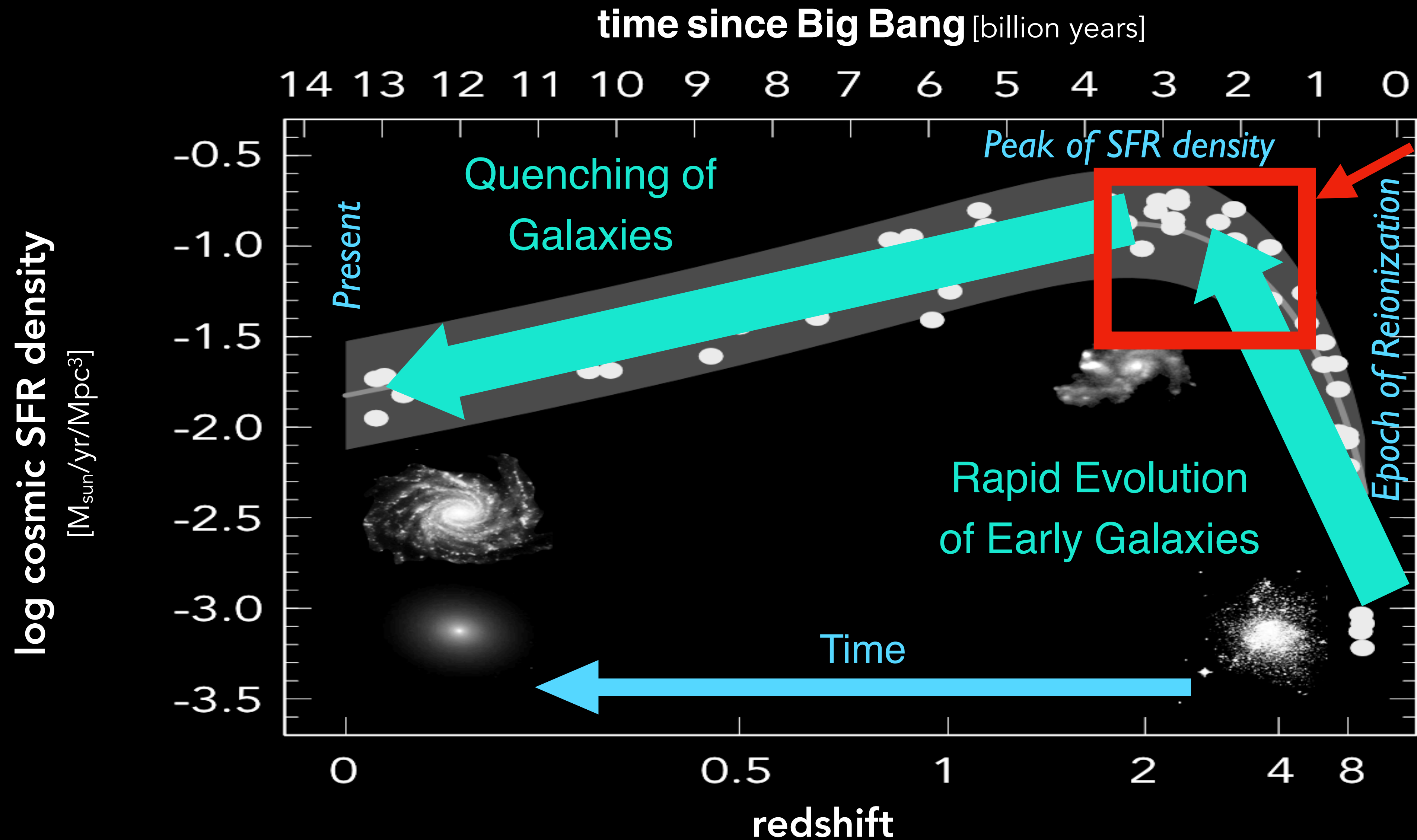
Production of Stars and Structure over Cosmic Time



Data from: Madau & Dickinson (2014); Bouwens et al. (2015)


Production of Stars and Structure over Cosmic Time

*How do
Galaxies
get here?*



Data from: Madau & Dickinson (2014); Bouwens et al. (2015)

**What characterizes
a galaxy?**

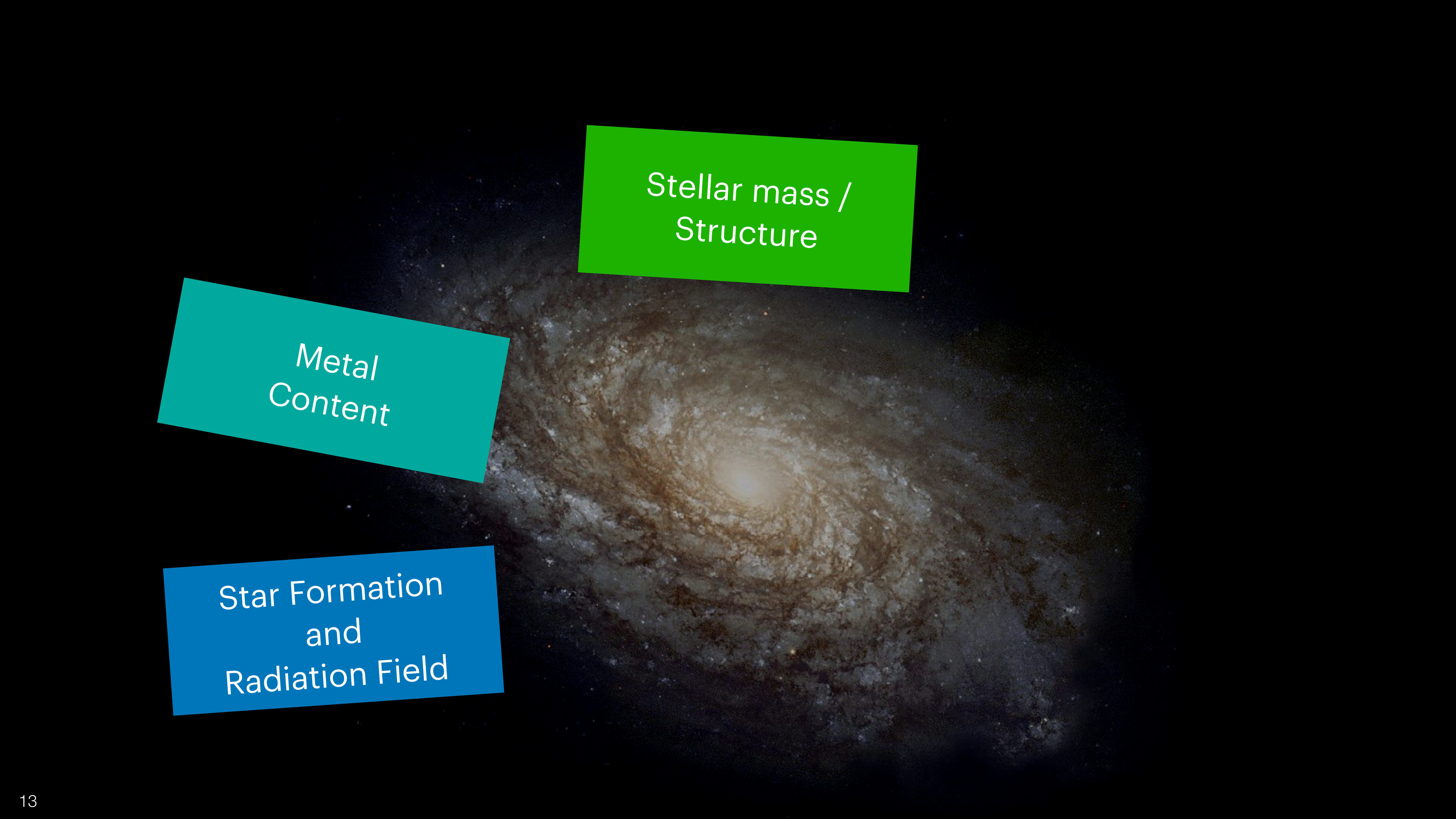


Star Formation
and
Radiation Field



Metal
Content

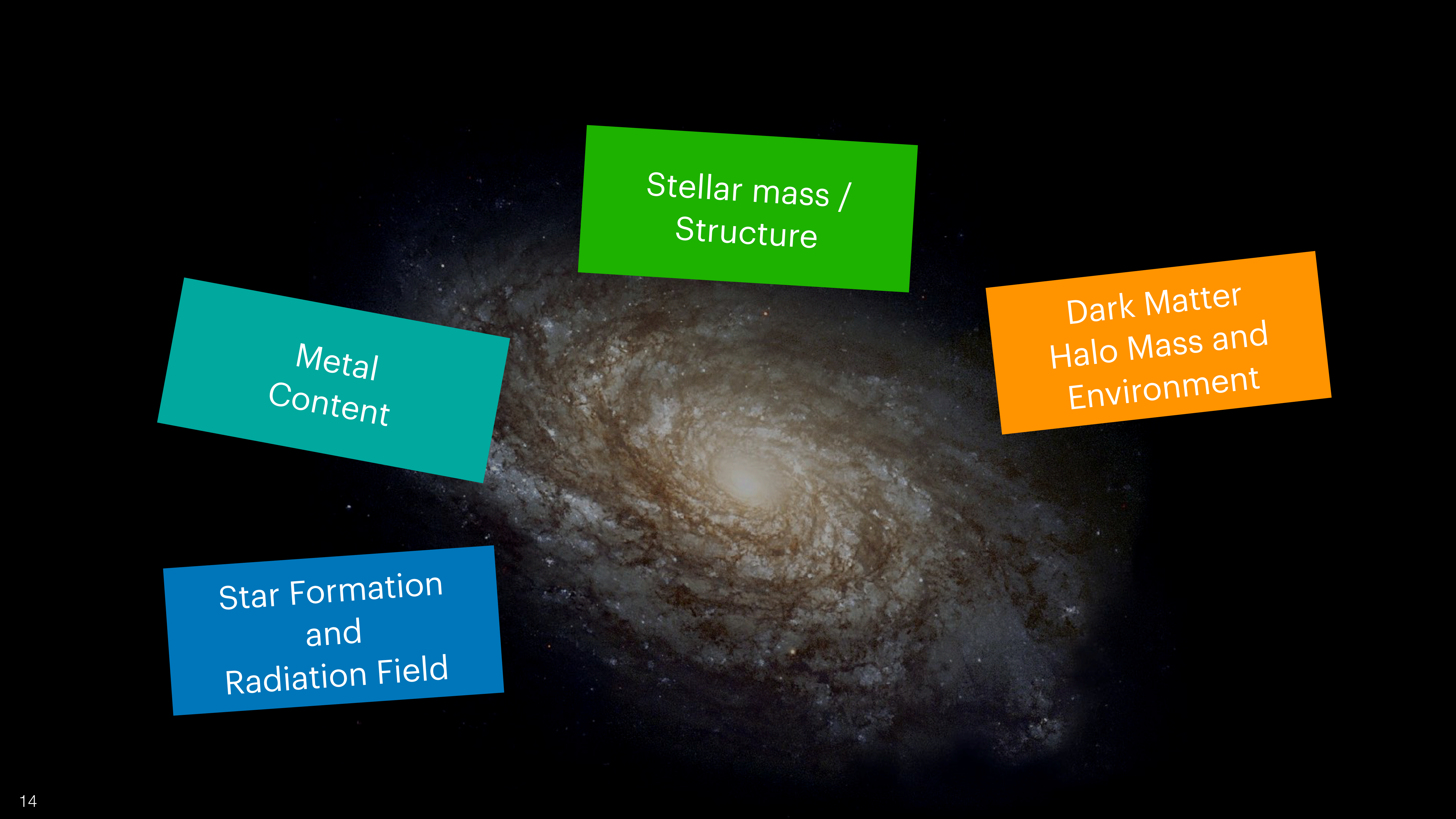
Star Formation
and
Radiation Field



Stellar mass /
Structure

Metal
Content

Star Formation
and
Radiation Field

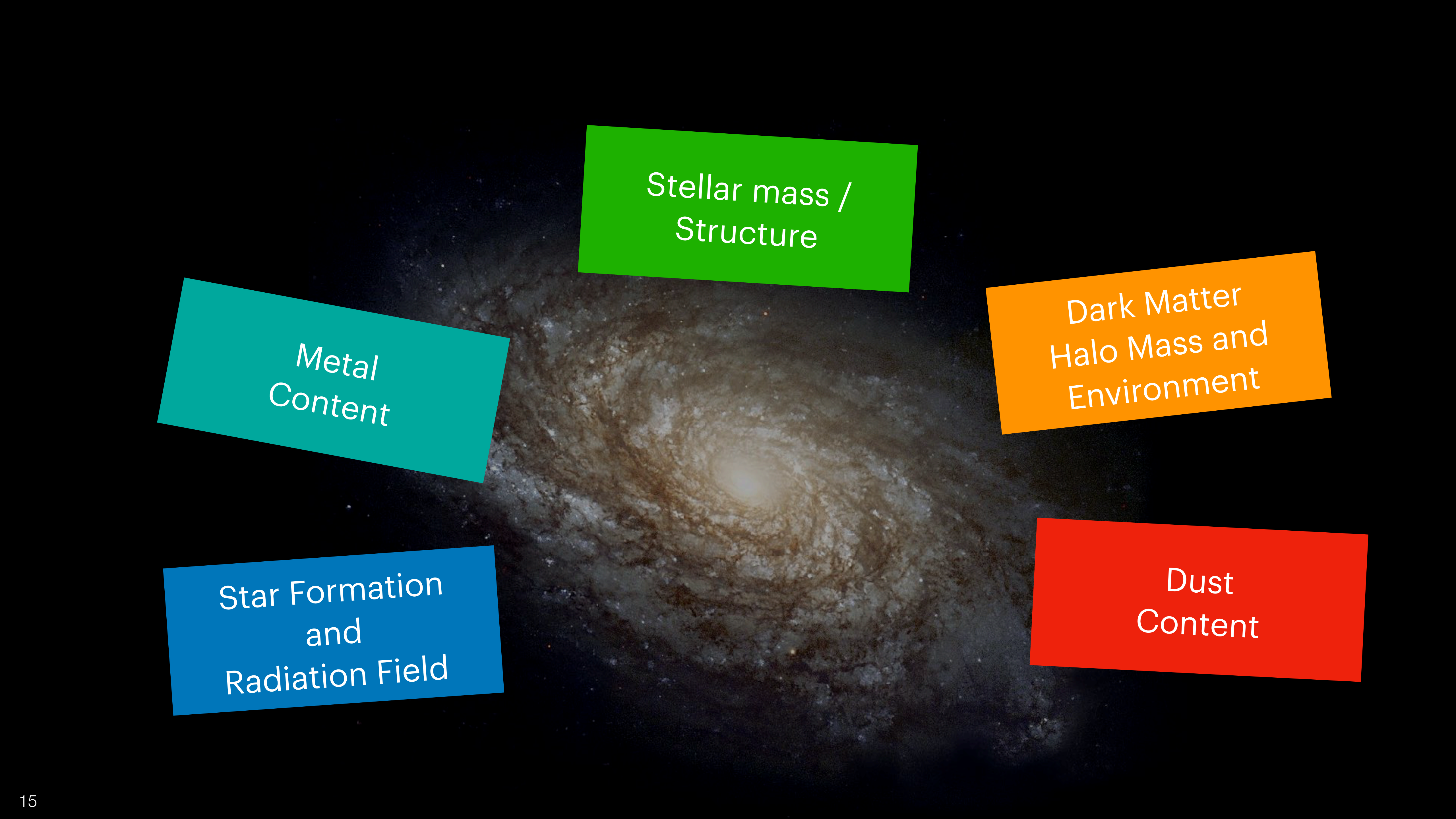
A background image of a spiral galaxy, likely the Milky Way, viewed from an angle. The galaxy's core is bright and yellowish, with several spiral arms extending outwards. The arms are composed of stars and dust, appearing in shades of brown and grey. Four colored callout boxes are overlaid on the image, each containing text related to galaxy properties.

Stellar mass /
Structure

Metal
Content

Dark Matter
Halo Mass and
Environment

Star Formation
and
Radiation Field



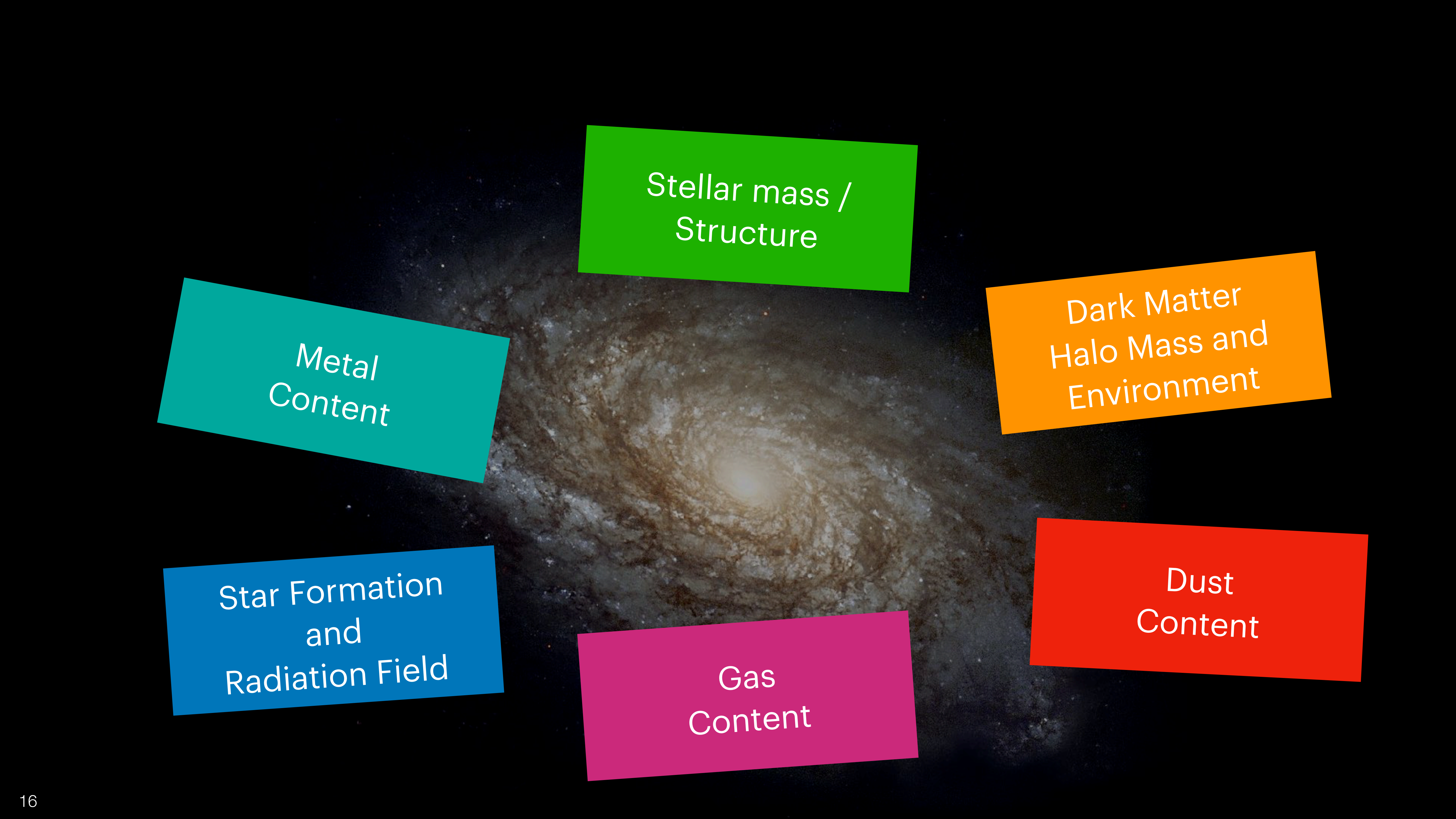
Stellar mass /
Structure

Metal
Content

Dark Matter
Halo Mass and
Environment

Star Formation
and
Radiation Field

Dust
Content



Stellar mass /
Structure

Dark Matter
Halo Mass and
Environment

Metal
Content

Star Formation
and
Radiation Field

Gas
Content

Dust
Content

Optical

Stellar mass /
Structure

Dark Matter
Halo Mass and
Environment

Metal
Content

**Multi-Wavelength
Sample is Needed**

Dust
Content

Star Formation
and
Radiation Field

Gas
Content

Ultra Violet

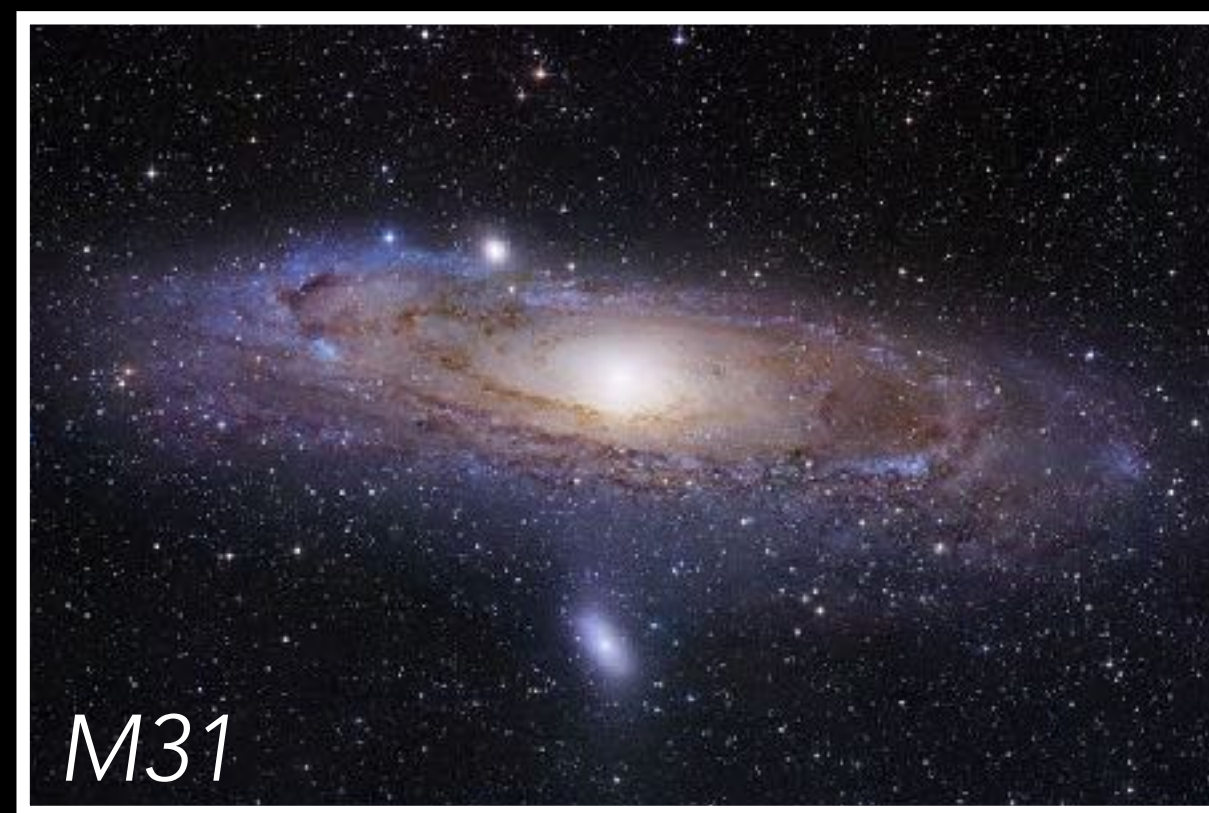
Infrared and sub-mm

**Can we extrapolate from
lower redshifts?**

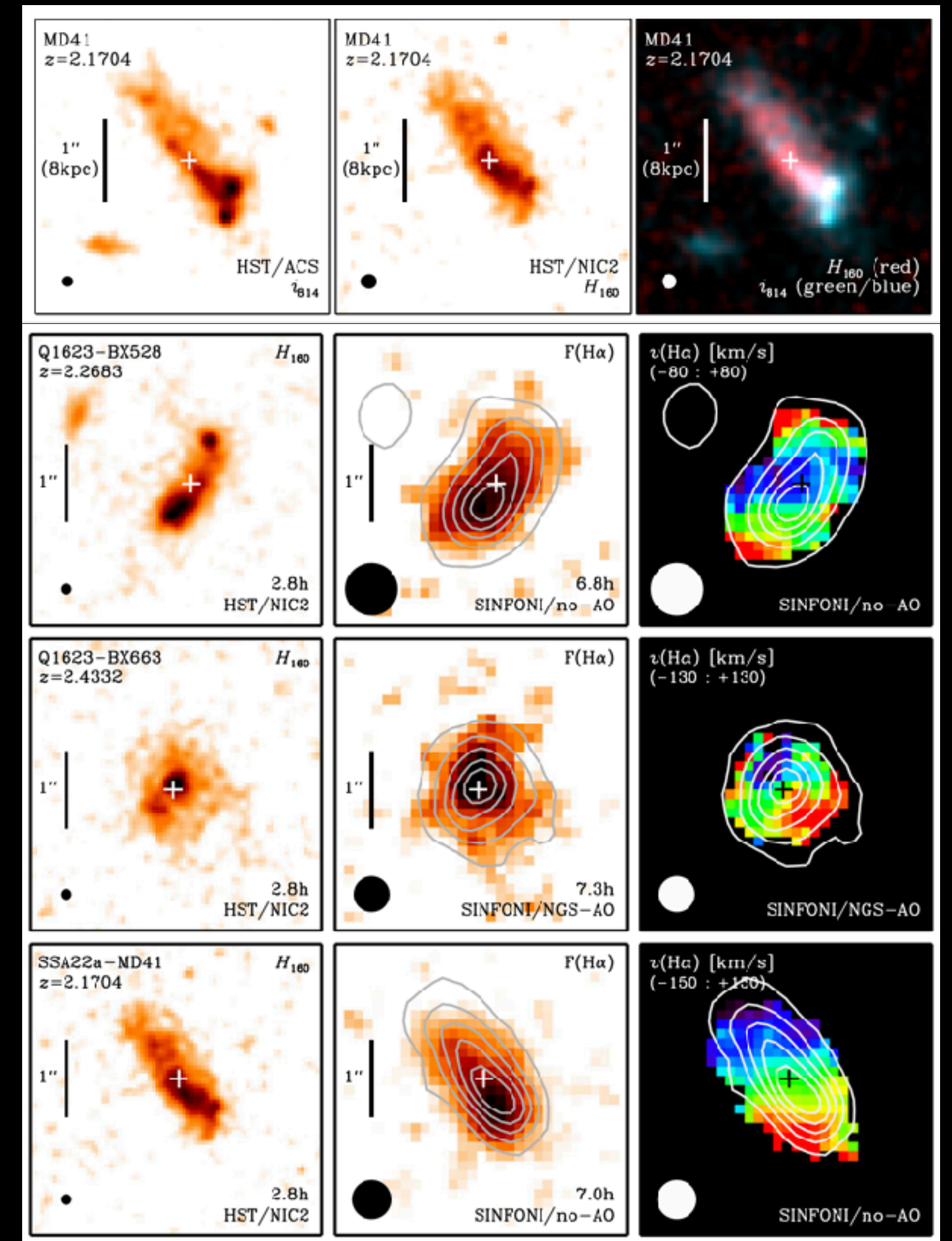
Extrapolation from Lower Redshifts

We can (maybe?) extrapolate the properties of high- z galaxies from galaxies at lower redshifts ($z < 3$)

