# Star Formation Rate Calculations in ALPINE [CII]-Selected Galaxies

Studying High-Redshift Galaxies using ALMA Large Programs

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# ALMA + JWST

| | **Atacama Large Millimeter-submillimeter Array** | **James Webb Space Telescope** |
|---|---|---|
| **Location** | Atacama Desert, Chile (Earth) | Around Lagrange point 2 (space) |
| **Type** | Ground-based interferometer | Space telescope |
| **Wavelength range** | Far infrared (.3–8.6 *mm*) | Near+mid-infrared (.6–28.5 *μm*) |
| **Used by me?** | Yes! | No |

*Image courtesy of the European Southern Observatory.*

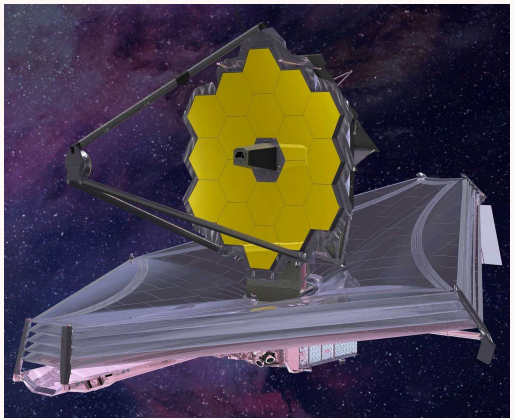
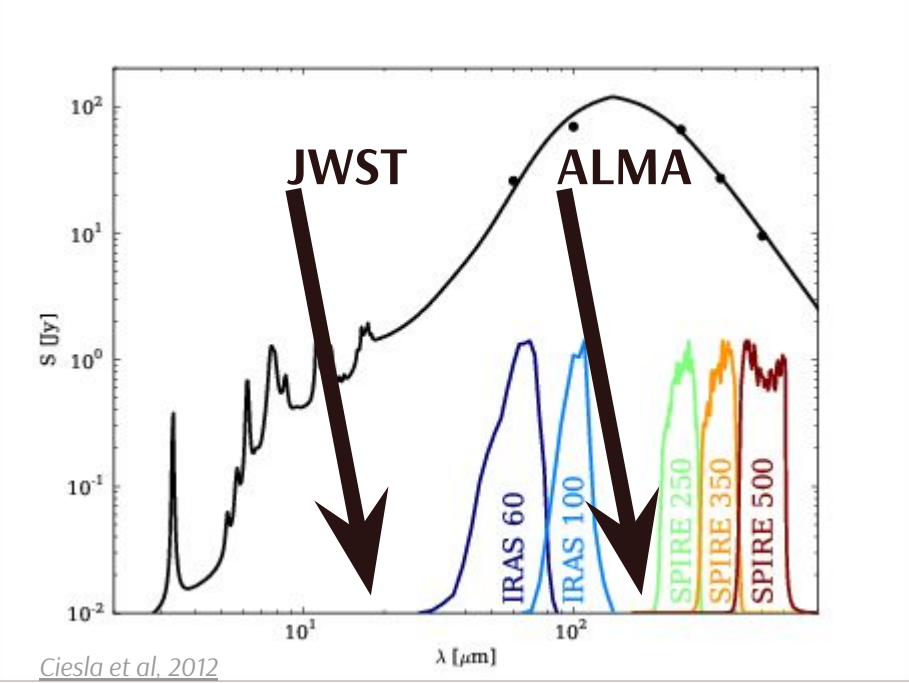


*Image courtesy of NASA, ESA, CSA, Northrop Grumman.*

www.eso.org
almascience.nrao.edu/
science.nasa.gov/mission/webb/

# Spectral Energy Distribution (SED) Fitting




*Ciesla et al, 2012*

SEDs show spectral flux density vs. wavelength.

Fitting the SED from ALMA or JWST data to models allows us to make inferences about galaxy properties.

Heavily model-dependent!

SED fitting useful for mass, star formation rate (SFR), dustiness, and more.

The more complete your data, the better your SED fitting.