- Irregular structure, suggesting turbulent gas accretion and growth, and possible lack of “disk galaxies”



$z = 2$



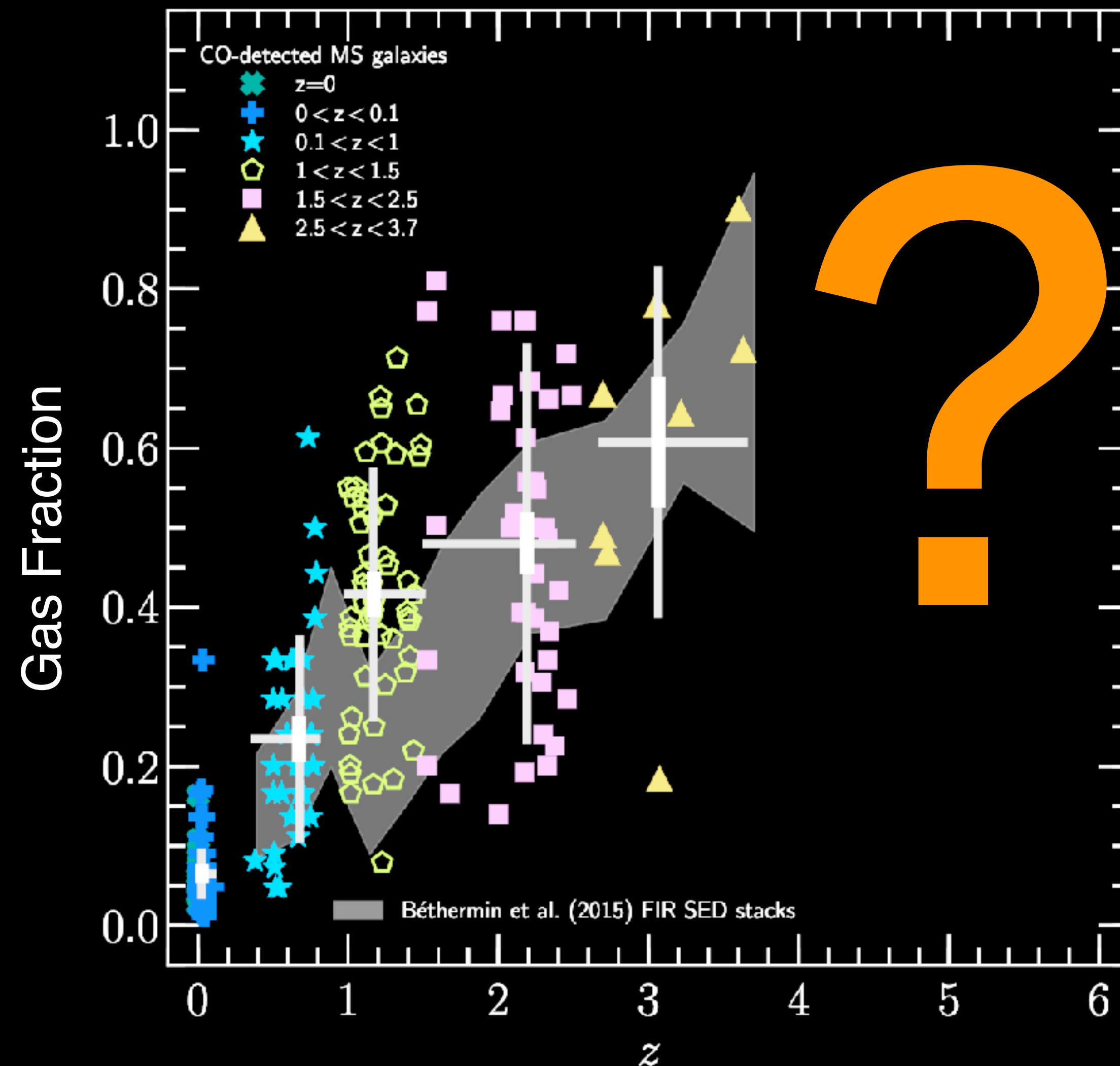
Förster-Schreiber et al. (2011)

Extrapolation from Lower Redshifts

We can (maybe?) extrapolate the properties of high- z galaxies from galaxies at lower redshifts ($z < 3$)

- Irregular structure, suggesting turbulent gas accretion and growth, and possible lack of “disk galaxies”
- Galaxies are rich in gas, suggesting high star formation rates

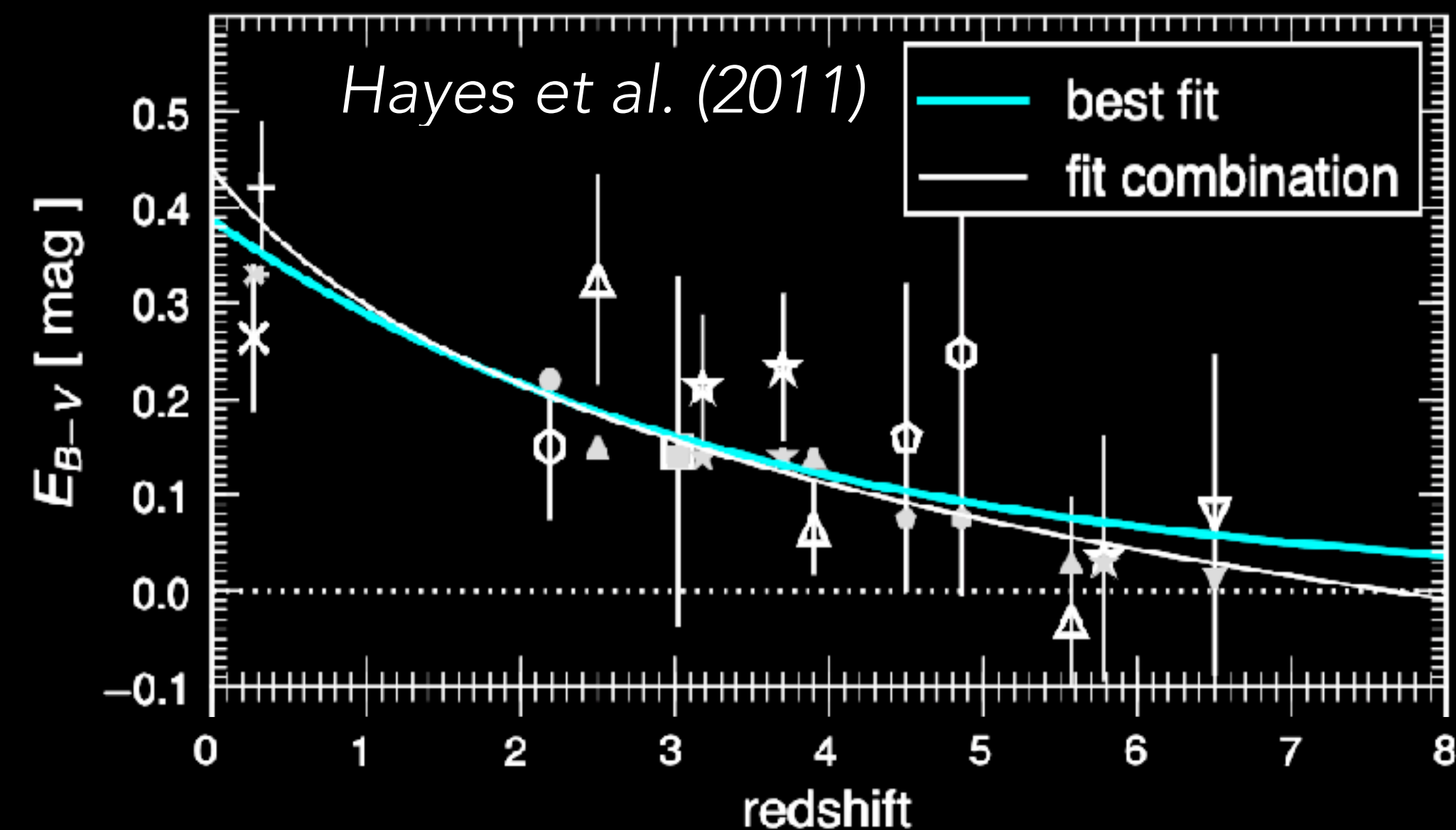
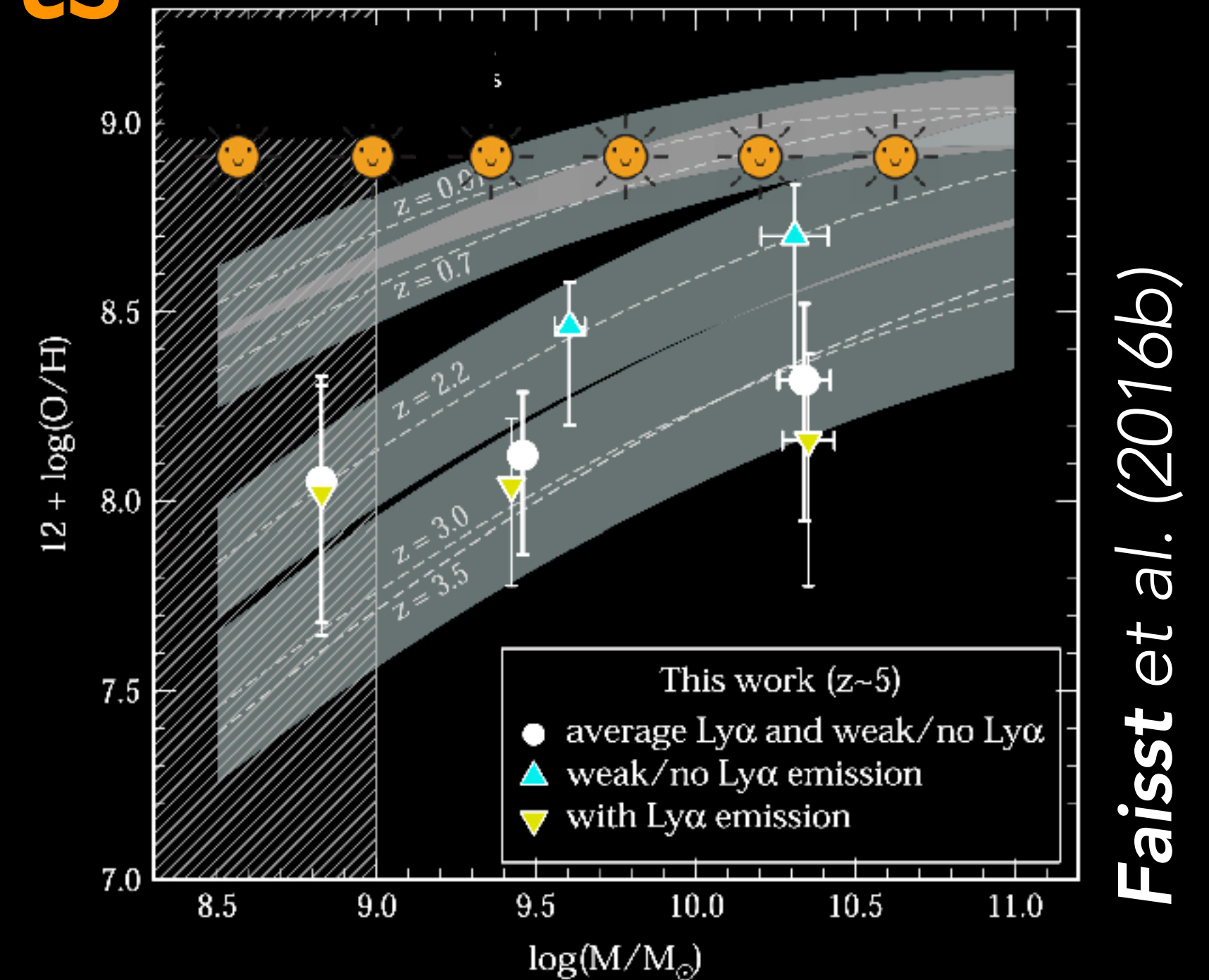
Dessauges-Zavadsky et al. (2020)
see also *Tacconi et al.*



Extrapolation from Lower Redshifts

We can (maybe?) extrapolate the properties of high- z galaxies from galaxies at lower redshifts ($z < 3$)

- Irregular structure, suggesting turbulent gas accretion and growth, and possible lack of “disk galaxies”
- Galaxies are rich in gas, suggesting high star formation rates
- Galaxies have less metals and probably very little dust



So, are we done?

The Role of ALMA

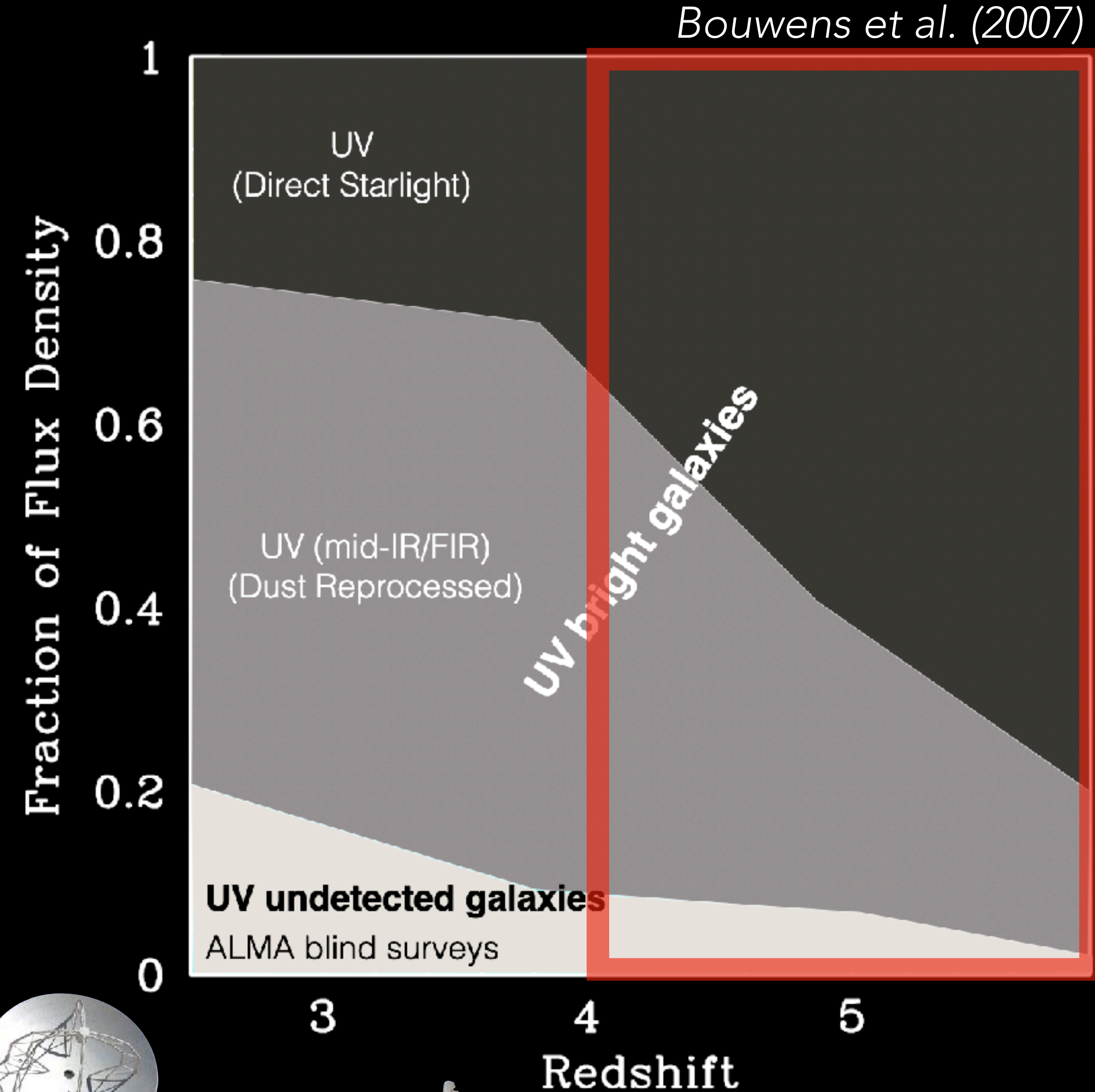
Large samples of $z > 4$ galaxies have been observed **mostly** at rest-frame UV (e.g., luminosity functions).

The Role of ALMA

Large samples of $z > 4$ galaxies have been observed **mostly** at rest-frame UV (e.g., luminosity functions).

BUT: at $z=4-6$ still $> 40\%$ of UV light is reprocessed by dust! And $\sim 10\%$ is missed completely!

ALMA is necessary to study the "missing" light!



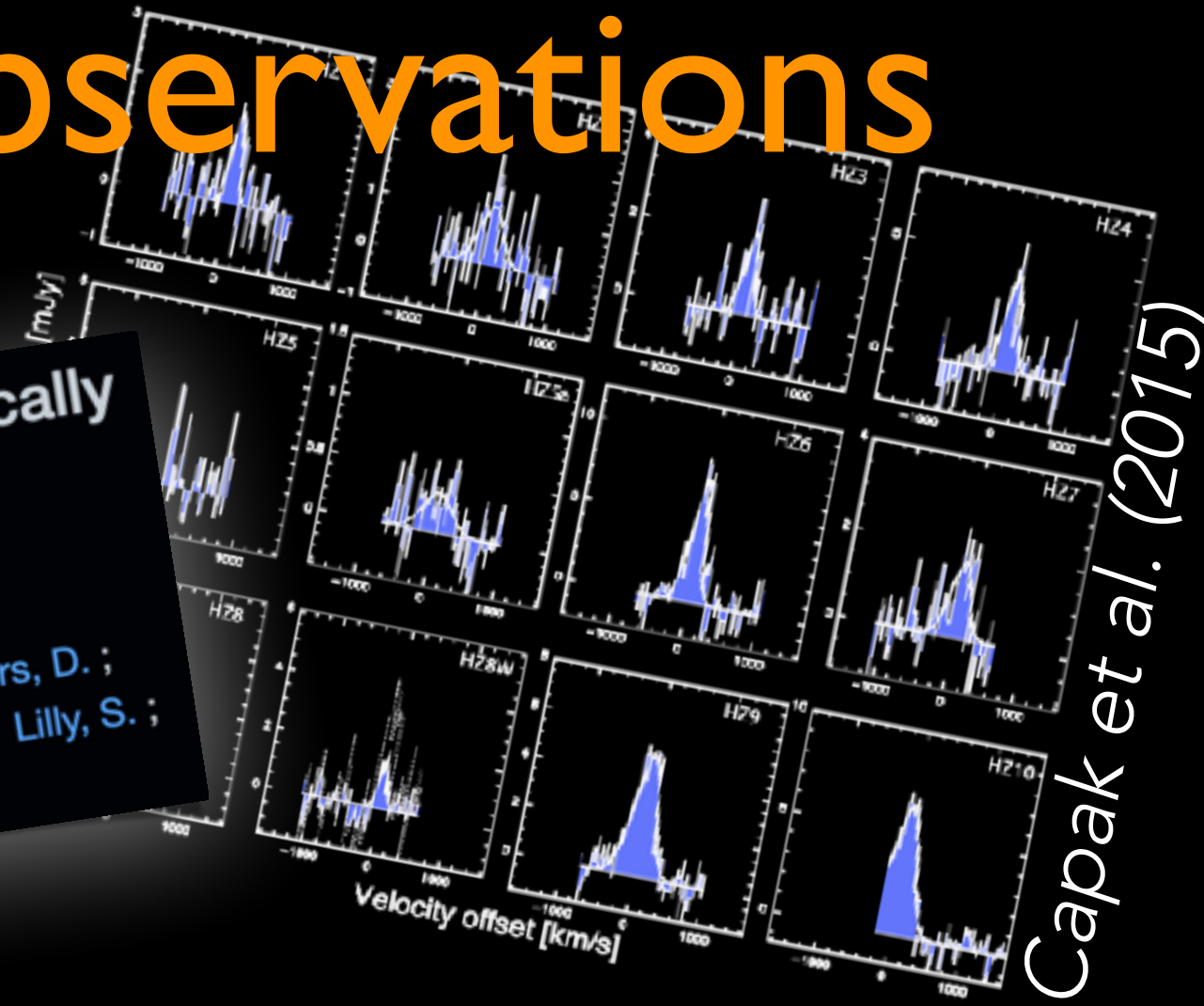
Small Sample with Multi-Wavelength Observations

- Bright sub-mm galaxies at $z > 4$ have been observed with ALMA
- Pre-2017: only 10 *typical* galaxies at $z > 4$ with ALMA measurements (Capak et al. 2015)

Galaxies at redshifts 5 to 6 with systematically low dust content and high [C II] emission

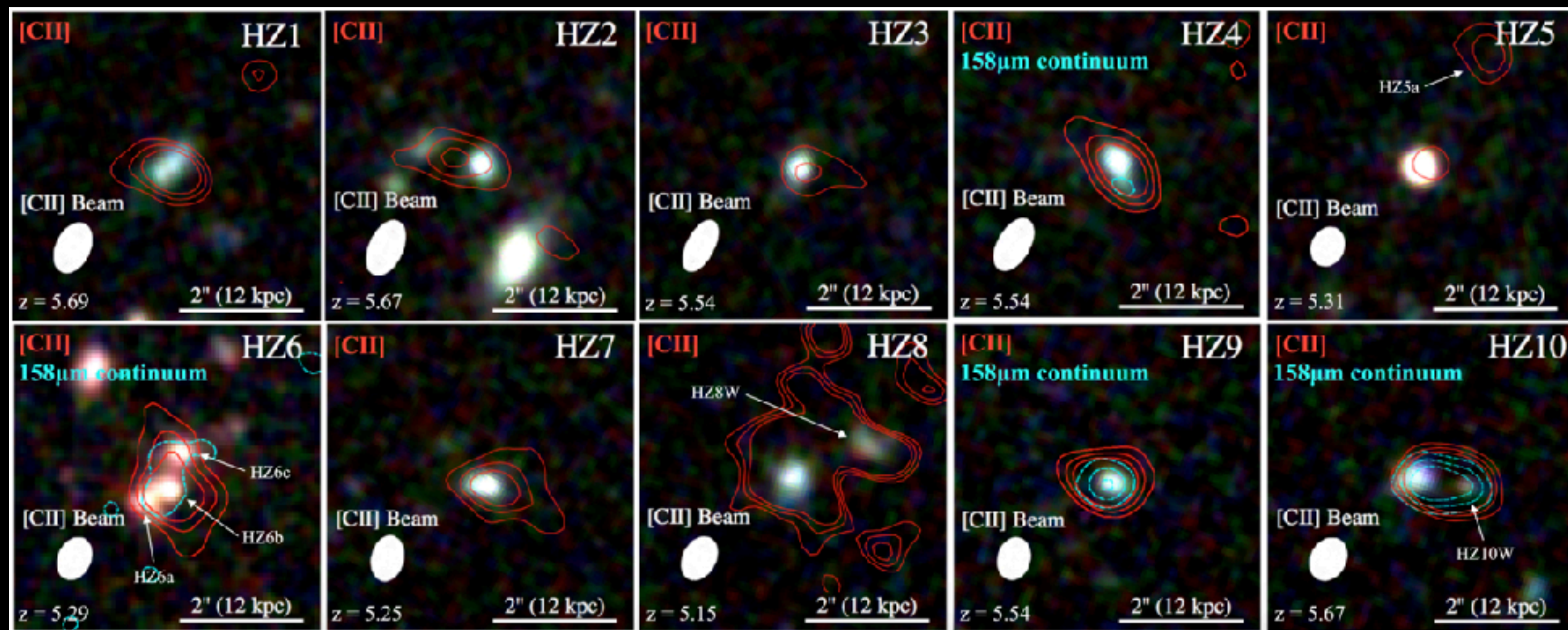
Show affiliations

Capak, P. L. ; Carilli, C.; Jones, G.; Casey, C. M. ; Riechers, D.; Sheth, K.; Carollo, C. M.; Ilbert, O. ; Karim, A.; Lefevre, O.; Lilly, S.; Scoville, N.; Smolcic, V.; Yan, L.

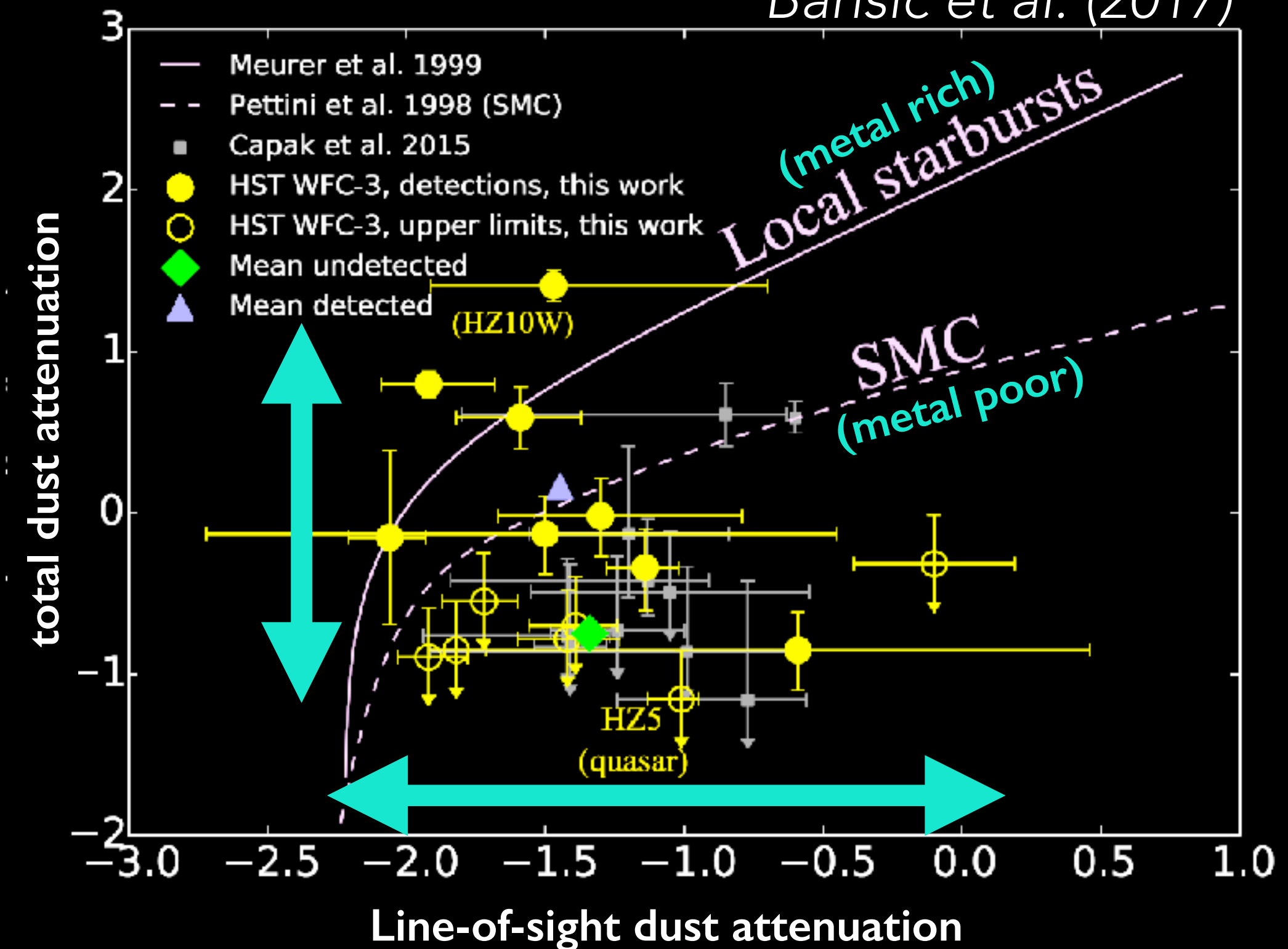


Capak et al. (2015)

Faisst et al. (2017)



Barisic et al. (2017)



We Need Larger Samples!

What about going for a large ALMA proposal?
... the birth of *ALPINE*



The ALPINE Survey

<http://alpine.ipac.caltech.edu>
https://cesam.lam.fr/a2c2s/data_release.php

ALPINE = **AL**MA **L**arge **P**rogram to **IN**vestigate C⁺ at **E**arly times

PIs: [LeFèvre](#), [Faisst](#), [Béthermin](#), [Cassata](#), [Schaerer](#), [Silverman](#), [Yan](#), [Capak](#)

- 70 hours of ALMA observations (cycle 5, Band 7) of **singly ionized Carbon** emission (C⁺) at 158 μ m and surrounding **dust continuum**
- **118 average teenage galaxies** in total (largest sample so far!)
- Redshifts **z = 4 - 6** (1- 1.5 billion years after the Big Bang)
- **First true multi-wavelength survey at z > 4!**

27 Papers since 2019!!

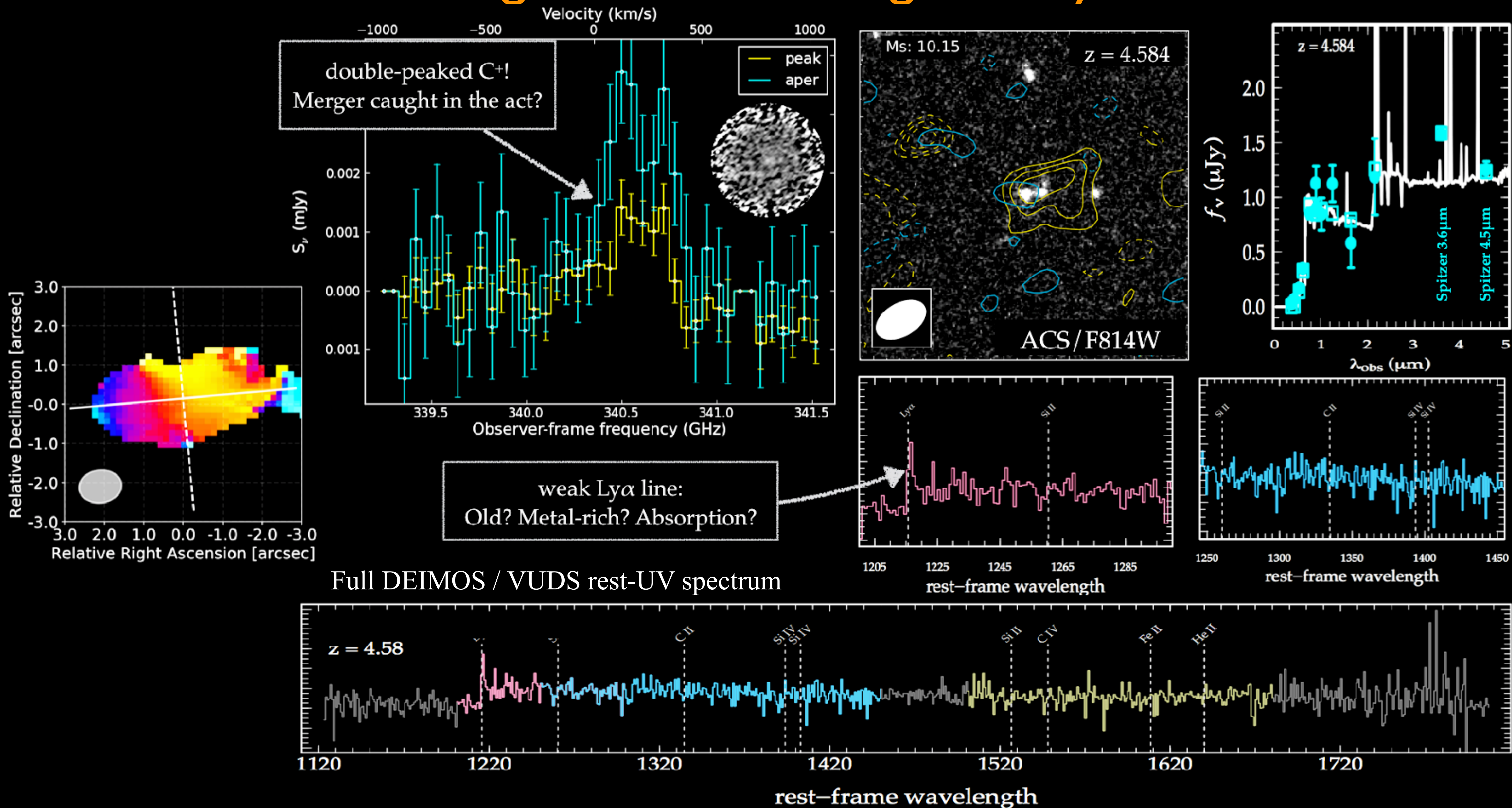
Measure C⁺ emission (gas)

- Kinematics (disk galaxies!)
- Gas fractions
- Outflows & Mergers

Measure 150 μ m continuum (dust)

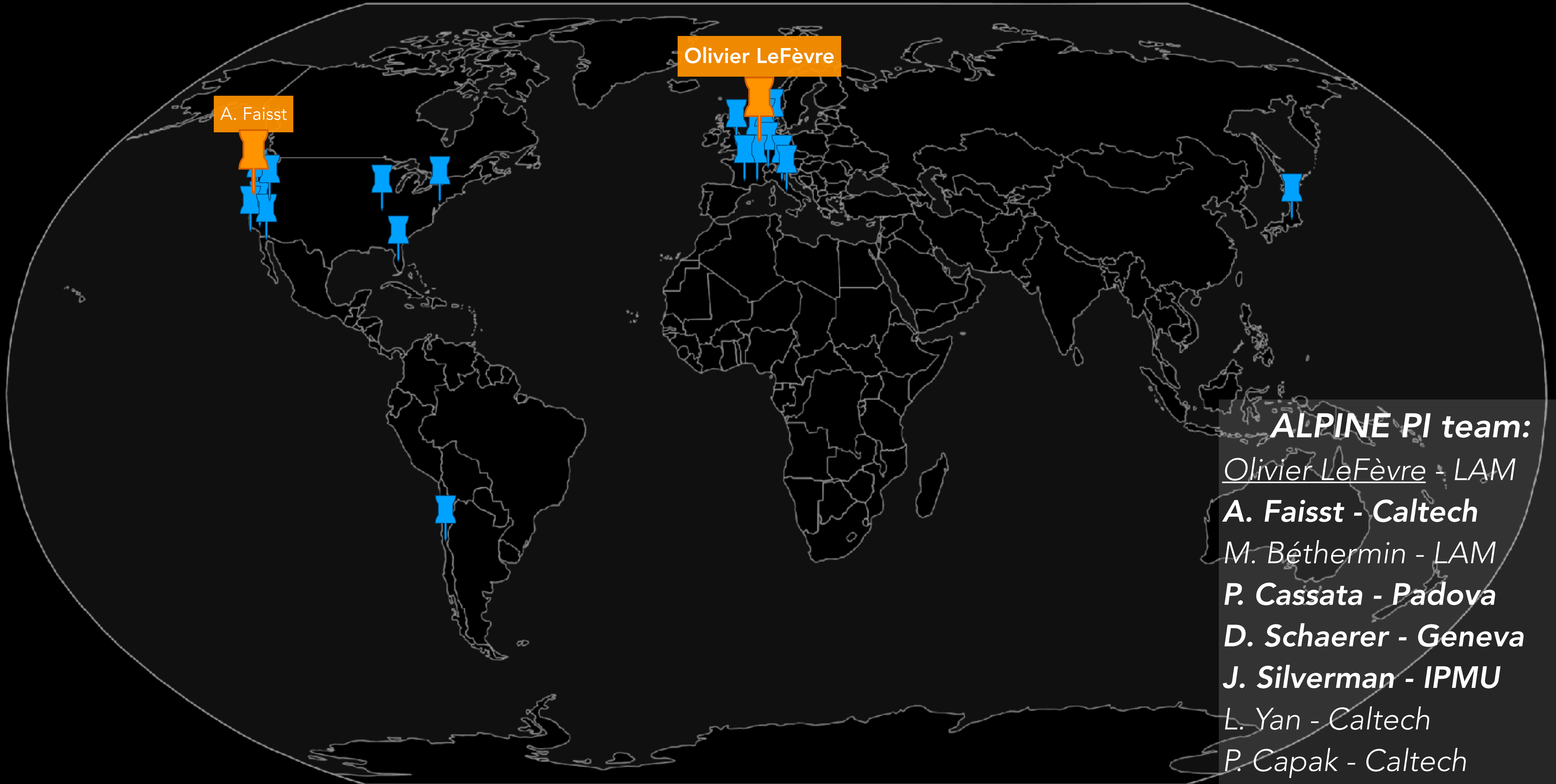
- Hidden star formation
- Dust content
- Finding dust-obscured galaxies

ALPINE: the First Large Multi-Wavelength Study of $z > 4$ Galaxies

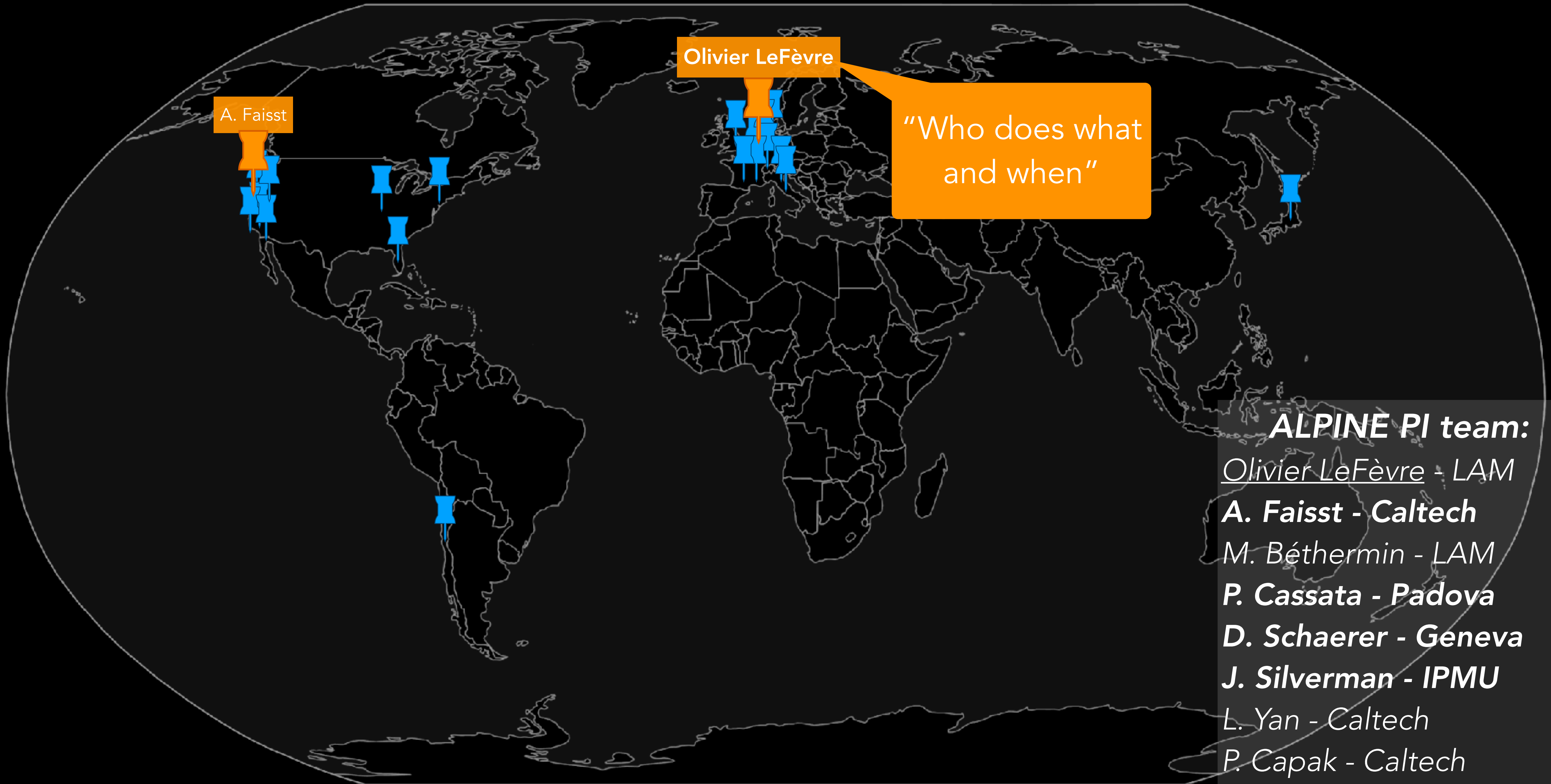


Full DEIMOS / VUDS rest-UV spectrum

ALPINE is Global



ALPINE is Global



A. Faisst

Olivier LeFèvre

Who does what
and when

- ALPINE PI team:**
Olivier LeFèvre - LAM
A. Faisst - Caltech
M. Béthermin - LAM
P. Cassata - Padova
D. Schaerer - Geneva
J. Silverman - IPMU
L. Yan - Caltech
P. Capak - Caltech

Original Google Doc listing ALPINE papers

(Olivier's favorite document)

Updated on February 3, 2021

Legend:

Completed and Accepted
Advanced and/or Submitted
Others: planned or ongoing.

A. Immediate large papers

These are papers that present ALPINE and should be cited when using ALPINE data...

#	Topic	Lead (Submission date)	Interested	Status
A1	Survey description paper <ul style="list-style-type: none"> Survey strategy and goals Detection function General properties of the survey (fields, ancillary data available, depth, etc.) Observational strategy, observation Presentation of the general properties of the sample (redshift, mass distribution, SFR, etc.) General source properties as seen by ALMA: [CII] flux distribution, broad classes and classification of [CII] features with examples for each 	Le Févry (March-May 2019)	ALL	Accepted

A2	Data reduction paper <ul style="list-style-type: none"> Data reduction Continuum Catalog Serendipitous sources with contamination Detection Continuum source properties [CII] catalog [CII] source properties 	Bethermin (May 2019)	ALL	Accepted
A3	Auxiliary data paper <ul style="list-style-type: none"> Photometry, line photometry Spectroscopy, Hα, Lyα SED fitting 	Faisst (May 2019)	Capak, Bethermin, Le Févry, Geneva, Fudamoto, Oesch, Scherer, Narayanan, Toft, ALL	Accepted

B. Immediate small papers (letters)

These are small papers on immediate interesting topics.

#	Topic	Lead (Submission date)	Interested	Status
B1	Letter on the IRX-Beta diagram of the ALPINE sample and evolution from z=3 to z=6	Fudamoto/Oesch (May 2019)	Capak, Bethermin, Faisst, Le Févry, Geneva, Narayanan, Richers	Accepted
B2	SFRD: FIR Outline from Mathieu Yan	Fudamoto (May 2019)	Capak, Bethermin, Le Févry, Narayanan	Accepted

B3	Papers of opportunity: Present some cool galaxies that rise above the sample and explore their properties with ACS imaging, spectra, [CII] and FIR continuum <ul style="list-style-type: none"> 150: Triple merger system + kinematics (Garett) 150: [CII] emission line offset 	May 2019	Faisst, Le Févry, Toft	Accepted
B5	Pair fraction and ("major") merger rate at z=5 <ul style="list-style-type: none"> Identify pairs, separations, mass ratio, merging timescale 	M. Romano	Tasca, Faisst	ongoing
B6	[CII] vs. SFR <ul style="list-style-type: none"> [CII] as SFR indicator Compare SFR from [CII] to other estimators (Also look at Hα from Spitzer) SFR_UV vs. SFR_IR 	Schaerer (May 2019)	Bethermin, Faisst, Le Févry	Accepted
B7	Luminosity function of FIR continuum serendipitous sources	Gruppioni, Bethermin (May 2019)	Talia, Pozzi, Bardelli, Zucca, Zamorani, Cassata, Capak, Le Févry	Accepted
B8	Velocity offsets between [CII], Ly α , absorption lines	Cassata, Faisst	Fudamoto, Ginoff, Le Févry	Accepted
B10	Kinematic modeling of [CII] <ul style="list-style-type: none"> Build up of disks over cosmic time Dynamical masses (collaborate with C8) High resolution follow-up ALMA observations Scaling relations (Girard) 	Jones, Pavese (May 2019)	Capak, Faisst, Girard, Dessauges, Richers, Silverman, Narayanan, Toft, Le Févry	ongoing (draft sent out to ALPINE community, comments by Feb 12)

B11	Outflows from [CII] profiles <ul style="list-style-type: none"> Quantity, presence of outflows and mass outflow rate Individual detections and stacking for average measurements Follow-up observations with ALMA to determine an inflow component is present as well Offset [CII] and continuum 	Ginoff, Jones (May 2019)	Narayanan, Silverman, Maiolino, Rupasingha	Accepted
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C. Papers presenting a complete statistical analysis of the [CII] sample (targeted and serendipitous)

#	Topic	Lead (Submission date)	Interested	Status
C1	IRX-B and dust mass evolution. Focused on attenuation <ul style="list-style-type: none"> SED (CIGALE) fitting including FIR measurements to get dust masses Redshift evolution of dust mass density Comparison to analytical models of dust attenuation/mass and evolution with stellar mass, and other properties Serendipitous galaxies? Low-z? "Merging" with E1	Ginoff, Schaerer, Fudamoto, Oesch, Boquien	Faisst, Capak, Cassata, Le Févry, Narayanan, Talia, Toft	Ongoing?
C2	Dust mass density (target+serendipitous) evolution with z	Pozzi, Gruppioni, Talia, Zamorani	Geneva, Faisst, Cassata, Capak, Narayanan, Toft, Le Févry	submitted
C3	[CII] luminosity function and using forward modeling to compute selection function. Also include blind [CII] detection	Yan, Bethermin	Capak, Le Févry	Accepted
C4	Molecular gas fractions and molecular gas depletion timescales <ul style="list-style-type: none"> Molecular gas masses derived from [CII] dynamical masses, dust continuum à la Scoville Comparison of the quantities at z > 4 with main sequence galaxies at z=1 Comparison of these quantities to other galaxy properties (redshift, SFR, stellar mass, distance from main sequence) 	Dessauges, Geneva, Toft+DAWN	Faisst, Scoville, Faisst, Ginoff, Capak, Le Févry, Narayanan, Pozzi, Richers, Silverman	Accepted
C5	Ly α properties of some specific [CII] detections	Morse, Cassata	Faisst, Bethermin,	working on

C8	Molecular line modeling with photo-ionization models (need follow up for more FIR lines). Use measured offsets of FIR, [CII], UV.	Vallini	Capak, Narayanan, Toft	Still interested, but not able to work on this on a short timescale
C10	Comparison of Ly α escape fraction and [CII] line. How does (Ly α) escape fraction vary with gas fraction (from [CII])? [no significant correlations found. Not very promising]	Toft + Student of DAWN	Faisst	Likely abandoned.
C11	MORPHOLOGY II: Sizes from UV plane Measure [CII] and continuum sizes from UV plane on brightest sources	Fujimoto	Bethermin, Faisst, Bardelli, Narayanan, Geneva, Le Févry, Toft	Accepted
C14	[CII] and FIR continuum emission from nonlogarithmic SPH simulations (spatial) -> Olsen et al. (2017)	Toft/Narayanan/Olsen	Faisst, Also Vallini-Ferrara?	still planned, but currently on hold
C15	Constraints on the dark matter content of high-z galaxies <ul style="list-style-type: none"> Based on rotation curves for the brightest C+ emitters From dynamical mass estimates (using vel. dispersion and half-light radius), back out the amount of dark matter required with consideration of stellar mass based on deep HSC imaging and gas/dust estimates from the ALMA continuum 	Silverman, Maiolino	Faisst	ongoing
C16	Measuring outflow velocities (mass outflow rates and energetics) through rest-frame UV absorption lines spectroscopy. We use the [CII] as a tracer of systemic redshift, align & stack the rest-frame UV spectra in bins of SFR, Mstar etc, and measure the velocity offsets of blueshifted absorptions (SiII, CII SiIV etc.)	Ginoff + Geneva + Paolo, Faisst	Talia	ongoing (most of analysis done)

C17	Stacking of C+ non-detections using the velocity offsets between detected C+ and Ly α	L. Morselli	Cassata, Faisst, ...	on going
C18	Resolved Kennicutt-Schmidt relation + models	Vallini+Dessauges+Ginoff	Fujimoto, Faisst	to be started now

D. Other papers
Important papers besides the [CII] emitters

#	Topic	Lead (Submission date)	Interested	Status
D1	Physical and molecular characterisation of sources in a virginal relation and their environment	Vergani	M. Dessauges, C. Gruppioni, M. Talia, Zamorani, Narayanan, B. Epinat + student (external collab)	started (results soon)
D2	Luminosity function of serendipitous CII sources. Also include archival data? Catalog paper and luminosity function	Loiacono (Ginoff/Talia)	Bethermin, Gruppioni, Pozzi, Bardelli, Zucca, Zamorani, Richers, Narayanan	Accepted
D3	Characterization of serendipitous CO and CII sources (physical properties, molecular gas, kinematics) focusing on environment and clustering properties	Gruppioni w/ student, Romano, Cassata, Talia	Pozzi, Vallini, Zamorani, Vergani, Dessauges, Richers, Narayanan, Bethermin, Faisst	ongoing
D6	Characterization of serendipitous continuum sources <ul style="list-style-type: none"> D6a: physical properties of the general sample, with a focus on molecular gas D6b: AGN candidates (BHAR vs z) D6c: HST dark sources (better characterization) comparing results with different sample 	D6a: Talia D6b: Gruppioni, Vergani D6c: Giacomelli (student), Gruppioni	D6a: Gruppioni, Pozzi D6b: Talia, Delvecchio (external collab) D6c: Talia	D6a: ongoing (draft soon) D6b: starting D6c: ongoing

D7	On one galaxy with [OII] measurement from Keck/MOSFIRE. Compare SFRs (UV, FIR, C+, [OII]) and also model [OII]C+ in CLOUDY.	B. Vanderhoof, Faisst		ongoing (complete draft in February)
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E. Papers in collaboration with people outside of the ALPINE collaboration

#	Topic	Lead (Submission date)	Interested	Status
E1	* We will start this science project within the PhD thesis of Jana Bogdanoska (LAM, France). Maybe 1 other young colleague working in LAM could also join later on. * Building a multi-wavelength catalogue of a sample of galaxies with z spec, UV-selected ALPINE + IR-selected SMGs at z > 4 - 5 (already done for photometry but we need to collect optical emission lines). * Using the OGALÉ code that allows to fit the photometric data points and the main features (lines, indices). * Constraining the evolution status of these galaxies and their stellar populations (SFR, Mstar, SFRD, etc.). * Constraining the dust characteristics from the dust emission and the dust attenuation law and the implication on the evolution of $\sim A_{FUV(z)}$.	D. Burgarella, Mederic Boquien	Bethermin, Cassata, Faisst, Schaerer, Silverman, Yan, Richers, Gruppioni, Talia, Jones, Hathi, Ibar, Ginoff, Lemaux, Vergani	ongoing
E2	Using ALPINE as comparison sample for z > 6 quasars (also from HSC team)	Fujimoto + Silverman et al.	Some HSC members	ongoing
E3	Focus on the ALPINE rotators, study them in details and then add these galaxies to: - a sample of 5 z ~ 4.5 rotators from the literature with accurate kinematic characterization (Sharda et al, Neelaman et al. 2020, Fraternali et al. 2020, Lelli et al. 2021, accepted) - a sample of 7 z ~ 4.5 lensed galaxies which have been studied in my two papers (https://ui.adsabs.harvard.edu/abs/2020Natur.584..201Riabst)	Francesca Rizzo	Jones, Ginoff, Fujimoto, Toft, Ibar, Lemaux, Dessauges, Faisst, Vergani	ongoing

By using this sample of ~ 17 galaxies I would like to investigate the dynamical scaling relations (e.g., Tully-Fisher, Fall relations) and compare them with predictions from cosmological simulations (e.g., EAGLE, IllustrisTNG50, https://ui.adsabs.harvard.edu/abs/2017MNRAS.464.3850/a/abstract, https://ui.adsabs.harvard.edu/abs/2019MNRAS.490.3196P/a/abstract).