# ALMA Large Programs

## ASPECS

ALMA SPECtral line Survey in the UDF: targeting galaxies at $z < 4$ in the Hubble Ultra Deep Field (below), one of the best-studied regions of space.

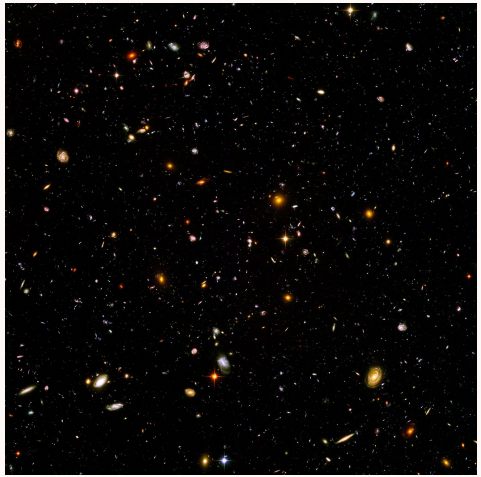
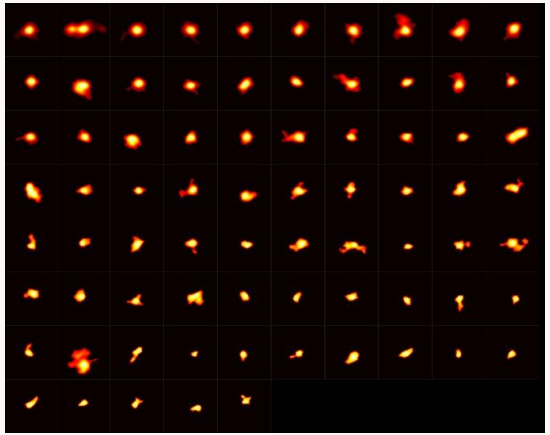


*Image courtesy of NASA and the ESA.*

## ALPINE

ALMA Large Program to INvestigate [CII] at Early times: targeting galaxies $4 < z < 6$, with a wealth of ancillary data.