Inclusive Spectroscopic Selection

ALPINE galaxies are selected from various spectroscopic programs to mitigate (as well as possible) spectroscopic selection biases.

Faisst et al. (2020)

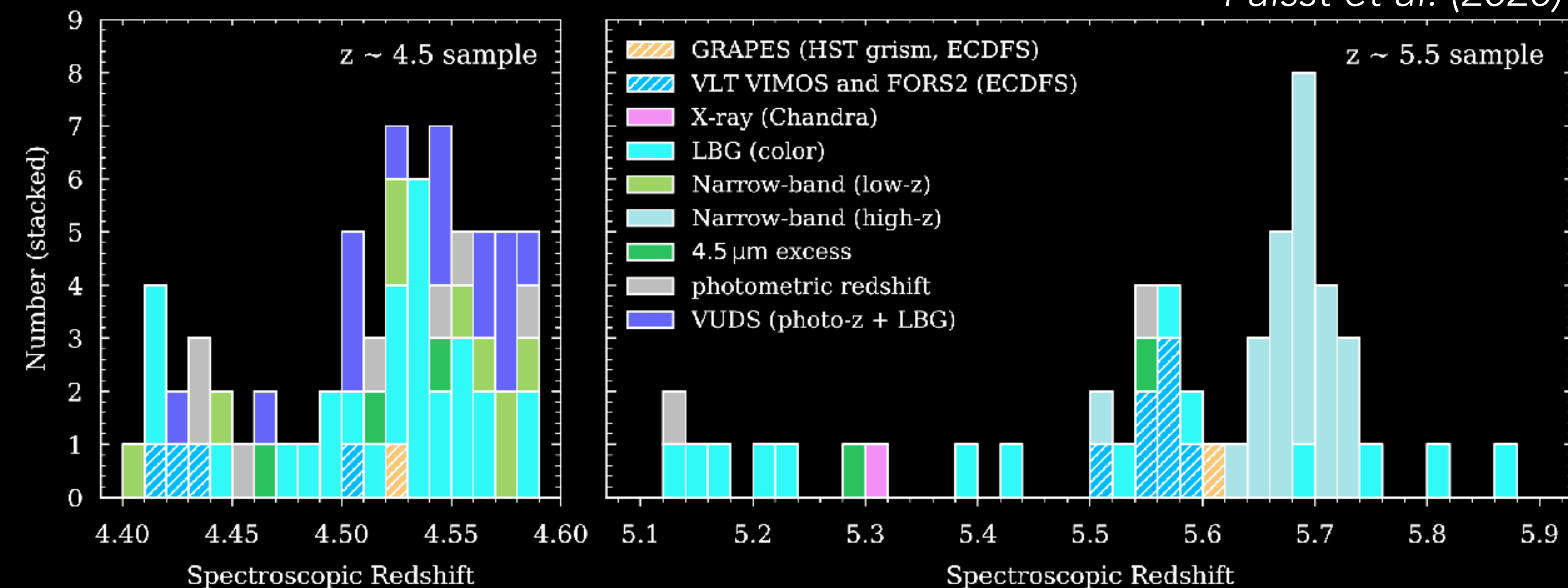


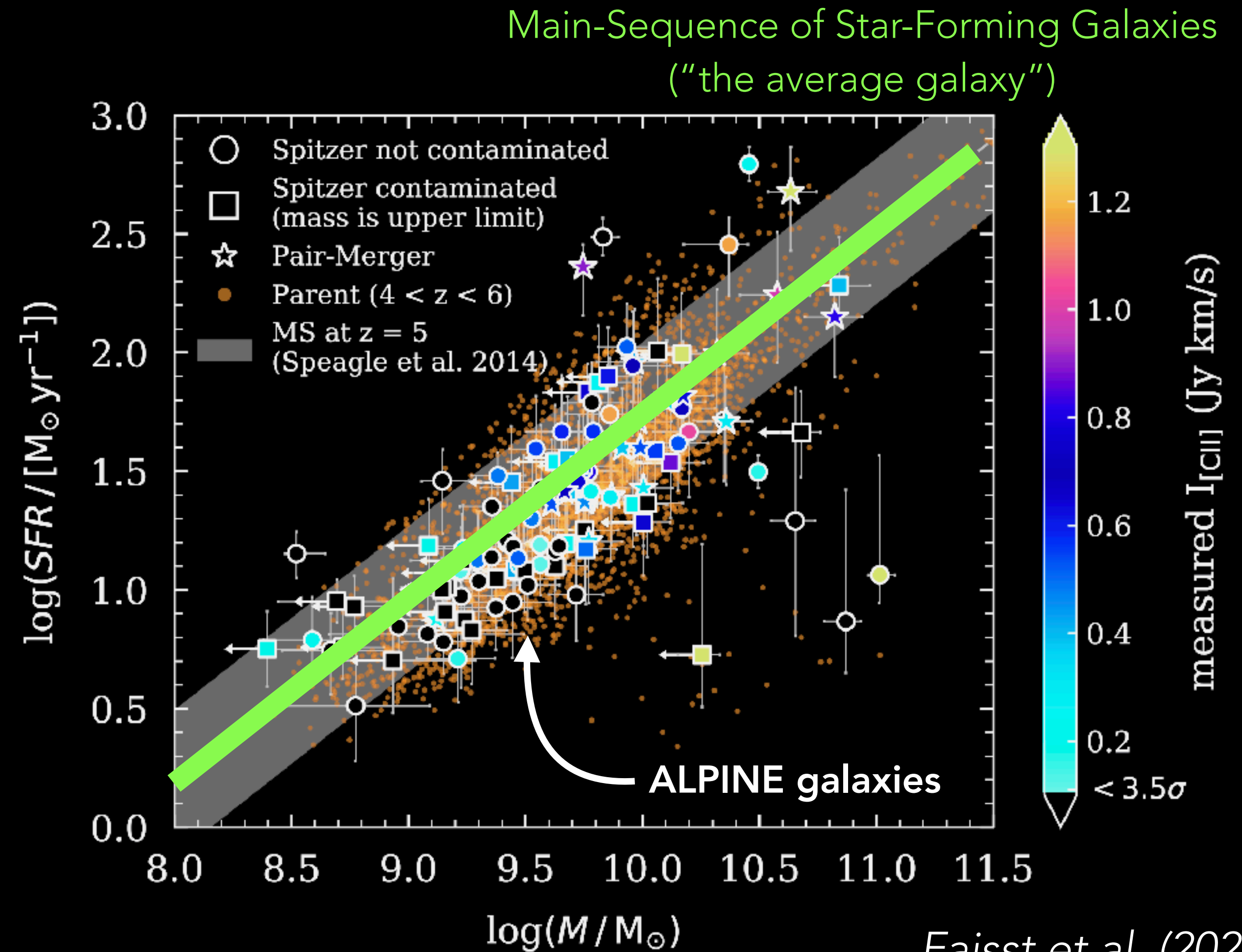
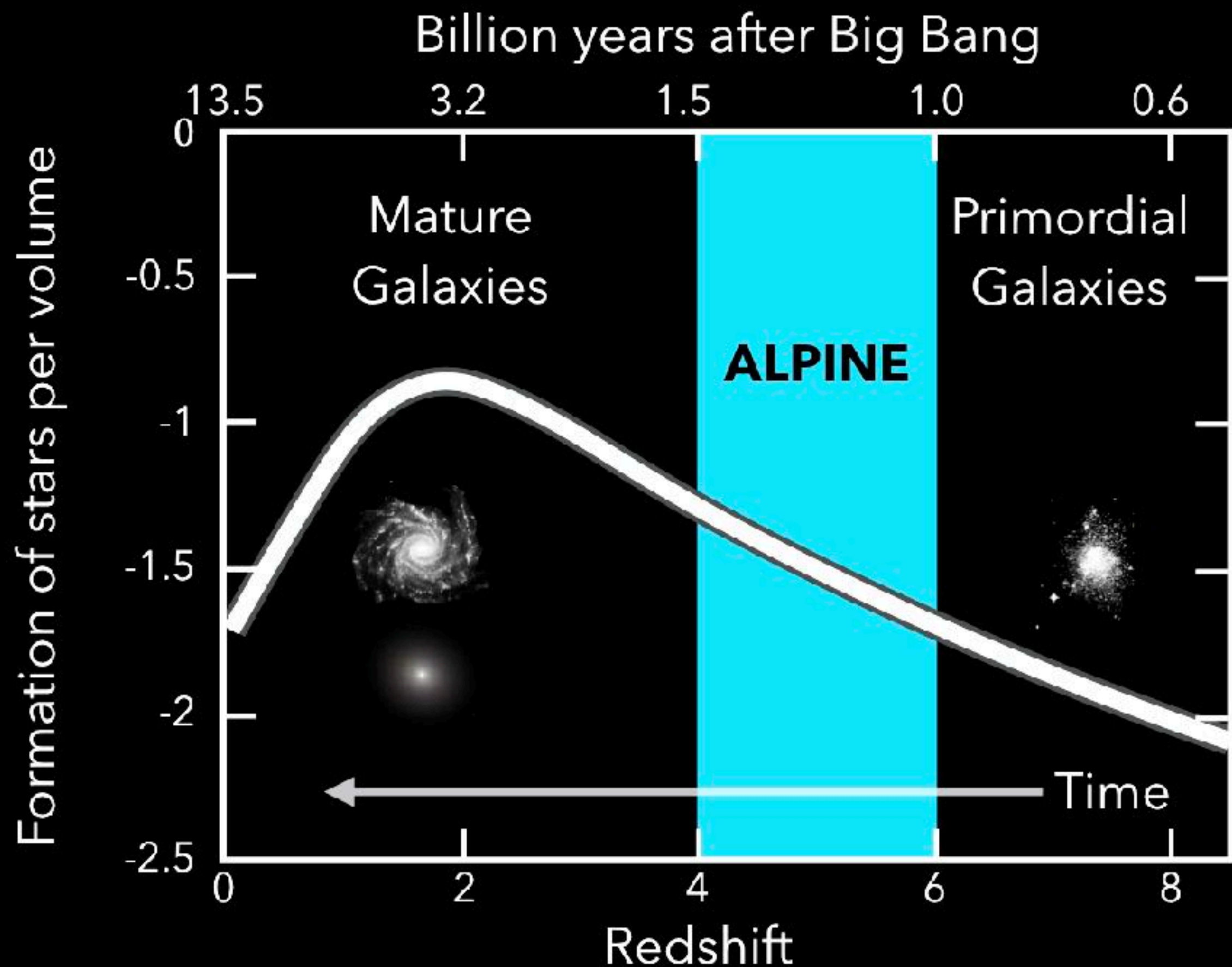
Table 1
Spectroscopy and Selection of ALPINE Galaxies

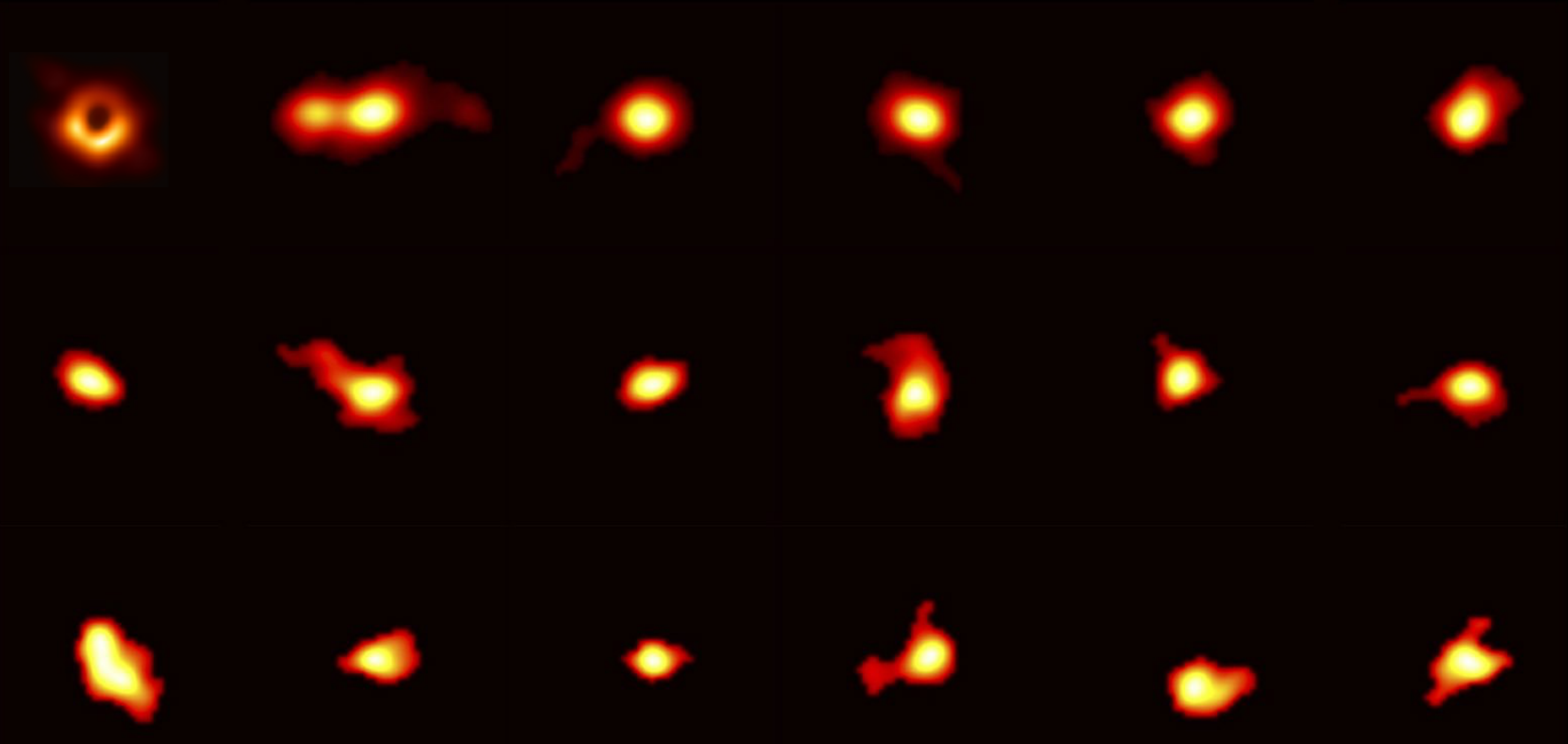
Survey	Selection	Number	Ref.
COSMOS field (105 galaxies)			
Keck/DEIMOS ^a		84	1
	narrowband ($z \sim 4.5$) ^c	6	
	narrowband ($z \sim 5.7$) ^d	23	
	LBG (color) ^e	41	
	pure photo- z ^f	9	
	4.5 μm excess	4	
	X-ray (<i>Chandra</i>)	1	
	with Ly α emission	66	
	weak Ly α emission or absorption	18	
VUDS		21	2
	photo- z + LBG	21	
	[narrowband ($z \sim 4.5$)	3] ^b	
	[narrowband ($z \sim 5.7$)	1] ^b	
	[LBG (color)	1] ^b	
	[4.5 μm excess	1] ^b	
	with Ly α emission	16	
	weak Ly α emission or absorption	5	
ECDFS field (13 galaxies)			
VLT GOODS-S		11	3
	primarily LBG (color)	11	
	total with Ly α emission	6	
	total without Ly α emission	5	
HST/GRAPES		2	4
	Grism (no a priori selection)	2	
	with Ly α emission	2	
	weak Ly α emission or absorption	0	

Olivier!!

Typical Galaxies at High Redshifts

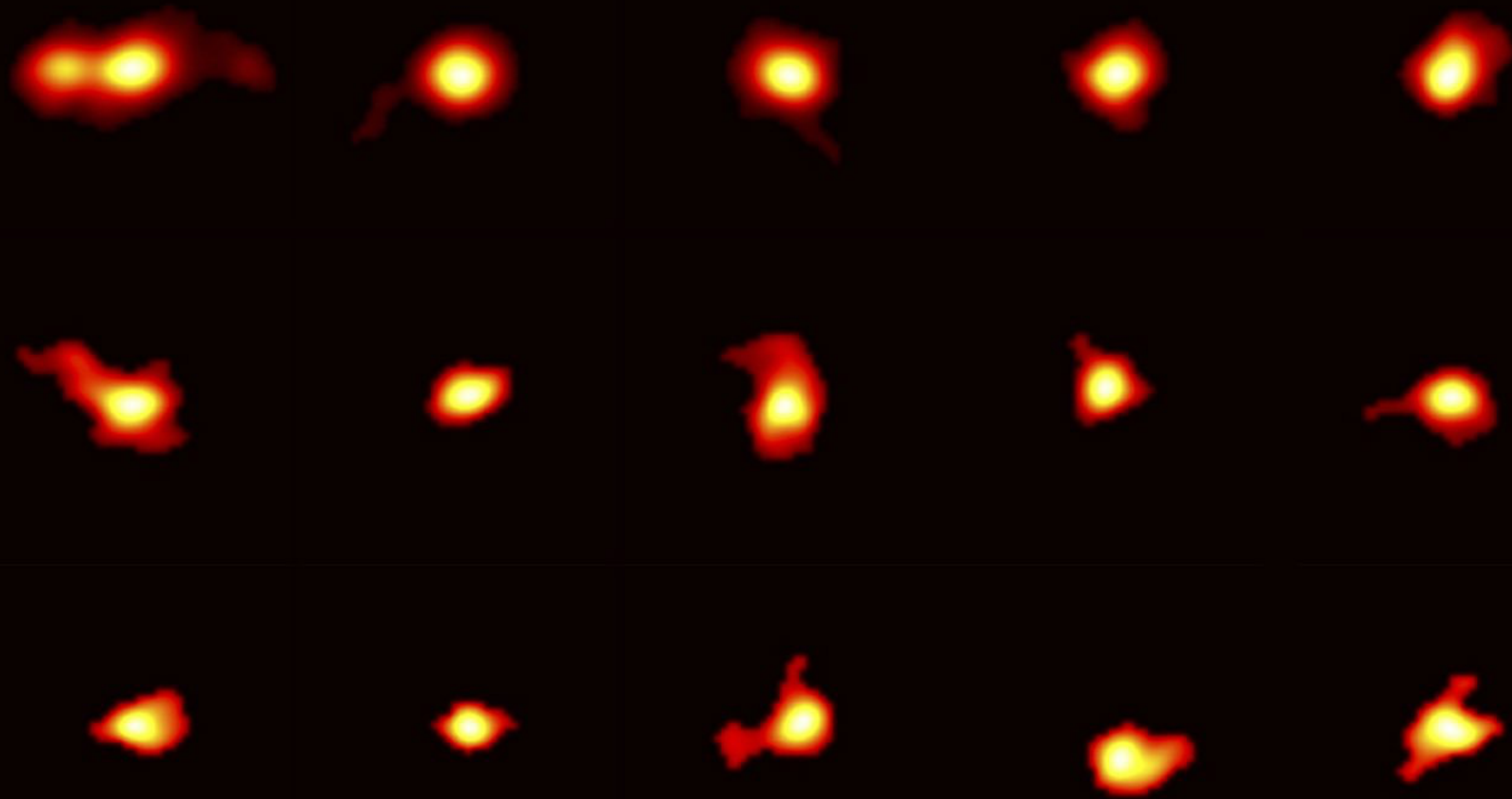
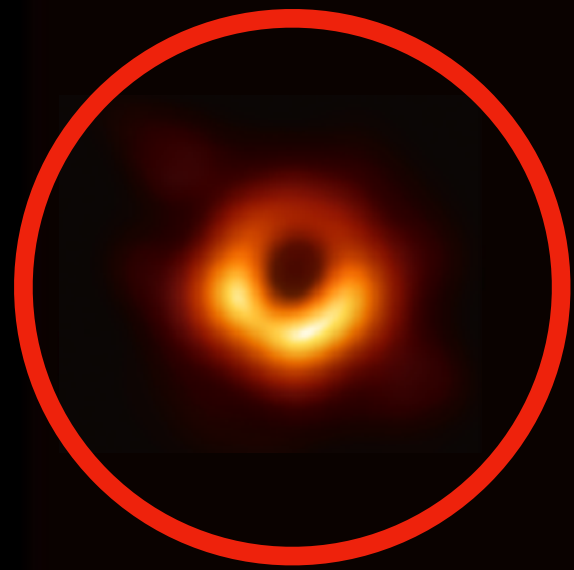
ALPINE galaxies are main-sequence galaxies living during the early growth phase at $z = 4 - 6$.





C⁺ emission at 158 μ m

Black Hole!



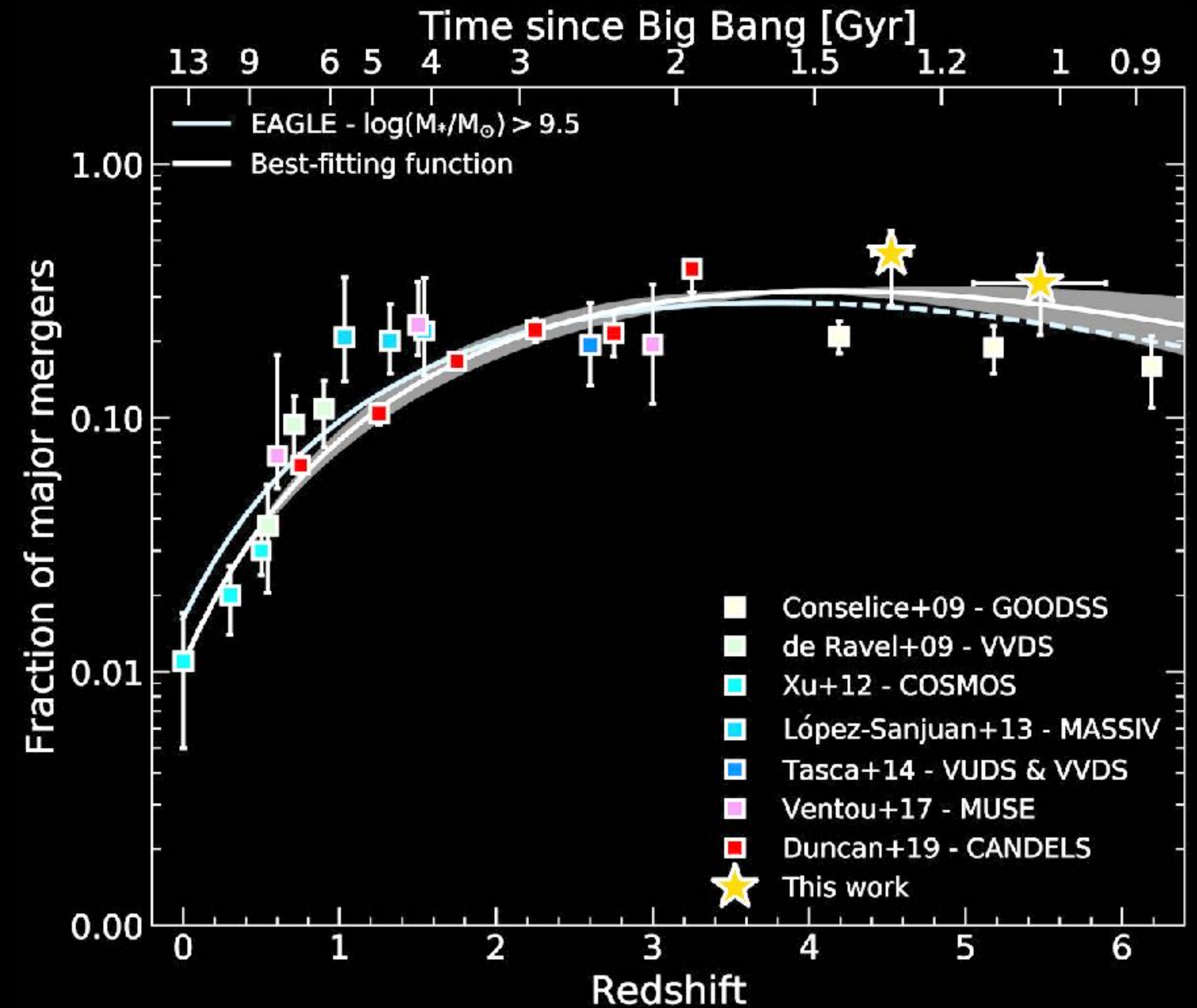
C⁺ emission at 158 μ m

**What does *ALPINE* tell us about
high- z (post-reionization)
galaxies?**

What Is ALPINE Telling Us About Early Galaxies?

Fraction of Major Mergers

- Michael Romano's talk



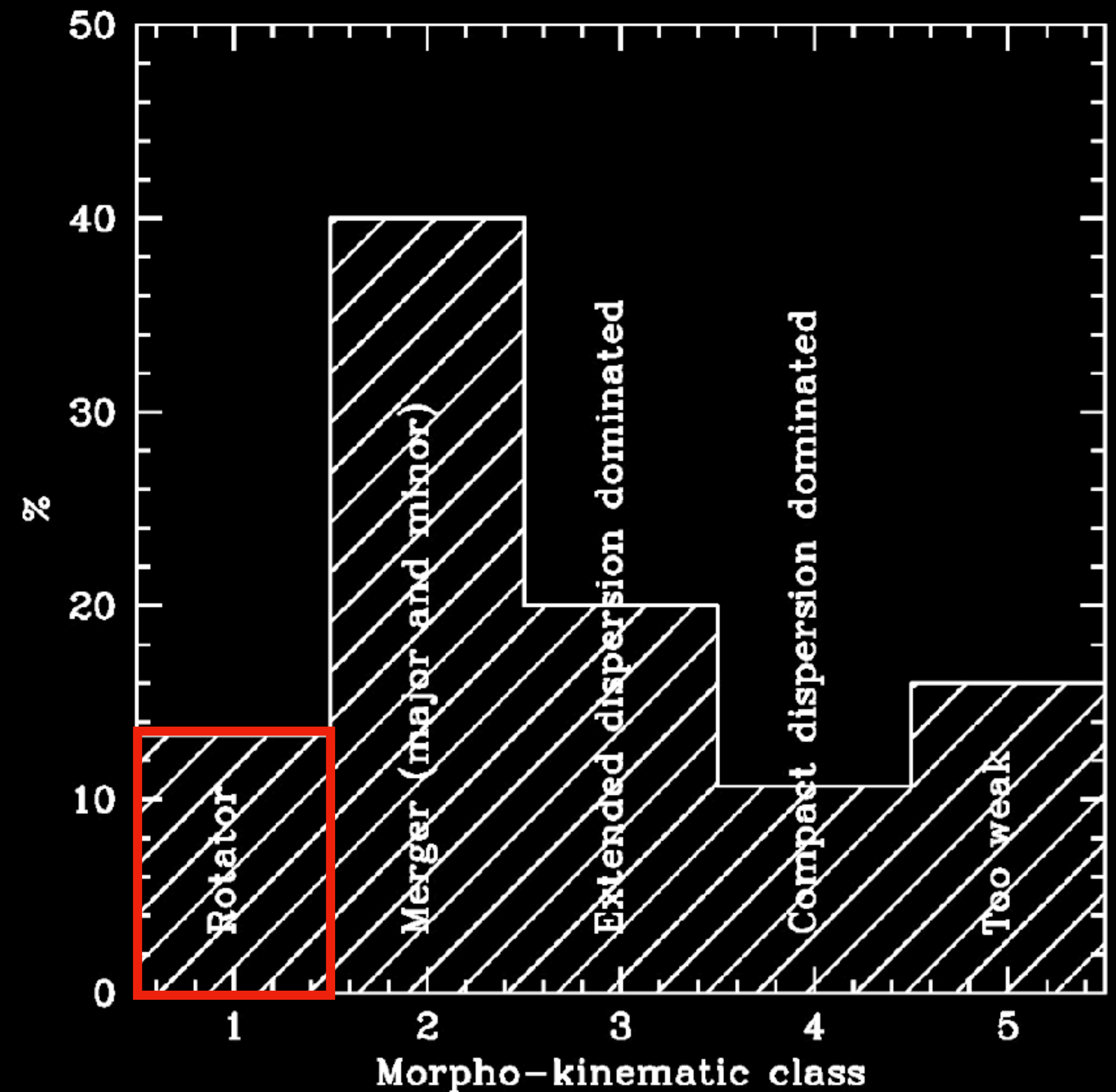
What Is ALPINE Telling Us About Early Galaxies?

Fraction of Major Mergers

- Michael Romano's talk

Structure of high-z galaxies

- 5 morpho-kinematic classes
- See Gareth Jones' talk!



PECULIAR MORPHOLOGY OF THE HIGH-REDSHIFT RADIO GALAXIES 3C 13 AND 3C 256
IN SUBARCSECOND SEEING

O. LE FÈVRE¹

Canada-France-Hawaii Telescope Corporation; and Meudon Observatory

F. HAMMER,¹ L. NOTTALE, AND A. MAZURE¹

Meudon Observatory

AND

C. CHRISTIAN¹

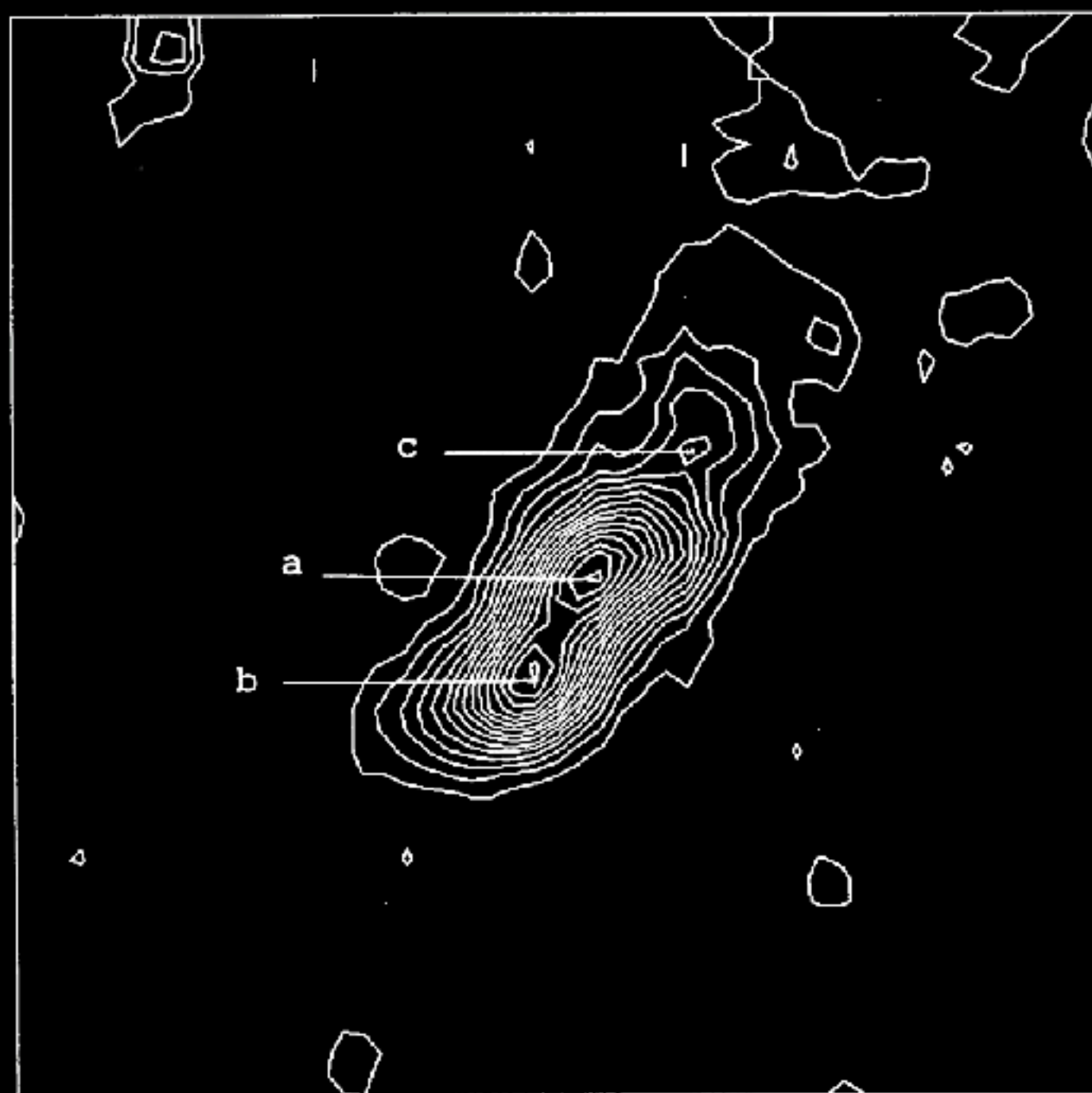
Canada-France-Hawaii Telescope Corporation and University of Hawaii

Received 1987 June 19; accepted 1987 October 8

ABSTRACT

We report high spatial resolution imaging of two radio galaxies from the 3C catalog, 3C 13 and 3C 256 with redshifts of 1.351 and 1.819, respectively. The excellent image quality obtained at CFHT, 0".6 FWHM for 3C 13 and 0".7 for 3C 256 in the R band, over long integration times, allowed us to resolve these distant galaxies into complex structures. As suggested by Le Fèvre and colleagues in 1987 for another source, the gravitational lens candidate 3C 224,

Le Fèvre et al. (1987)



"The excellent image quality obtained at CFHT, [...] allowed us to resolve these distant galaxies into complex structures."

FIG. 2.—3C 256 ($z = 1.819$): 1 hr exposure in R band at CFHT prime focus. FWHM is 0".7. The multiple component structure is aligned on a common axis. North is up, and the image is 10.5×10.5 arcsec².

PECULIAR MORPHOLOGY OF THE HIGH-REDSHIFT RADIO GALAXIES 3C 13 AND 3C 256 IN SUBARCSECOND SEEING

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Astronomy
&
Astrophysics

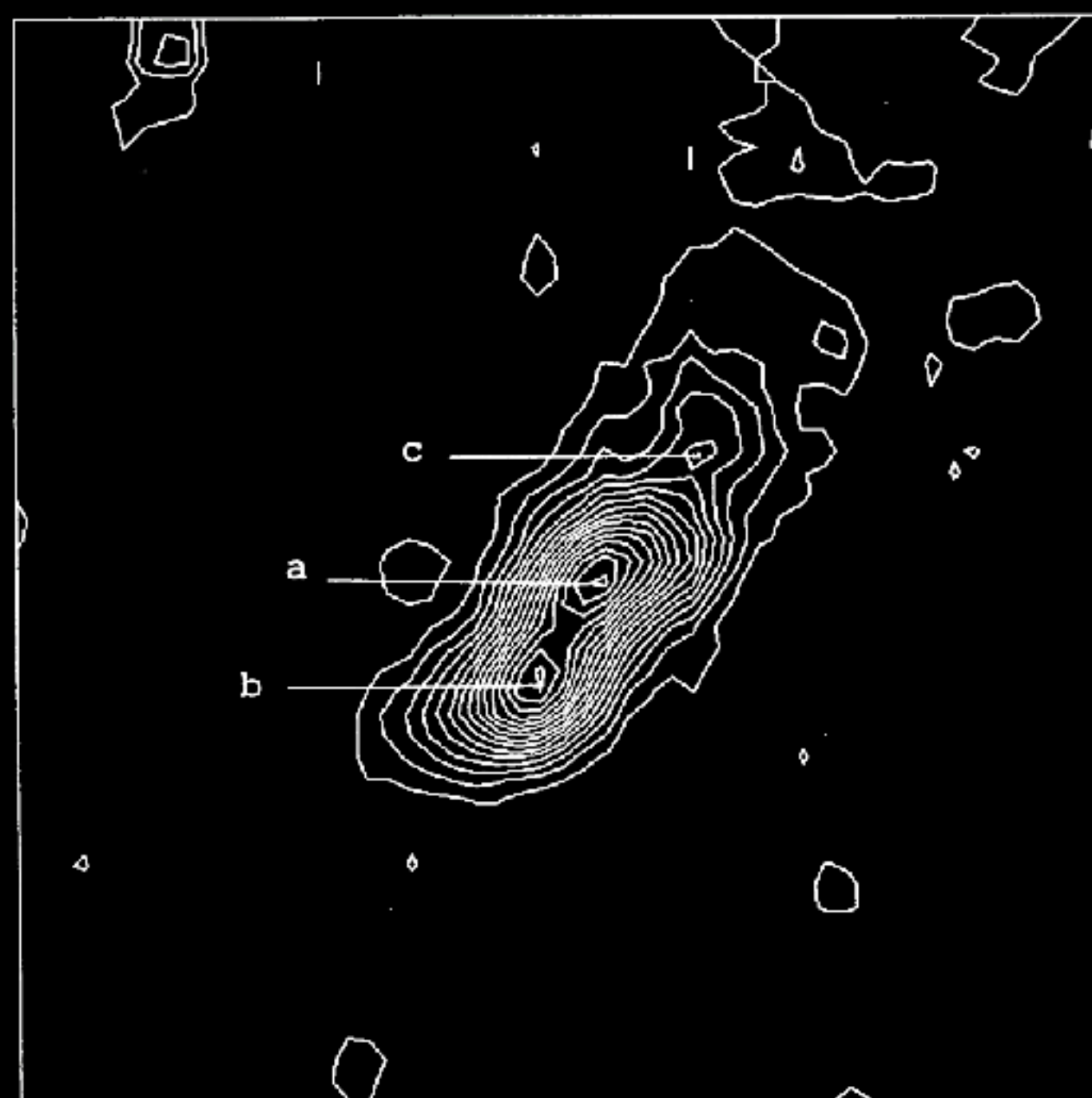
Survey strategy, observations, and sample properties of 118 star-forming galaxies at $4 < z < 6$

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ABSTRACT

The ALMA-ALPINE [CII] survey is aimed at characterizing the properties of a sample of normal star-forming galaxies (SFGs). The ALMA Large Program to INvestigate (ALPINE) features 118 galaxies observed in the [CII]-158 μm line and far infrared (FIR) continuum emission during the period of rapid mass assembly, right after the end of the HI re-ionization, at redshifts of $4 < z < 6$. We present the survey science goals, the observational strategy, and the sample selection of the 118 galaxies observed with ALMA, with an average beam minor axis of about 0.85", or ~ 5 kpc at the median redshift of the survey. The properties of the sample are described, including spectroscopic redshifts derived from the LIV-rest for a signal-to-noise ratio (S/N) threshold larger than 3.5 corresponding to a 95% purity (40% detection rate for $S/N > 5$). Based on a visual inspection of the [CII] data cubes together with the large wealth of ancillary data, we find a surprisingly wide range of galaxy types, including 40% that are mergers, 20% extended and dispersion-dominated, 13% compact, and 11% rotating discs, with the remaining 16% too faint to be classified. This diversity indicates that a wide array of physical processes must be at work at this epoch, first and foremost, those of galaxy mergers. This paper sets a reference sample for the gas distribution in normal SFGs at $4 < z < 6$, a key epoch in galaxy assembly, which is ideally suited for studies with future facilities, such as the James Webb Space Telescope (JWST) and the European Extremely Large Telescope (E-ELT).

Le Fèvre et al. (1987)



"The excellent image quality obtained at CFHT, [...] allowed us to resolve these distant galaxies into complex structures."

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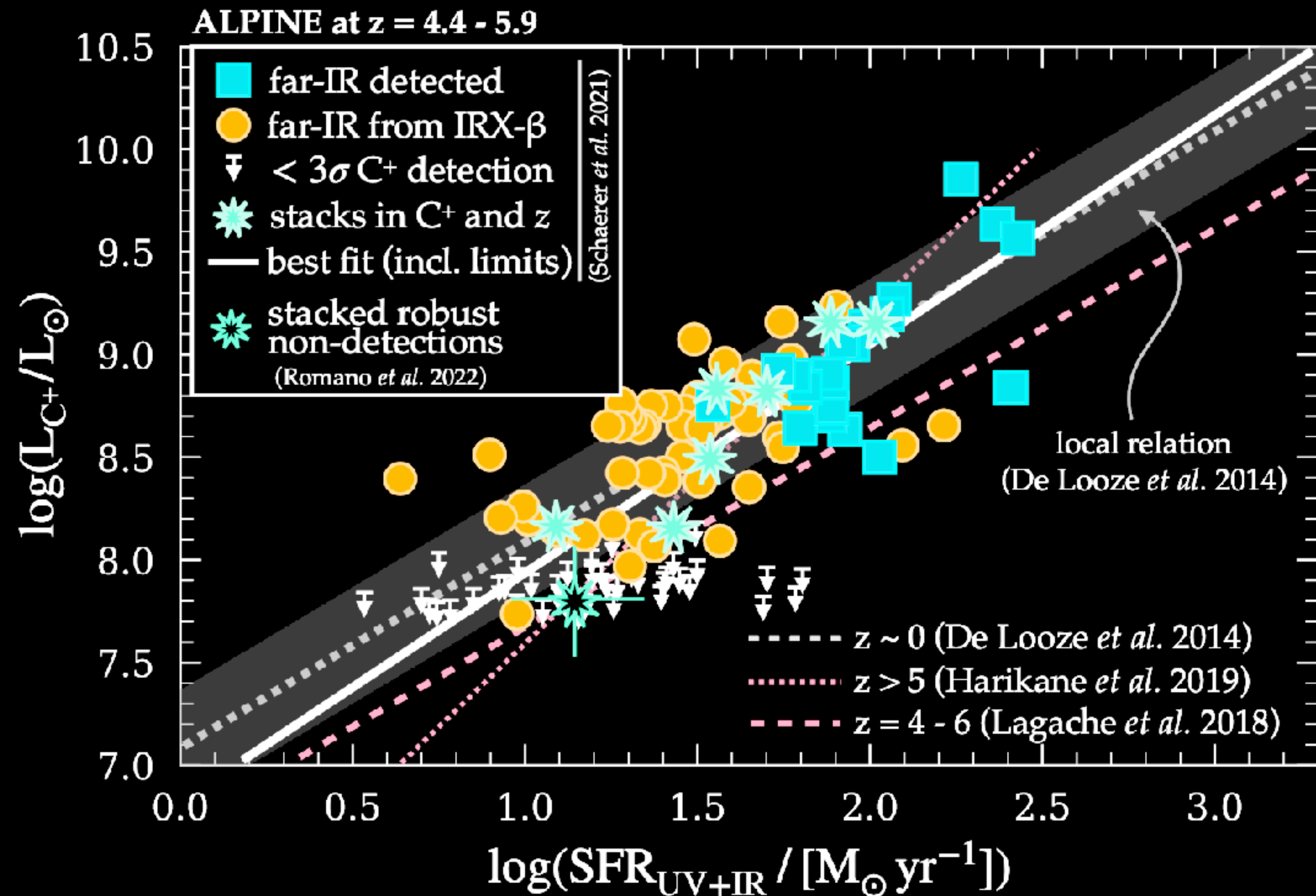
"Based on a visual inspection of the [CII] data cubes together with the large wealth of ancillary data, we find a surprisingly wide range of galaxy types [...]"

FIG. 2.—3C 256 ($z = 1.819$): 1 hr exposure in R band at CFHT prime focus. FWHM is 0".7. The multiple component structure is aligned on a common axis. North is up, and the image is 10.5×10.5 arcsec².

What Is ALPINE Telling Us About Early Galaxies?

The SFR vs. C⁺ relation and C⁺ deficit

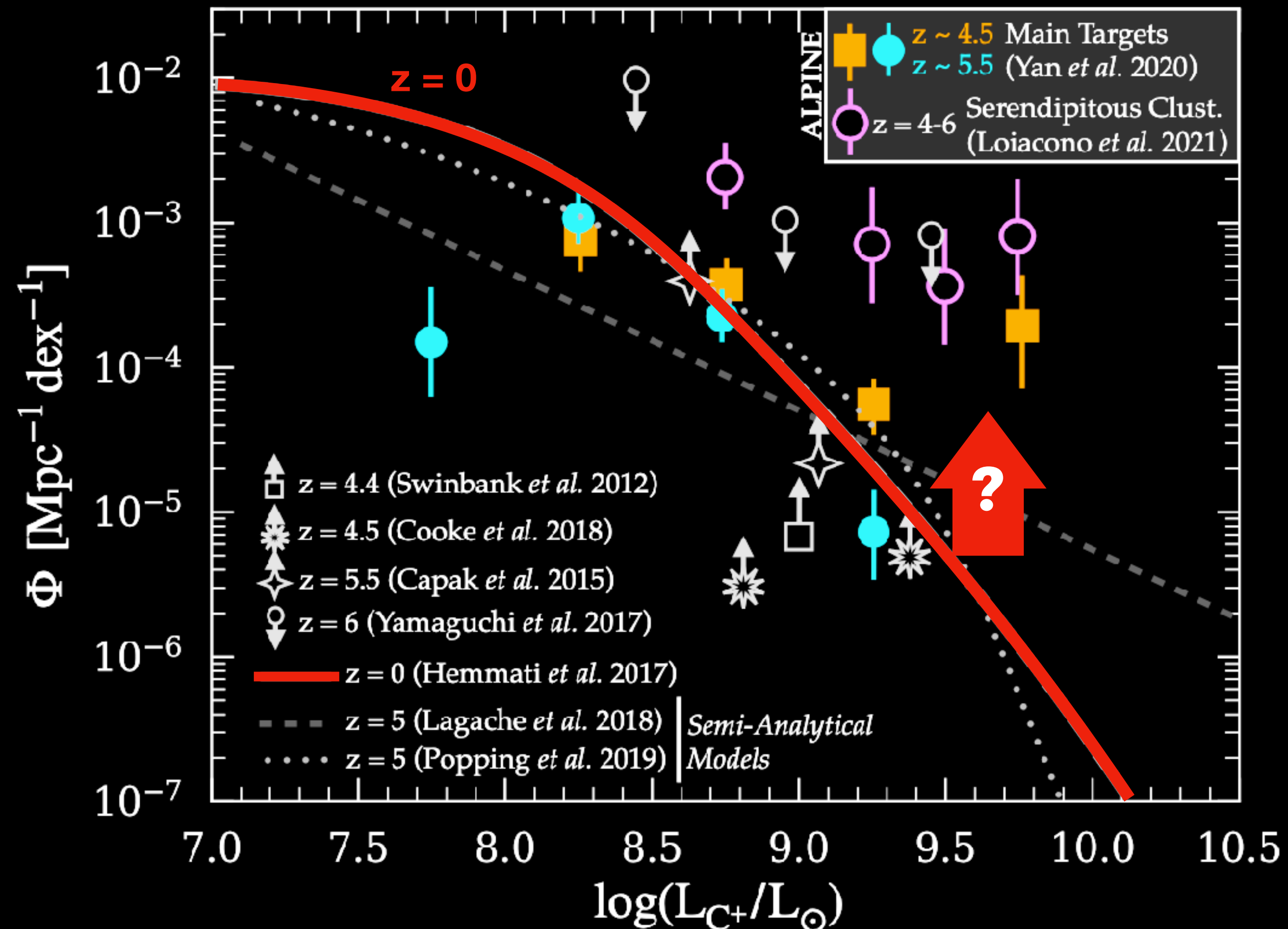
- No deviation found with respect to local SFR-C⁺ relation
- No deficit in C⁺ found
- C⁺ is a reasonable tracer of SFR at z=4-6 for relatively massive galaxies



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- C⁺ overdensity compared to z = 0 LF??

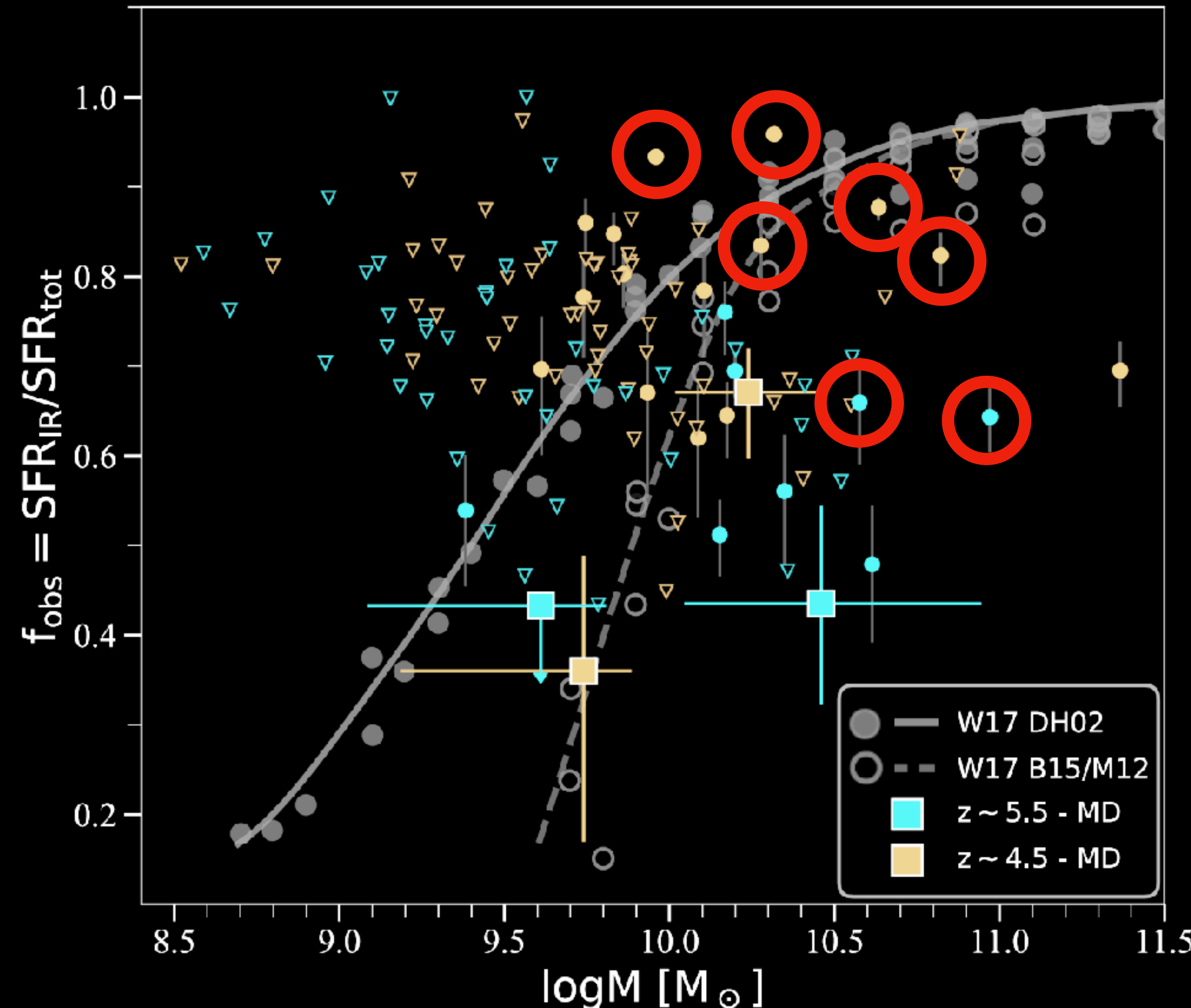


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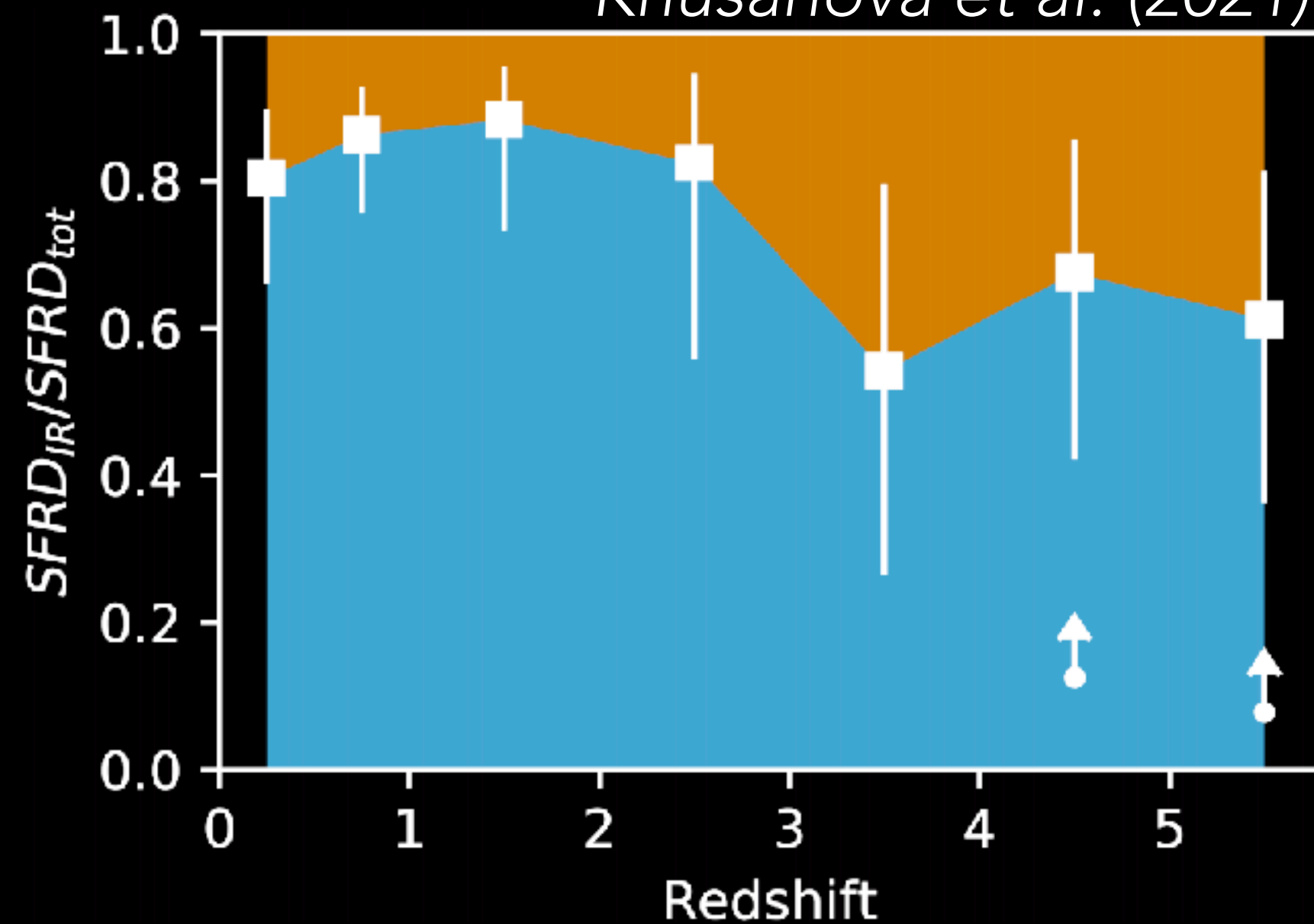
Are high- z galaxies really dust poor?