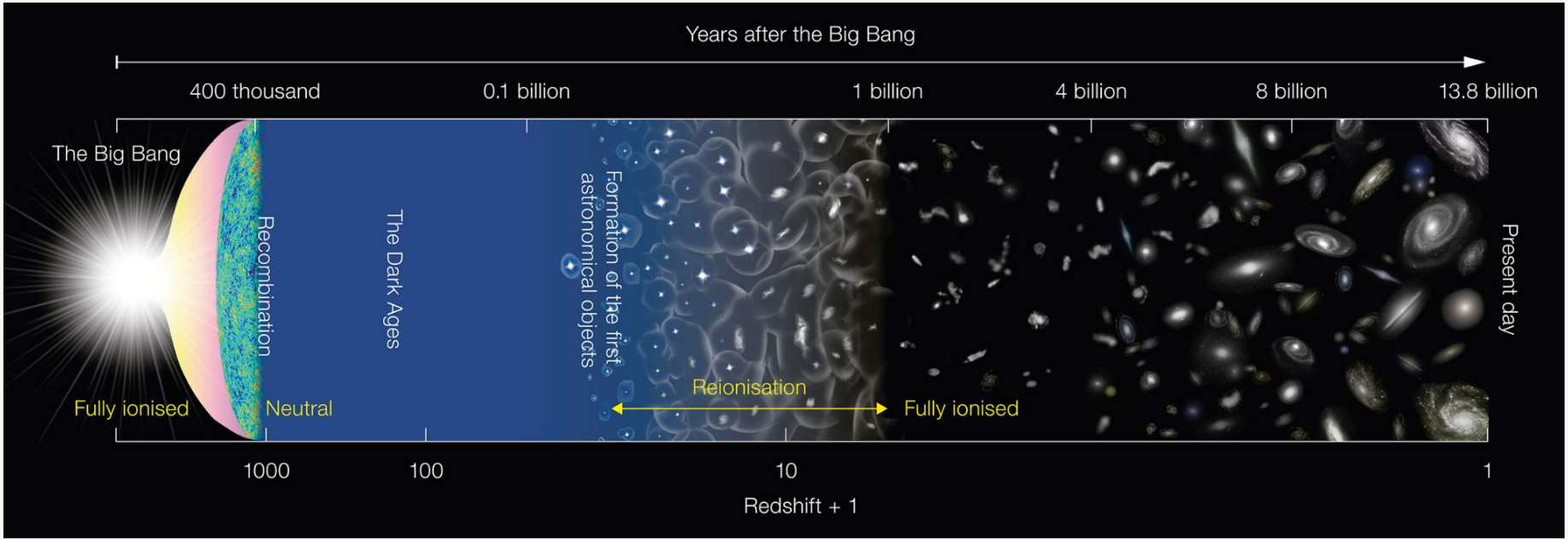
*almascience.eso.org/*

## REBELS

Reionization Era Bright Emission Line Survey: targeting $z > 6$ galaxies with no known spectroscopic redshift based on bright [CII] emission.


*Fudamoto et al. 2021*

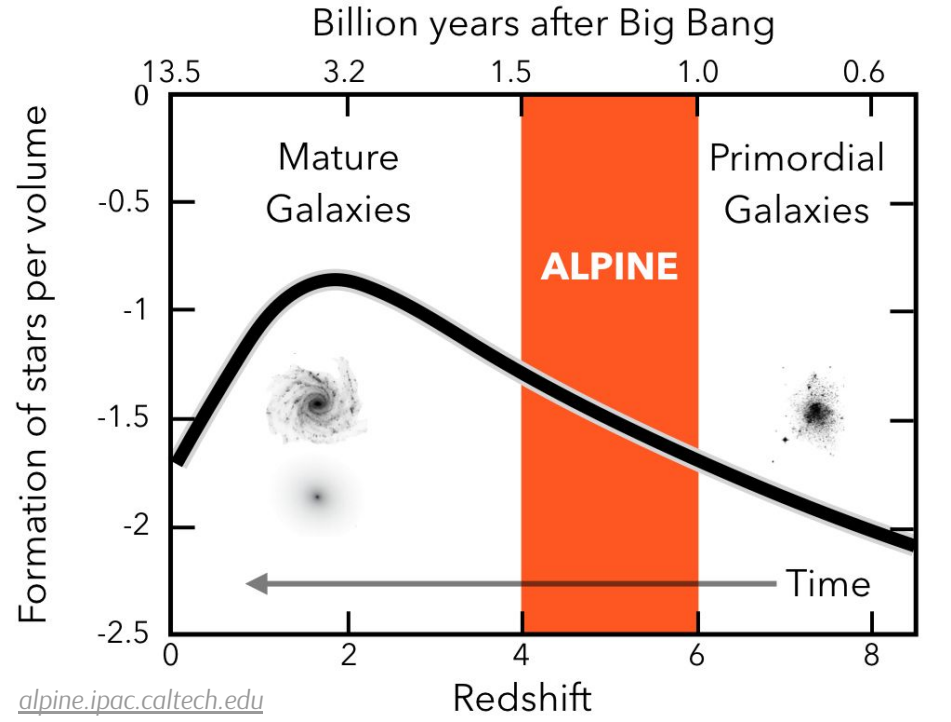
# The History of the Universe




REBELS ALPINE ASPECS

NAOJ via www.astronomy.com

# ALPINE Data




ALPINE observed emission lines of galaxies using ALMA band 7.