- Generally high- z galaxies do have a lower dust content
- Most massive galaxies, however can be quite dust-rich

Fudamoto et al. (2020)



Khusanova et al. (2021)

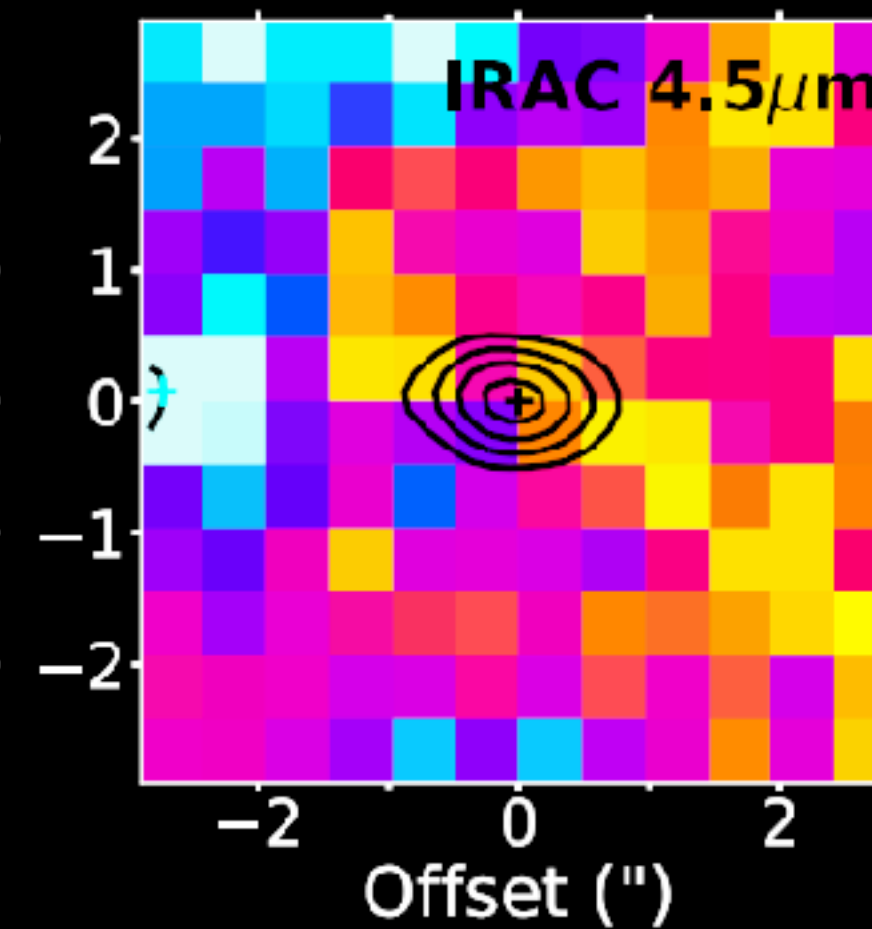
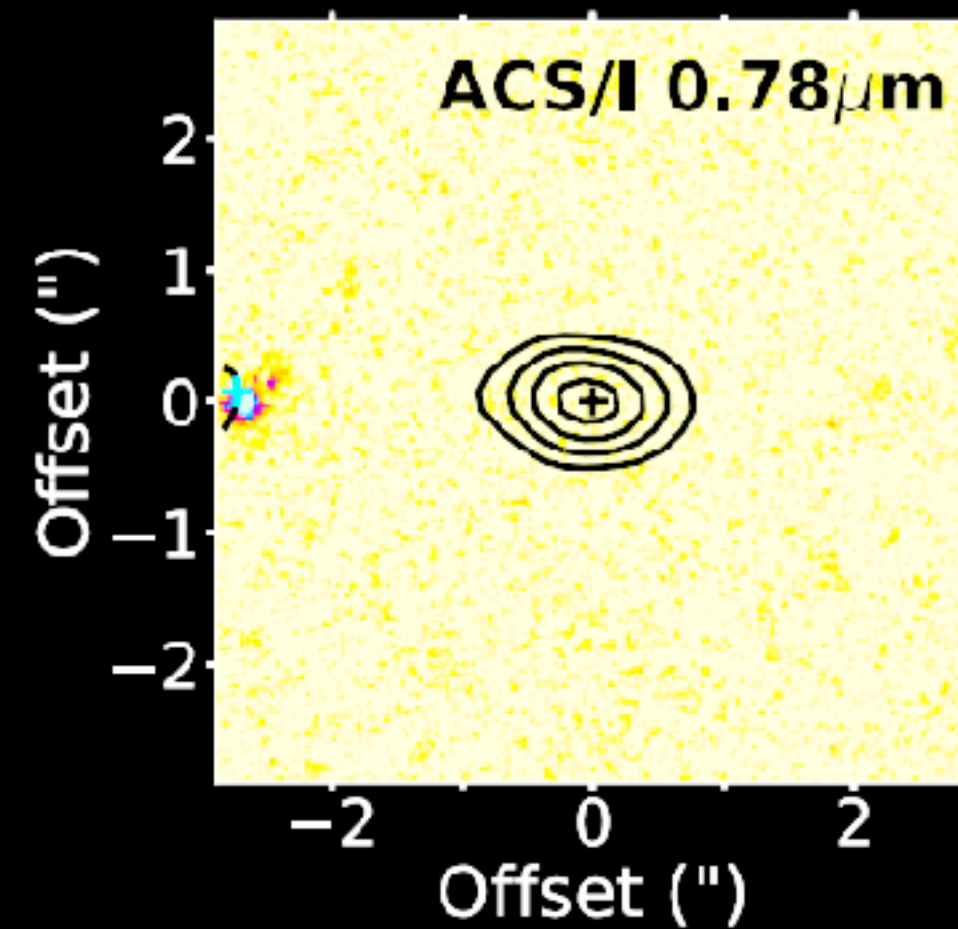
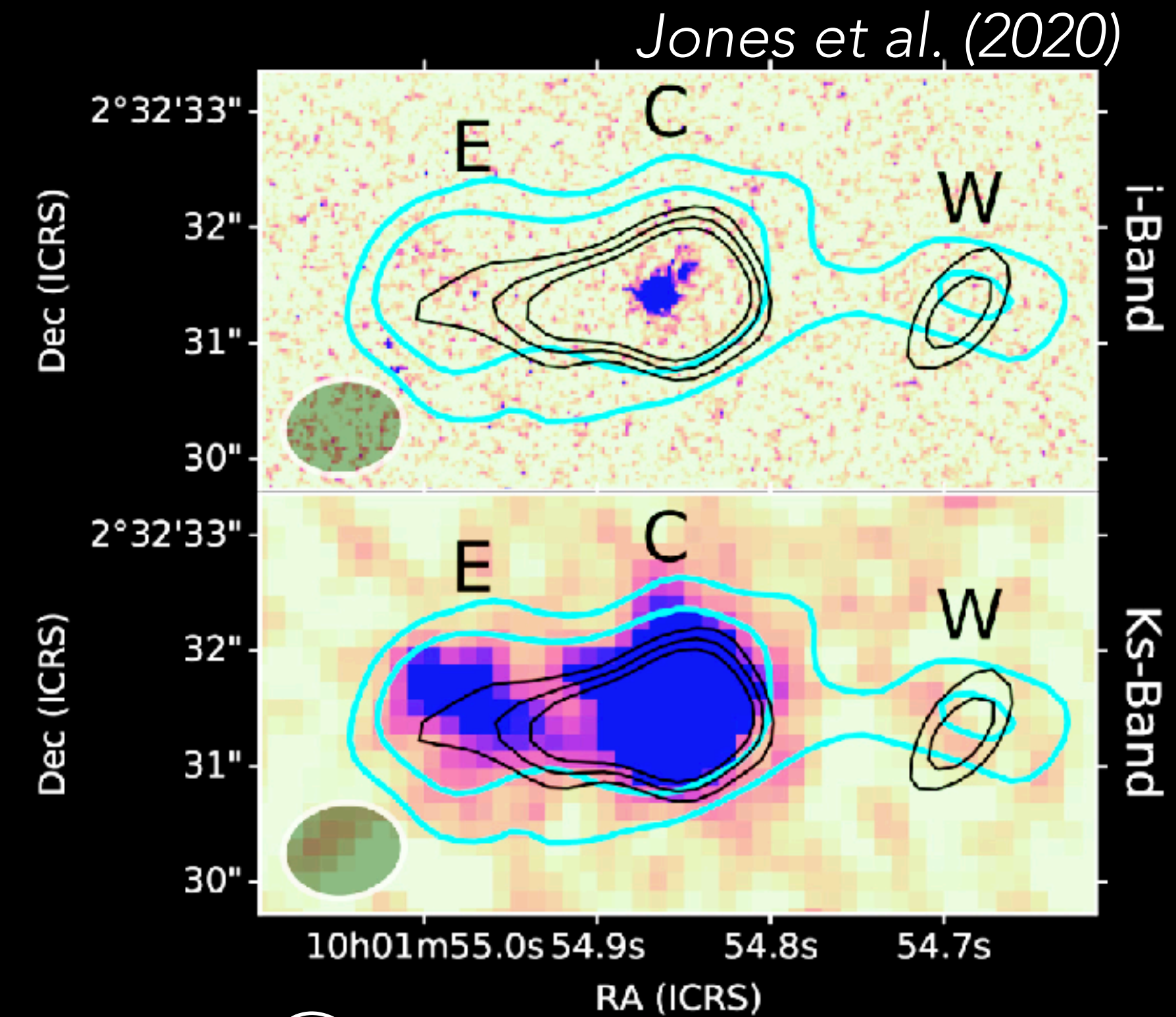


POSTER!

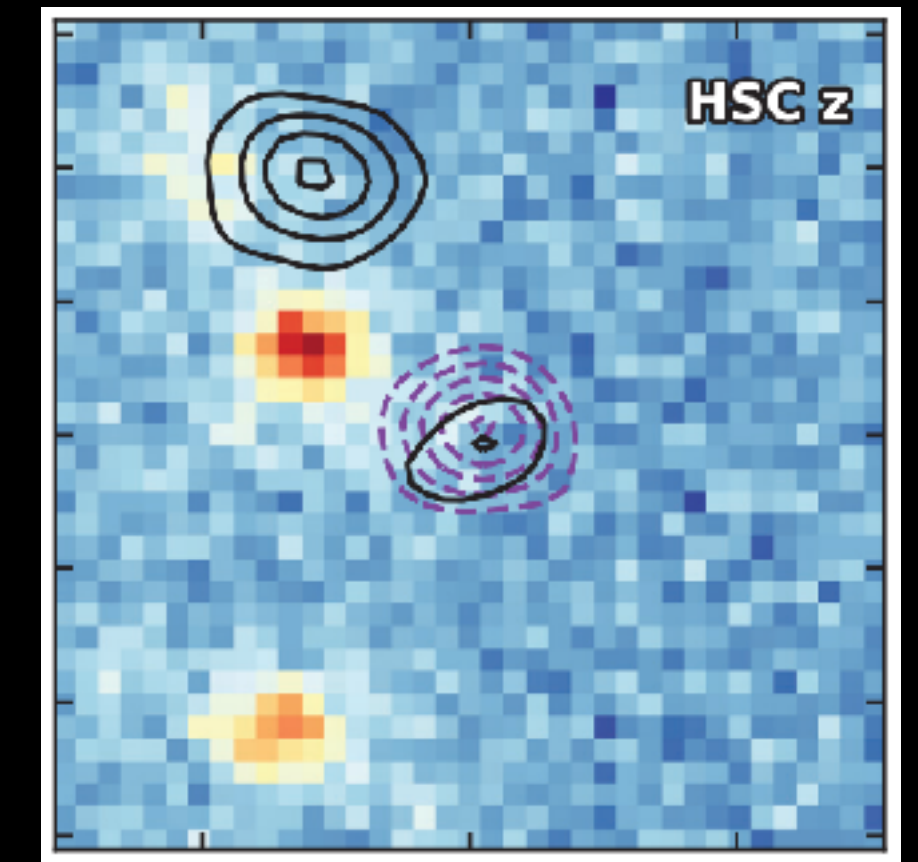
What Is ALPINE Telling Us About Early Galaxies?

Are high-*z* galaxies really dust poor?

- Generally high-*z* galaxies do have a lower dust content
- Most massive galaxies, however can be quite dust-rich
- Significant amount of dust obscured ("UV/optical-dark") galaxies!



Loiacono et al. (2021)
Gruppioni et al. (2020)



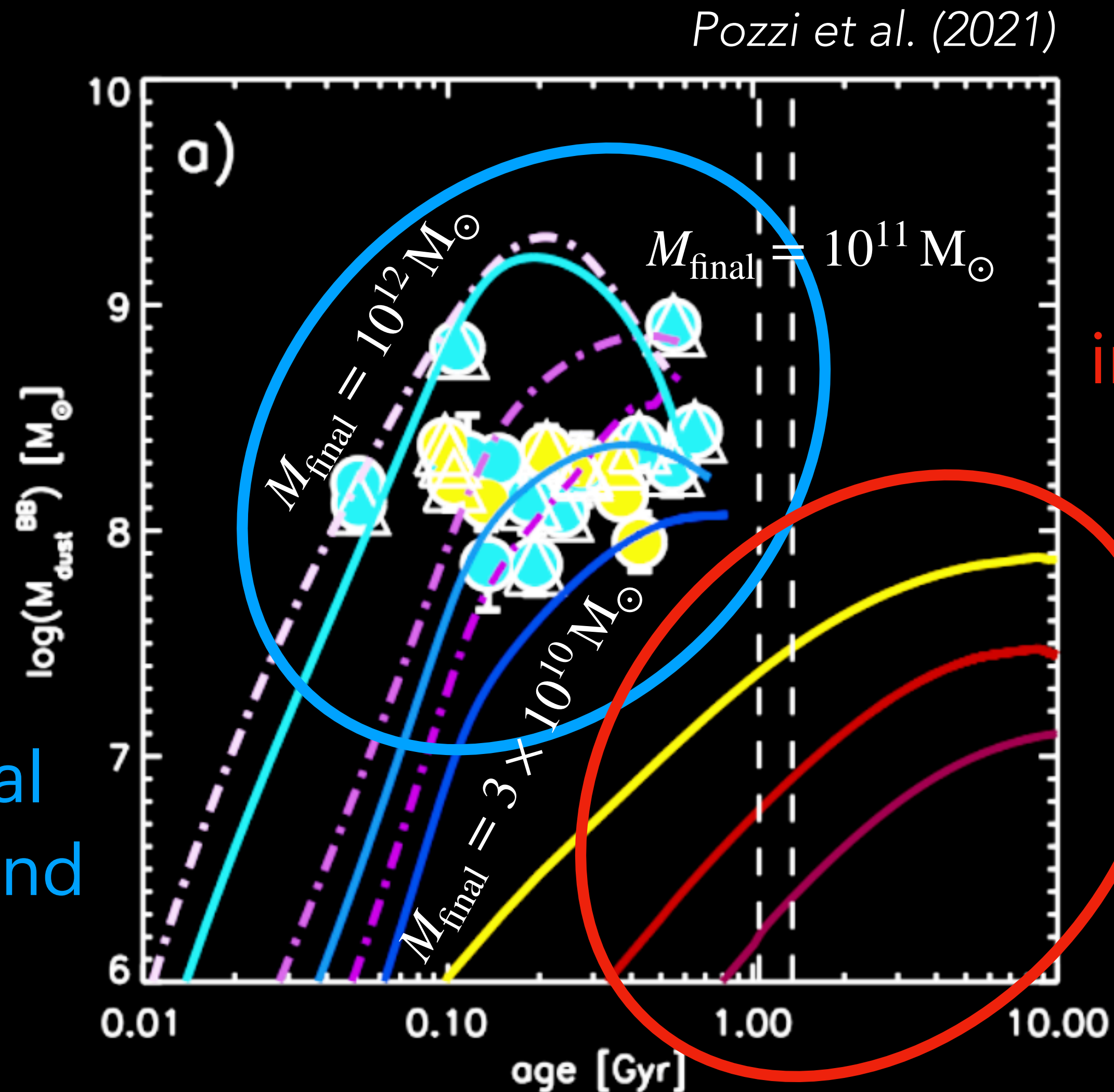
Romano et al. (2020)

What Is ALPINE Telling Us About Early Galaxies?

Total dust mass and age can constrain evolutionary stage

- Statistically, ALPINE galaxies are likely progenitors of local elliptical galaxies (spheroids) as opposed to local disk galaxies.
- Consistent with high fraction of merging galaxies?

Proto-Spheroidal (collapse and burst)



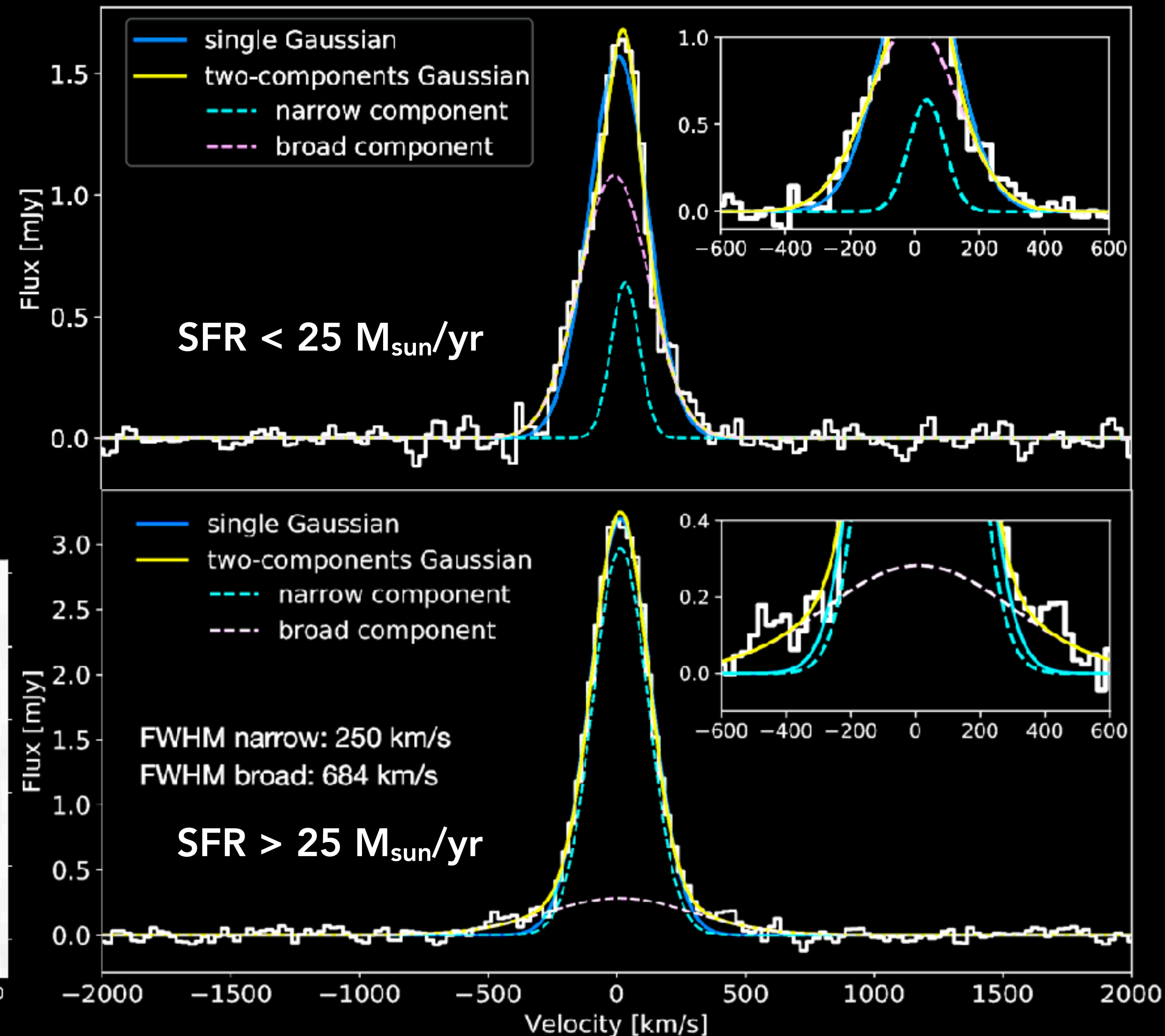
Disk Galaxies (smooth inside-out growth)

What Is ALPINE Telling Us About Early Galaxies?

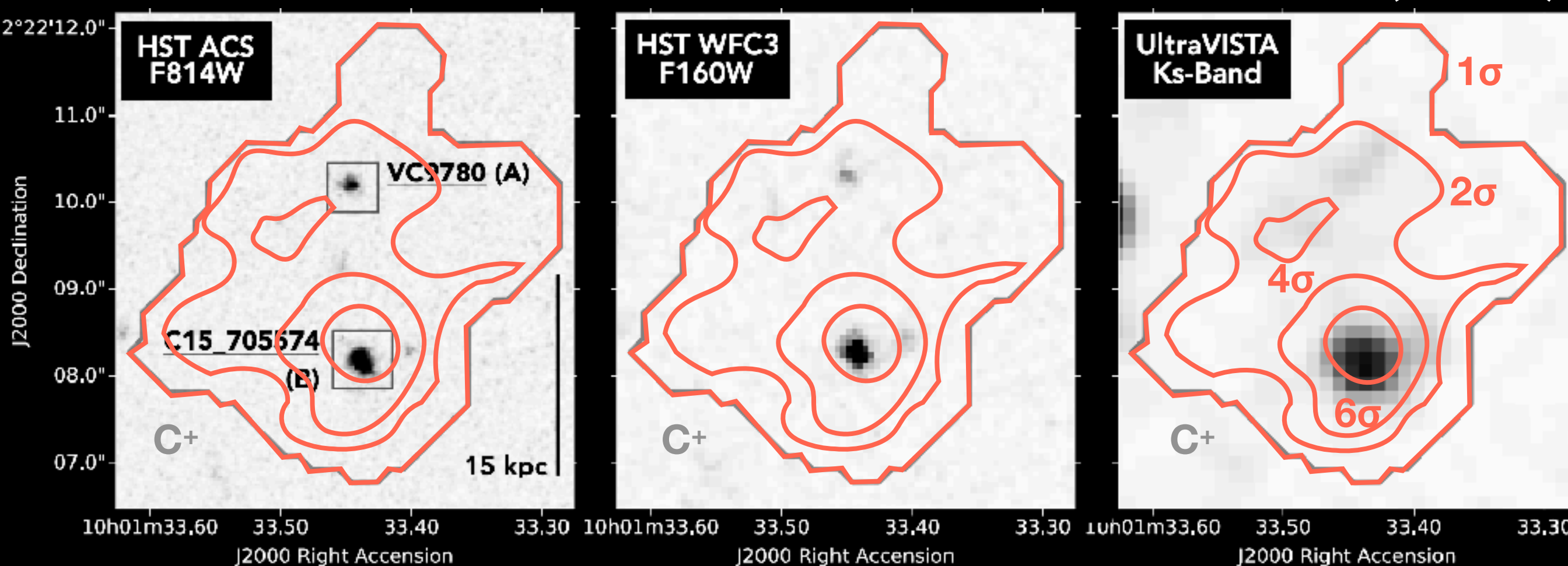
How do high- z galaxies interact with their environment?