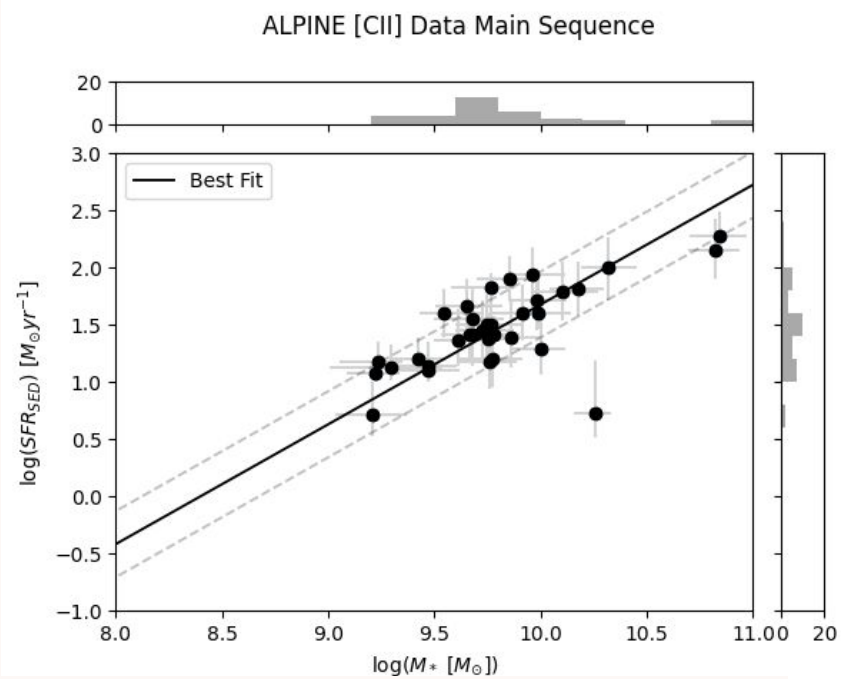
Targeted 118 galaxies looking for their [CII] line—tracer of ionized and unionized gas in galaxies.

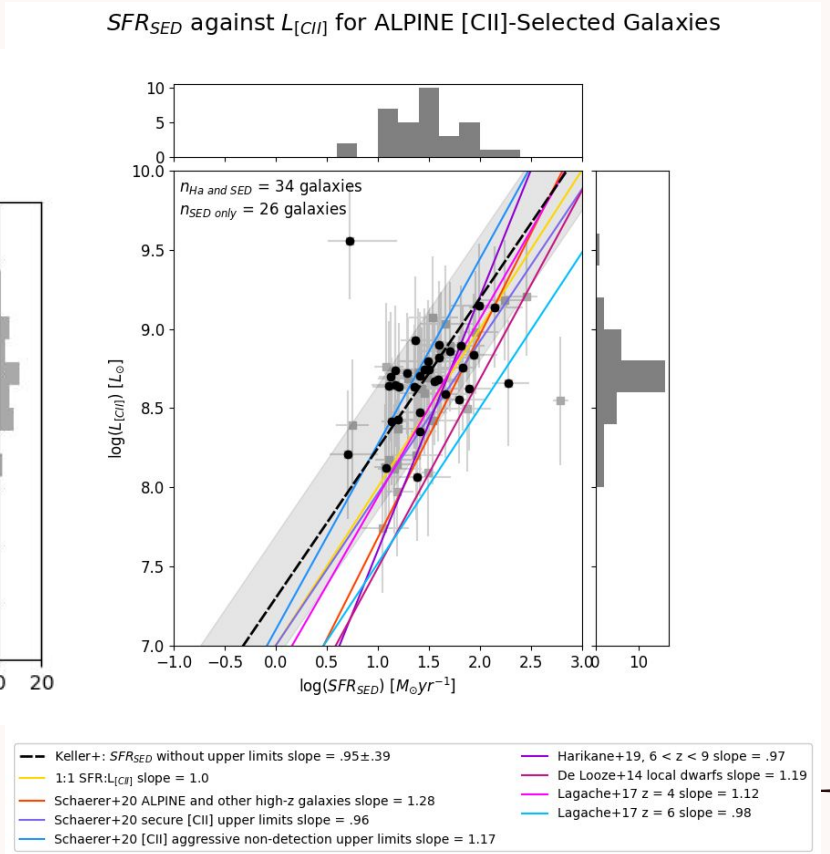
[CII] is a very bright, very versatile emission line that can describe:

- ☆ star formation rate (SFR)
- ☆ interstellar medium makeup
- ☆ galactic mass outflows
- ☆ usually-obscured gas dynamics