- Outflows and distribution of gas in merging systems enrich the surrounding IGM
- Outflows likely dominated by star formation (not AGN)

Ginolfi et al. (2020a)



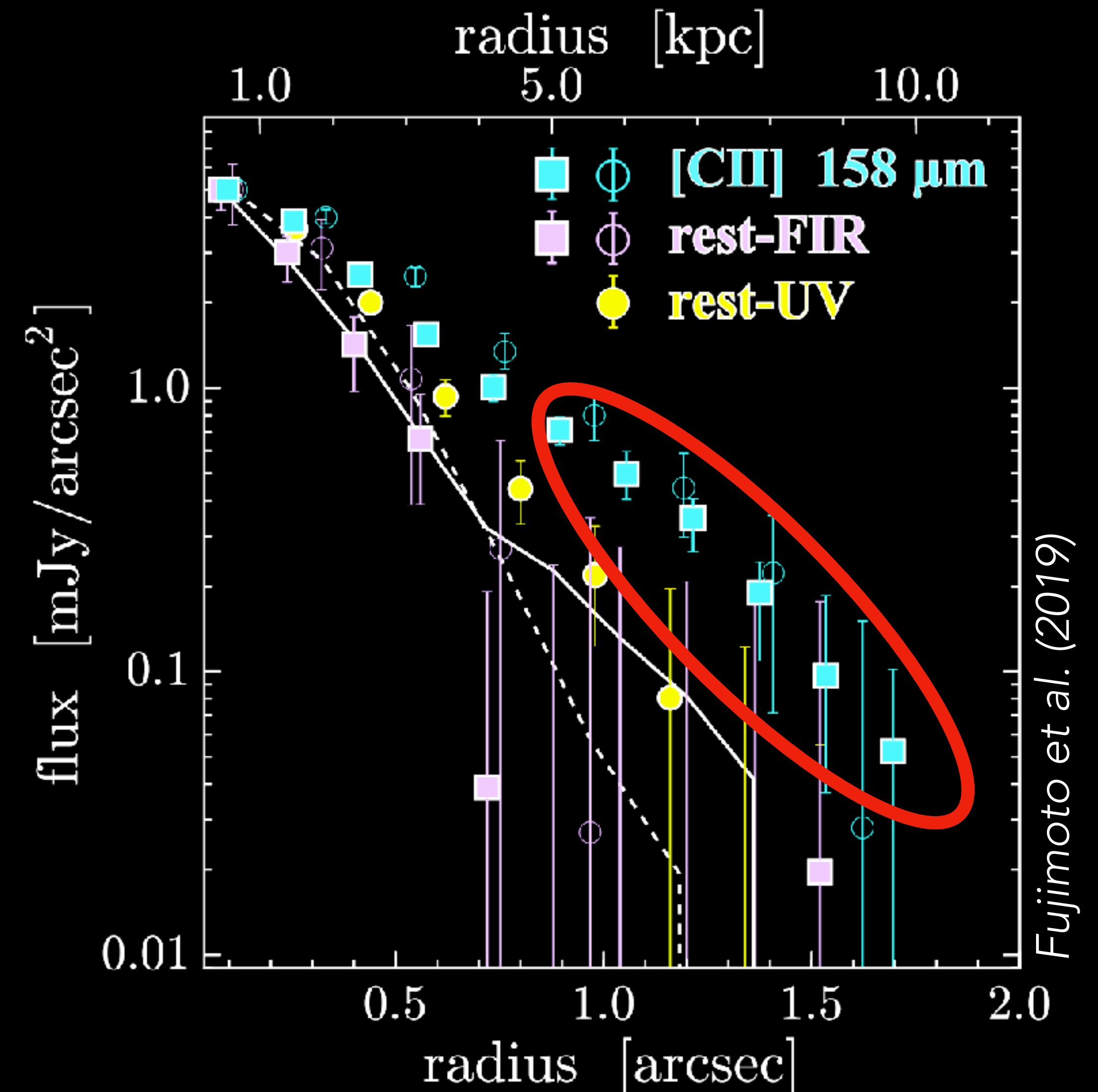
Ginolfi et al. (2020b)



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How do high- z galaxies interact with their environment?

- Outflows and distribution of gas in merging systems enrich the surrounding IGM
- Outflows likely dominated by star formation (not AGN)
- C^+ halos (likely common) produced by outflows, heating, gigantic disks, minor satellites (?)



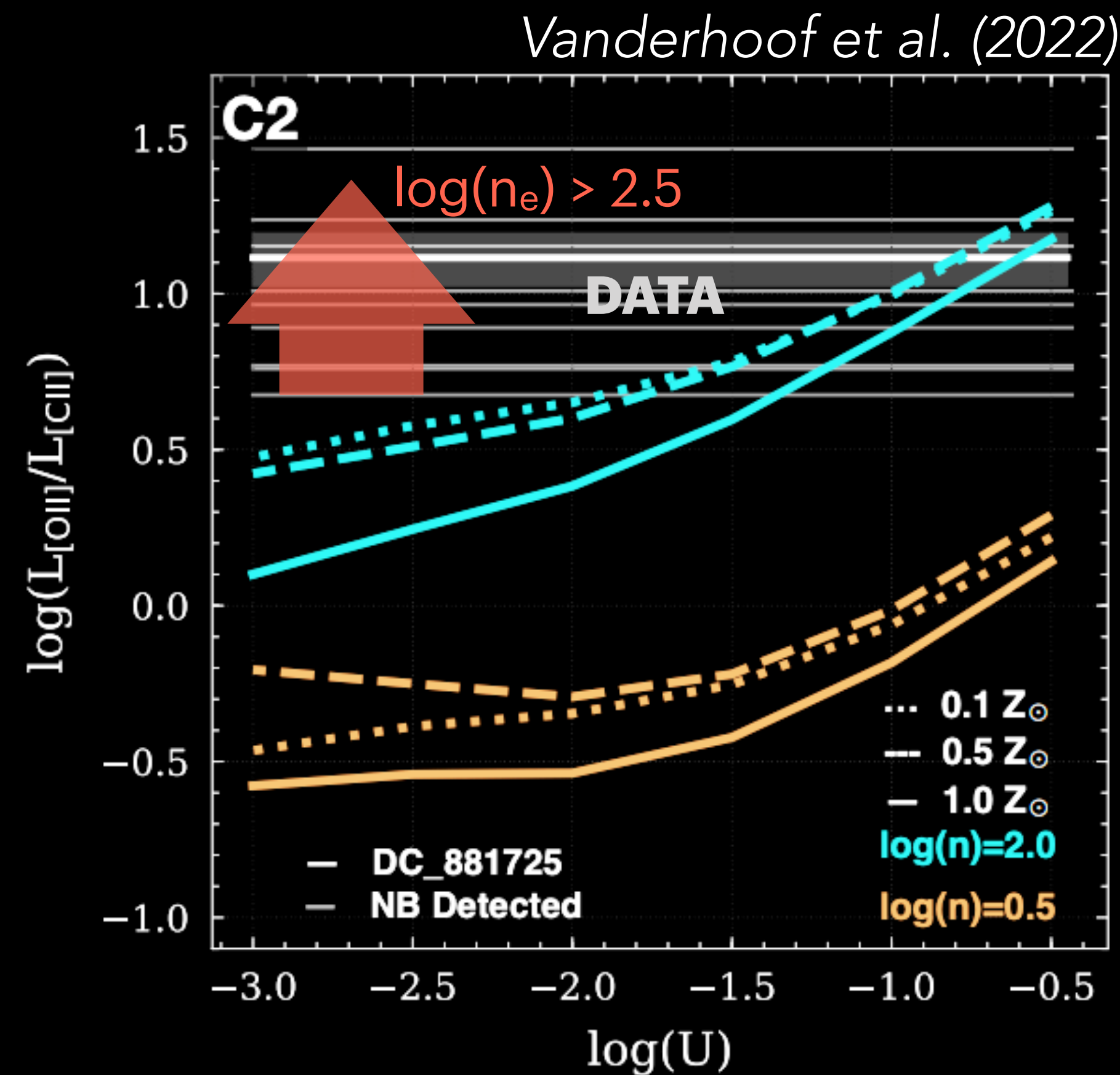
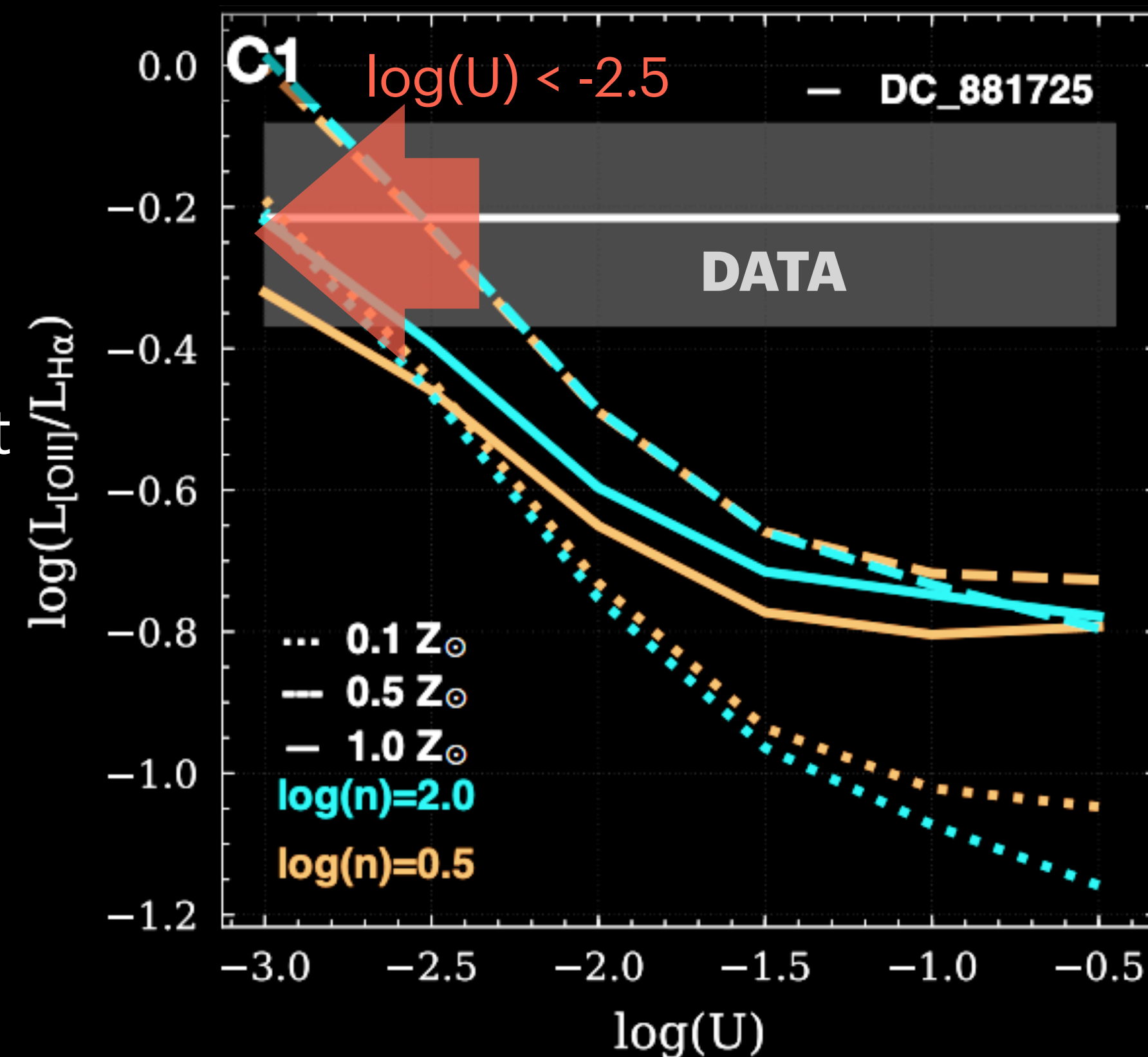
What Is ALPINE Telling Us About Early Galaxies?

Constraints on ISM properties of high-z galaxies

- 10 galaxies have $[\text{OII}]_{\lambda 3727}$ and C^+ measured: **ONLY** sample at $z > 4.5$!!
- $[\text{OII}]_{\lambda 3727}$ from MOSFIRE (1) and Subaru NB (9) observations of C3VO cluster

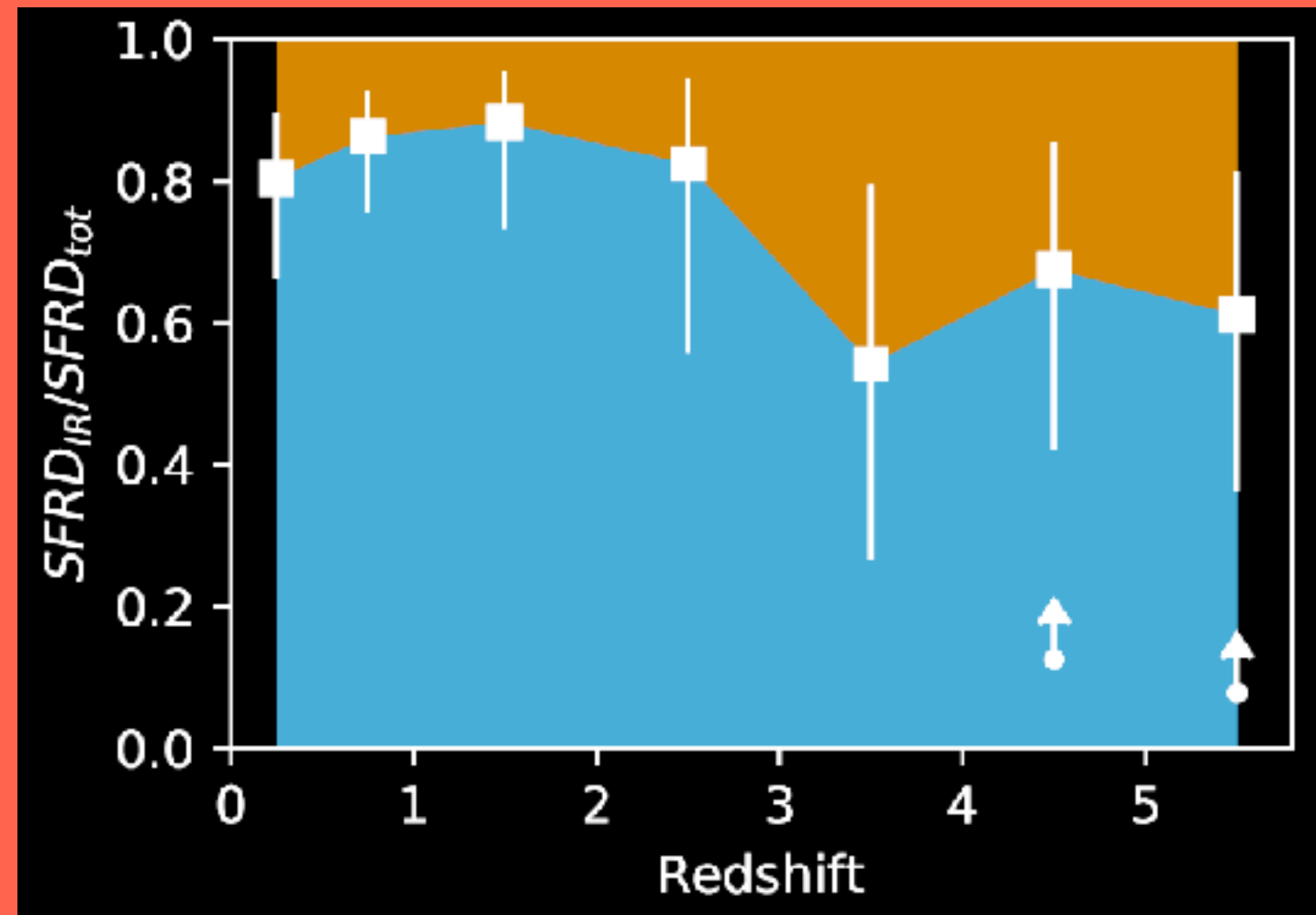
(Lemaux et al. 2020; Shen et al. 2021)!

- $\text{H}\alpha$ from Spitzer colors (Faisst et al. 2019)
- Results:
 - ➔ $\log(U) < -2.5$ (consistent with $z=2-3$ galaxies)
 - ➔ $\log(n_e) = 2.5-3$ (slightly higher than $z=2-3$ galaxies at same SFR)



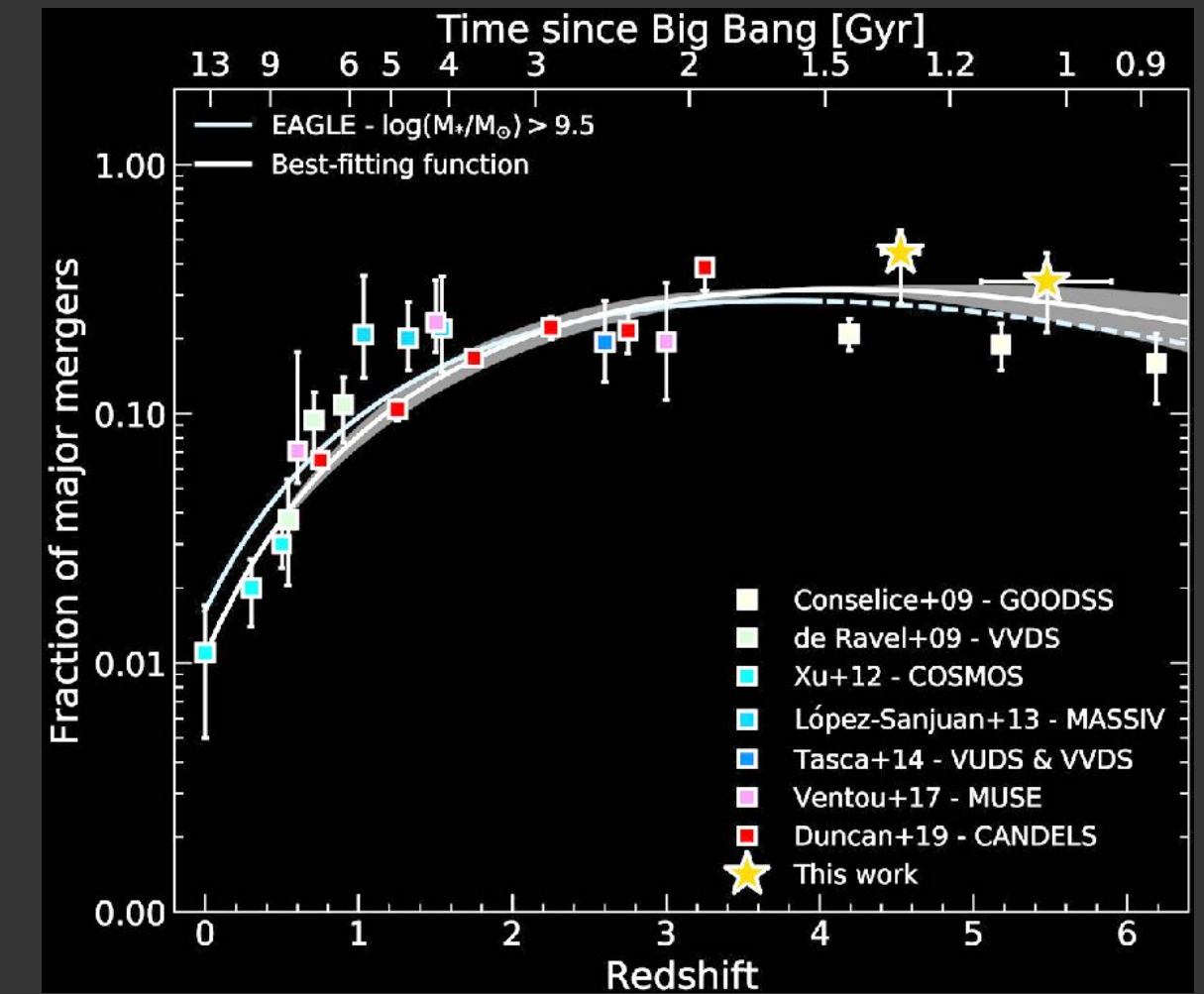
More results in following presentations!

Yana Khusanova (Poster)



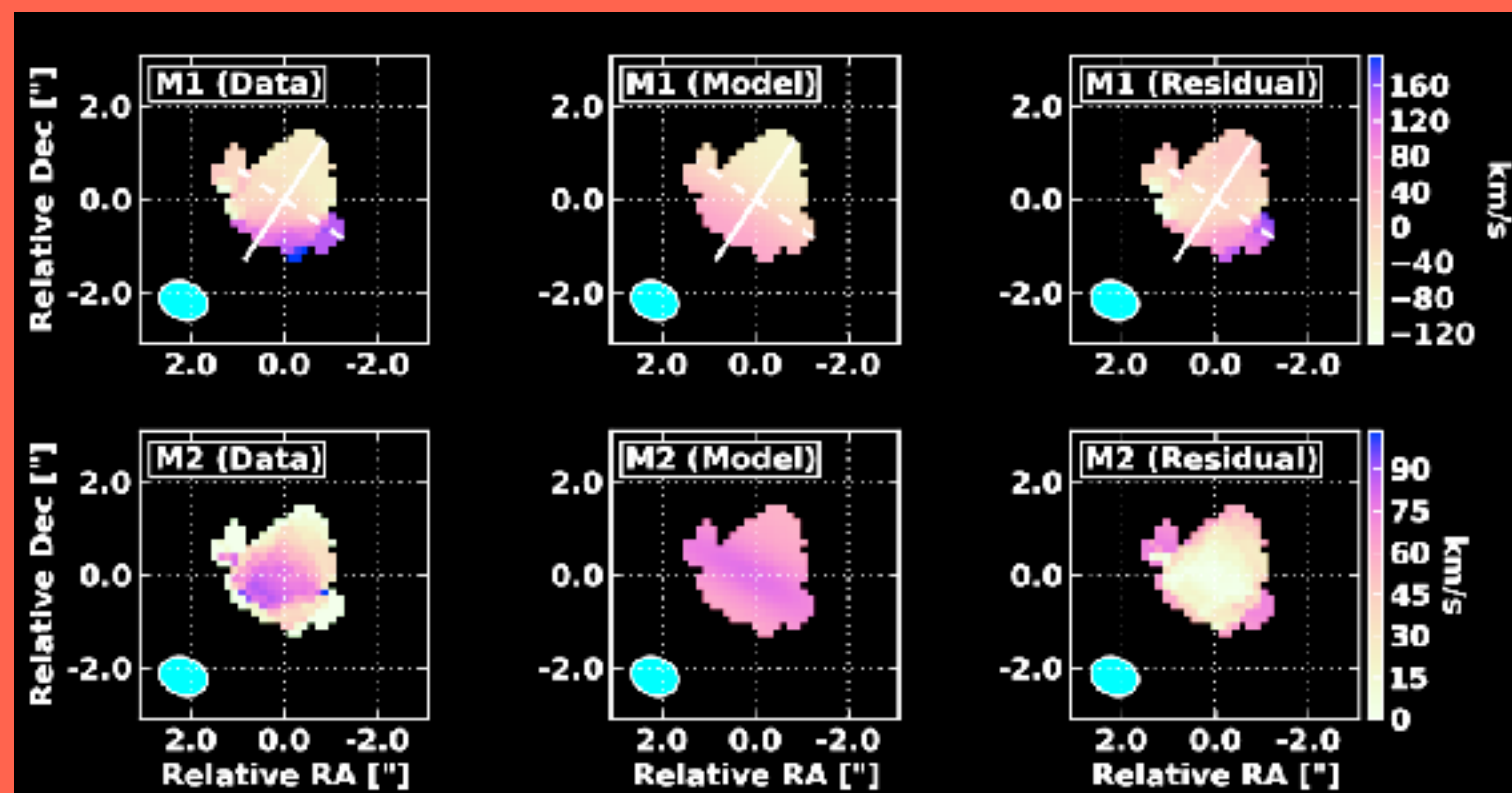
Main sequence and SFR density

Michael Romano



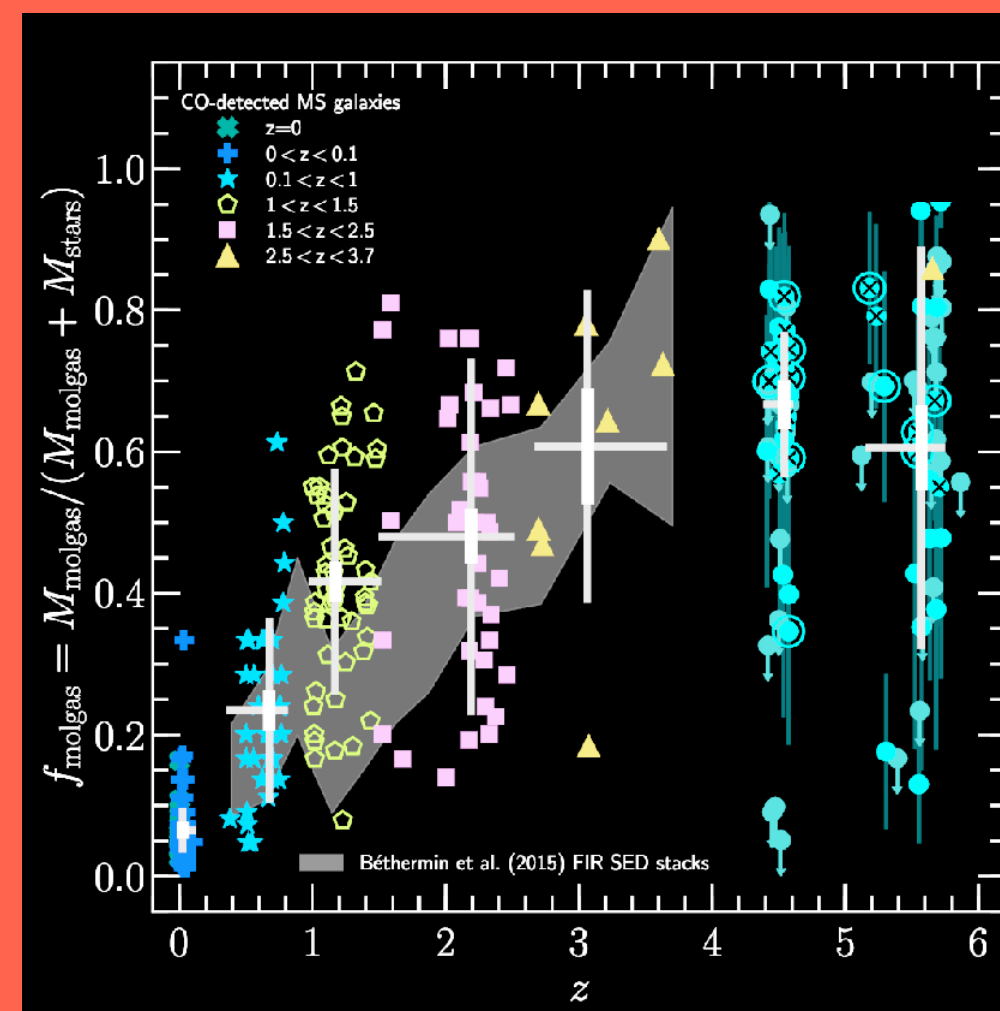
Major mergers and obscured sources

Gareth Jones



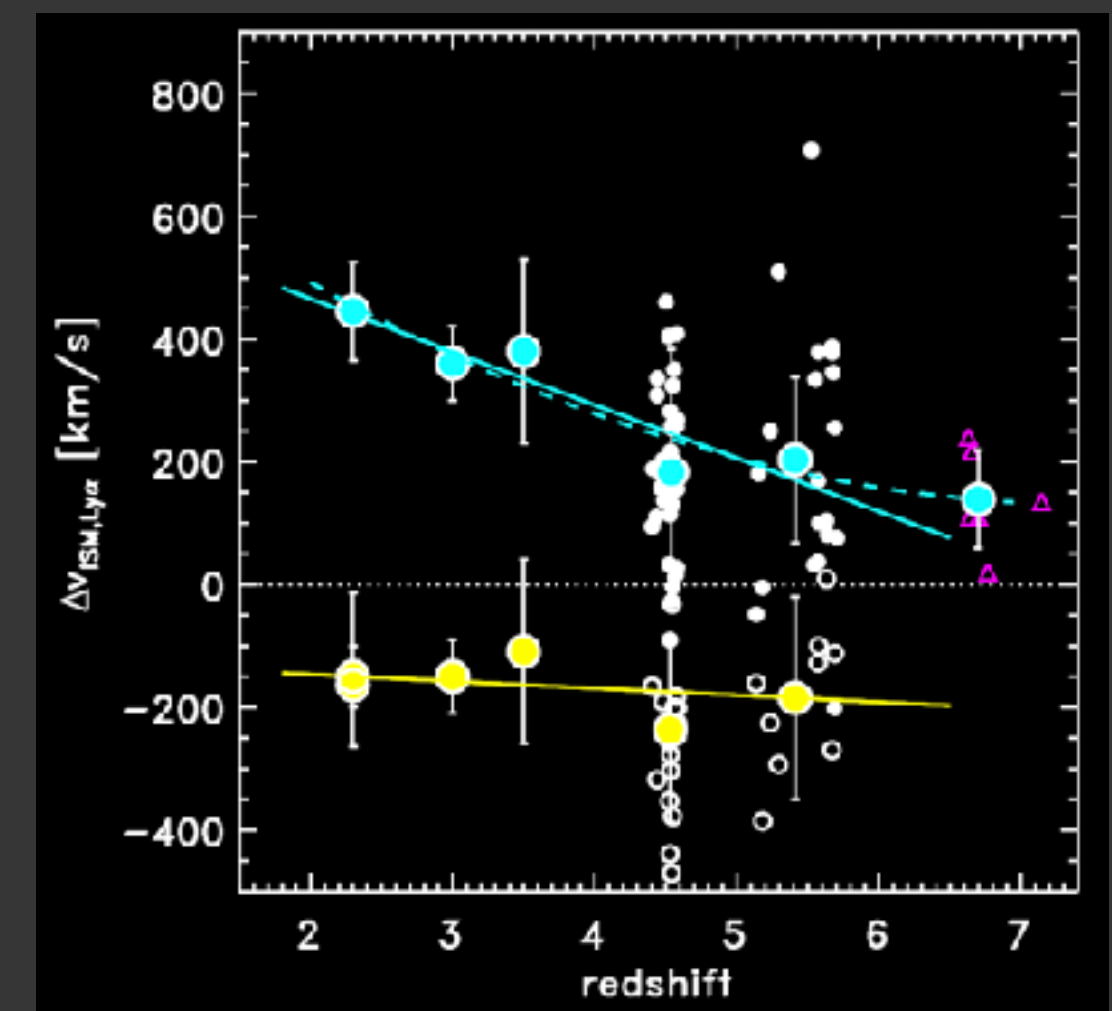
Kinematic analysis

Mirka Dessauges-Zavadsky



Molecular gas mass and depletion

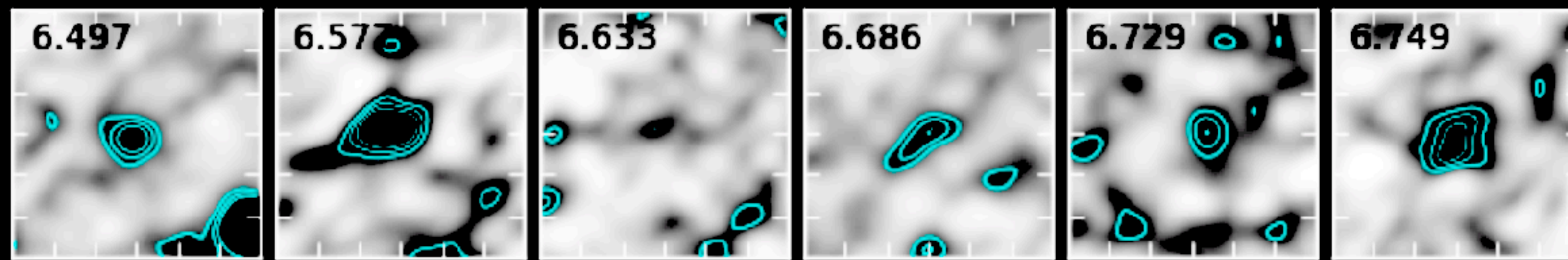
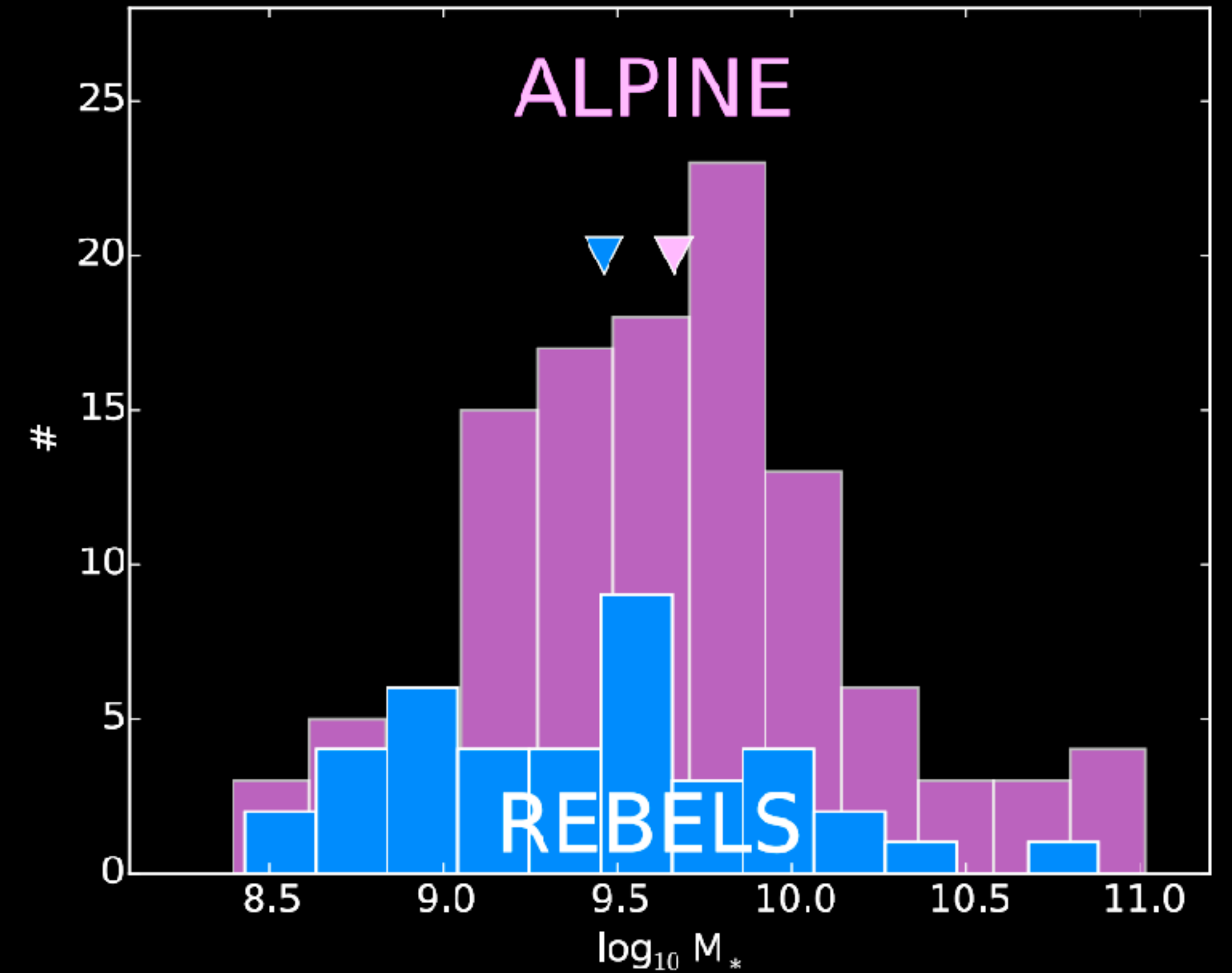
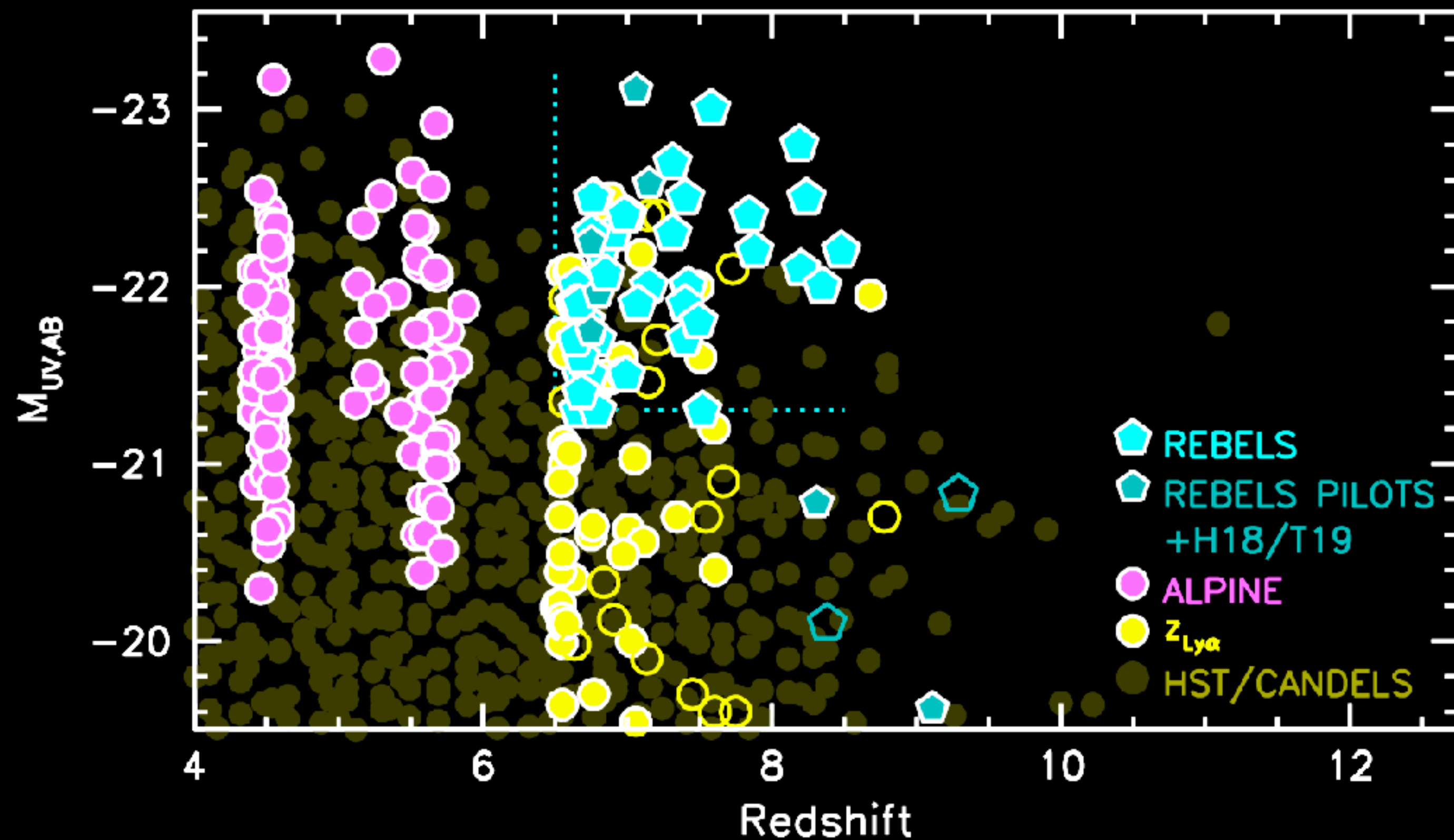
Paolo Cassata



Velocity offsets between Ly α and C $^+$

What About Higher Redshifts?

REBELS survey (Bouwens et al. 2021) is ALPINE continuation to $z > 7$

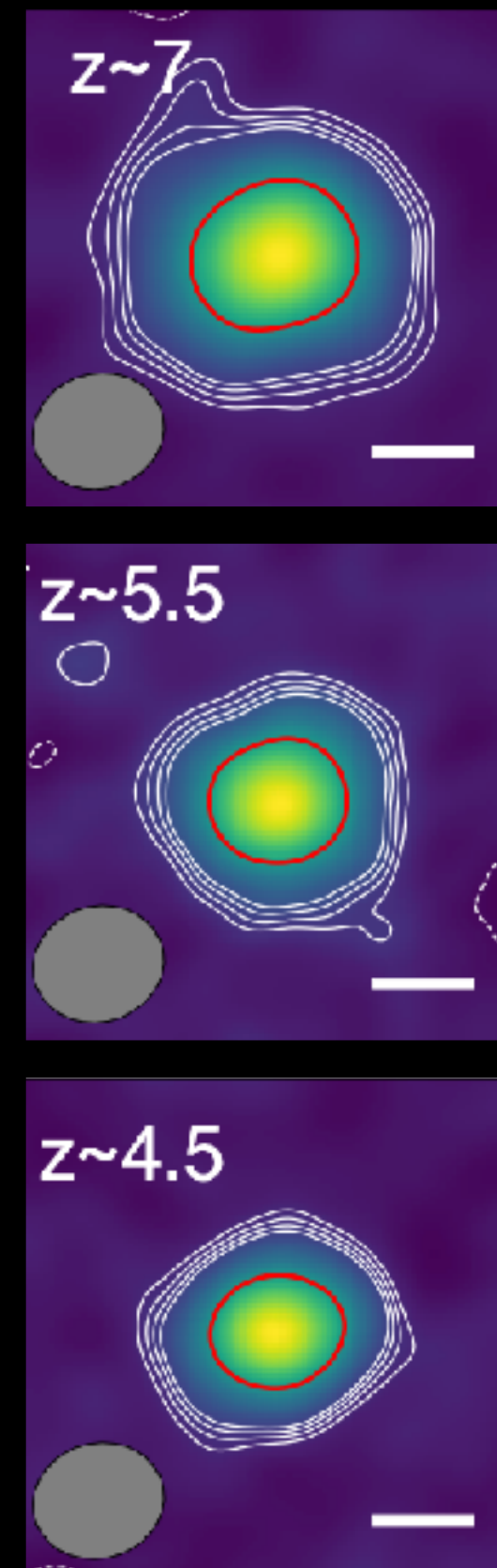
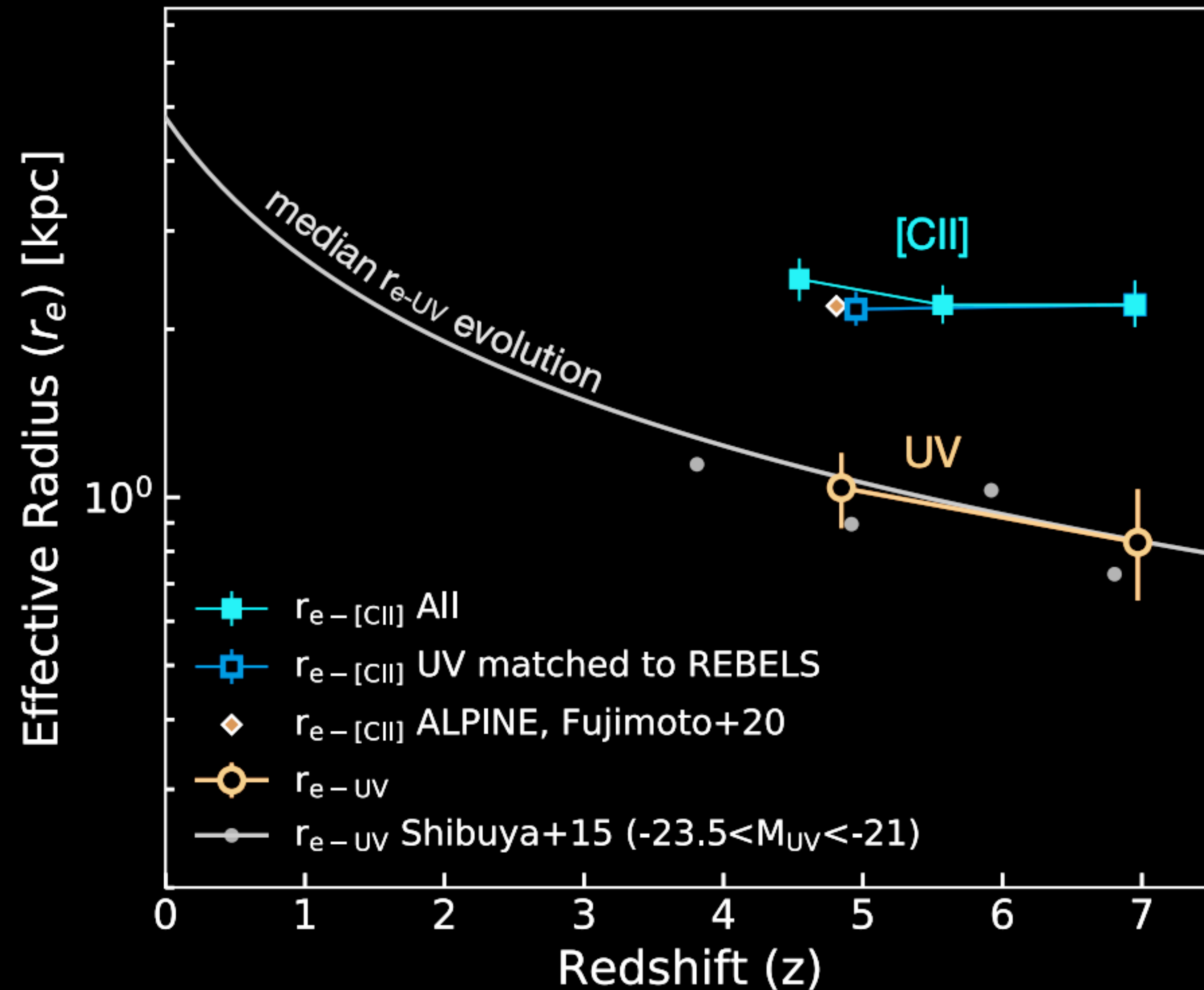


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- Evolution of C^+ halo size from $z = 7$ to $z = 4$

Fudamoto et al. (2022)

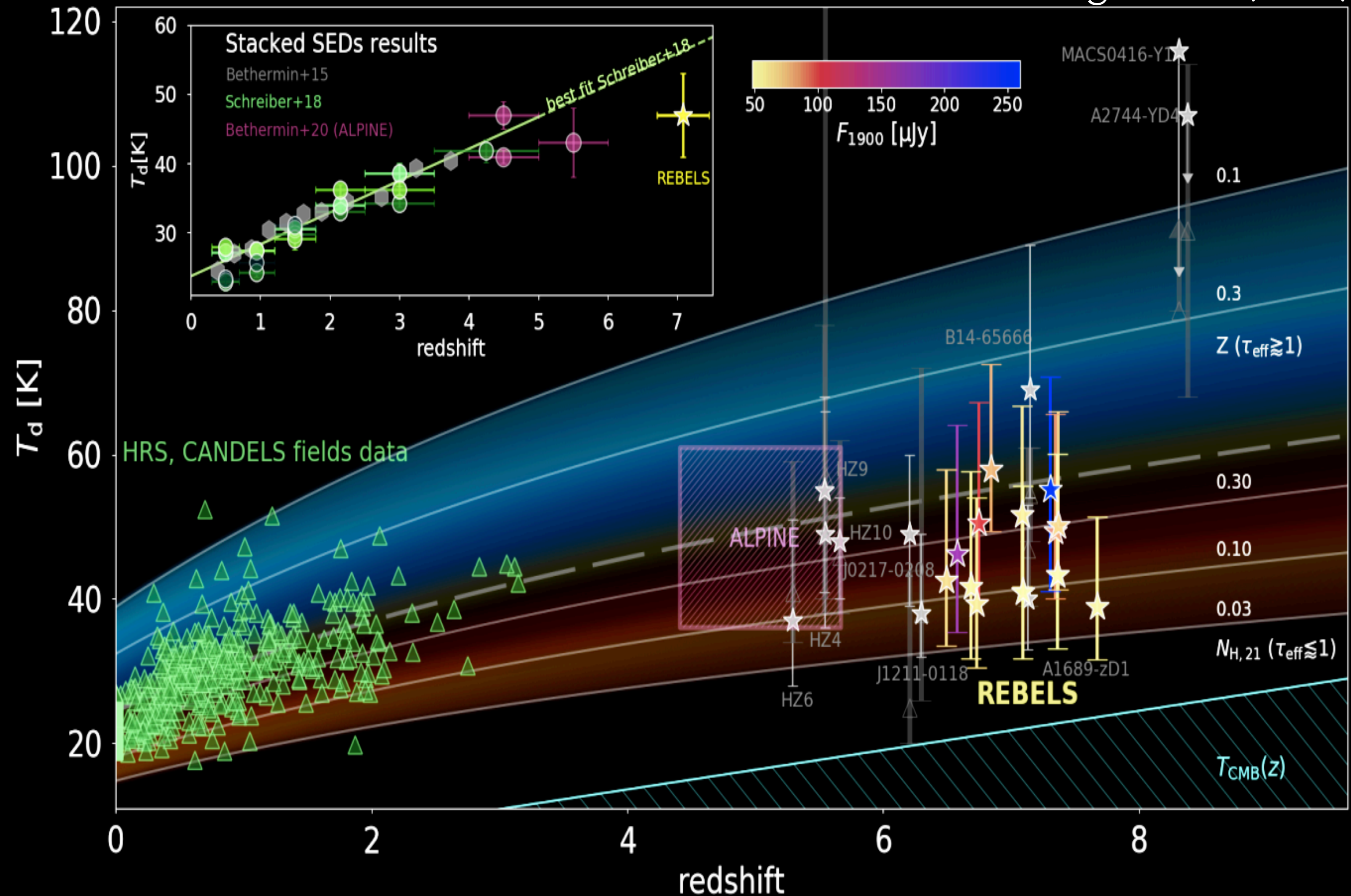


What About Higher Redshifts?

REBELS survey (Bouwens et al. 2021) is ALPINE continuation to $z > 7$

- Evolution of C⁺ halo size from $z = 7$ to $z = 4$
- Evolution of dust temperature from $z = 7$ to $z = 4$ (see Laura Sommovigo's talk)

Sommovigo et al. (2022)

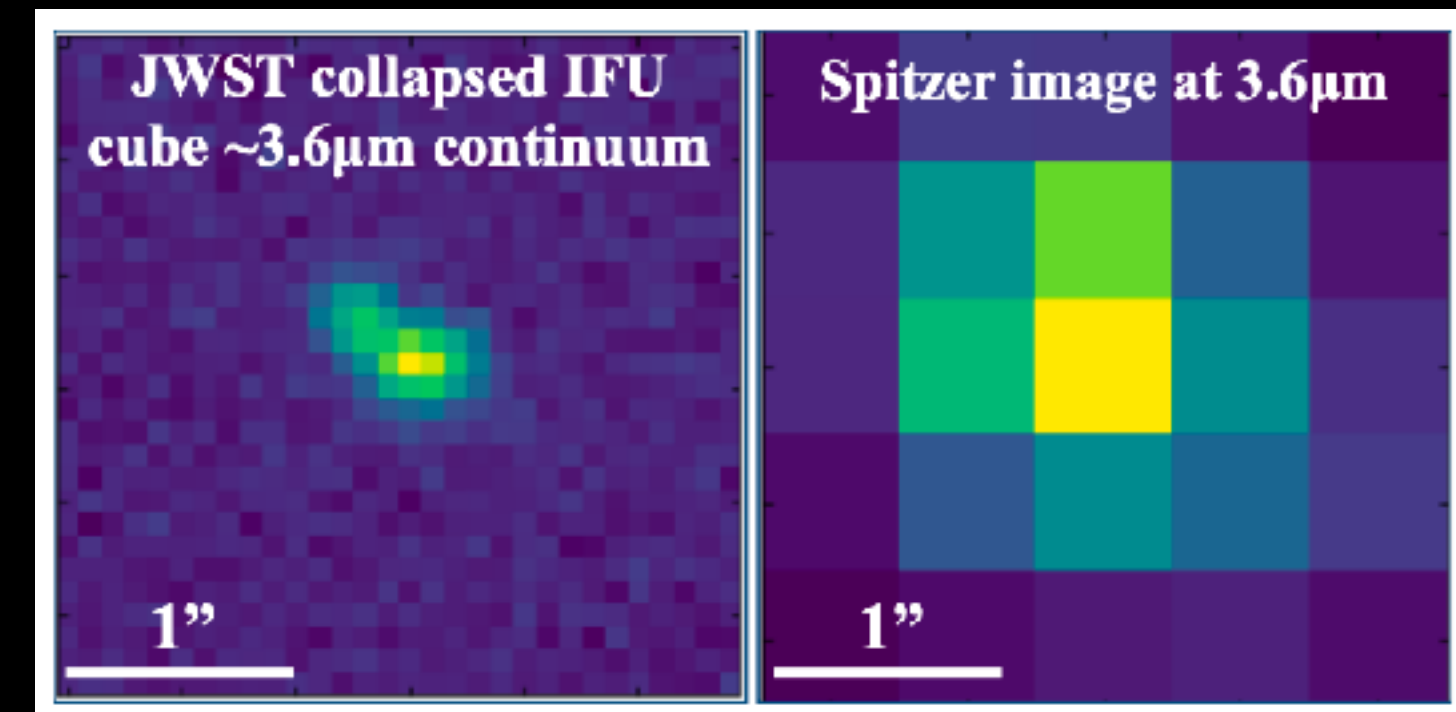


Conclusions

- ALPINE, providing the **first true multi-wavelength study**, has significantly improved our understanding of **how galaxies evolve in a post-reionization time**.
- ALPINE builds the necessary **baseline sample** that can be further expanded (by more galaxies and observations) and serves as **comparison sample** for other redshifts.

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