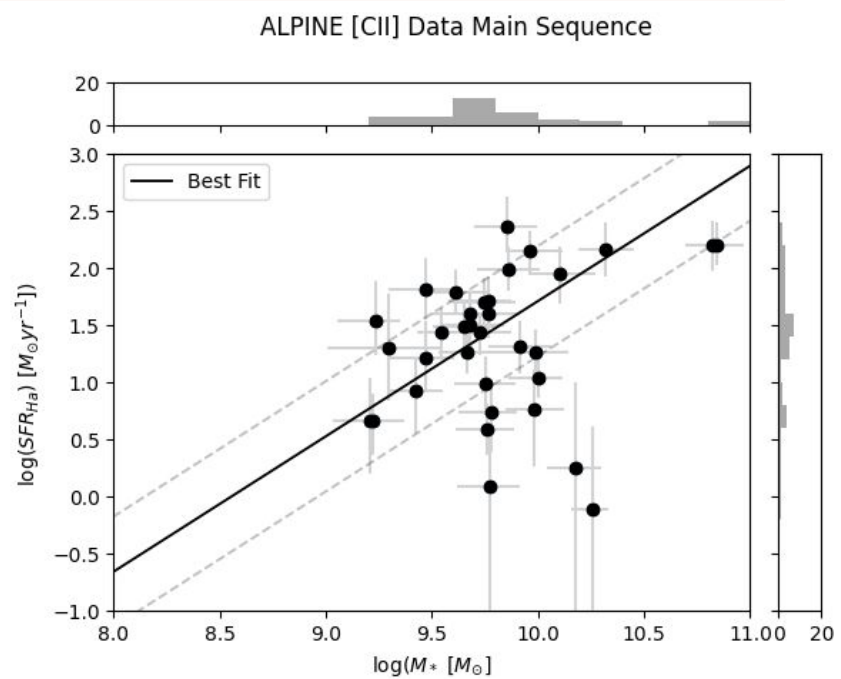
Found [CII] line in 75/118 galaxies!

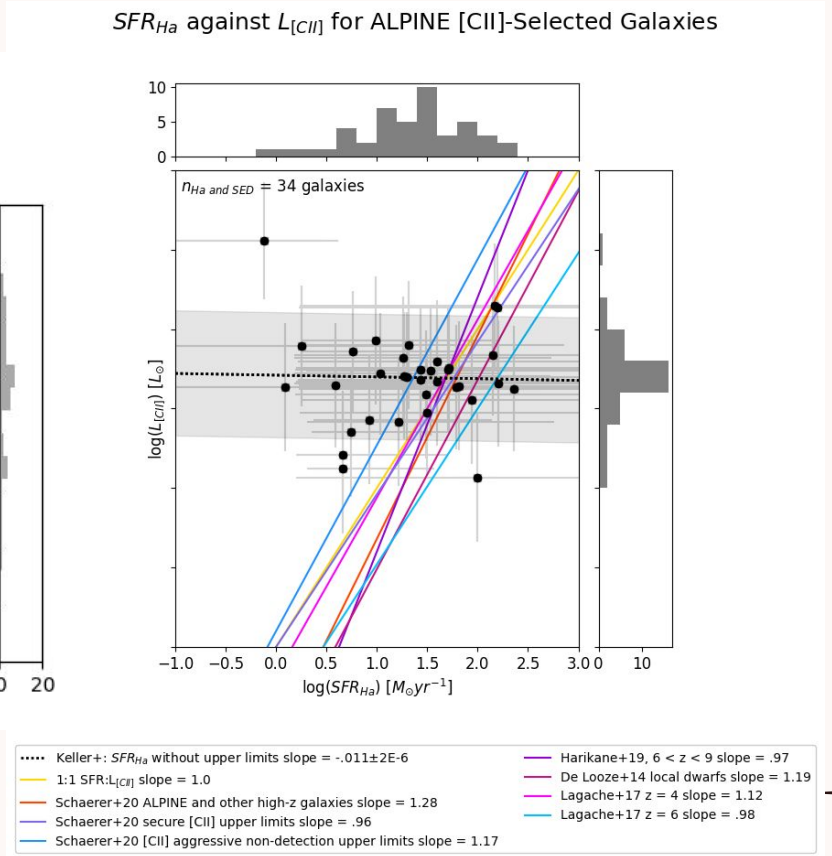
# SED-derived SFR Relations

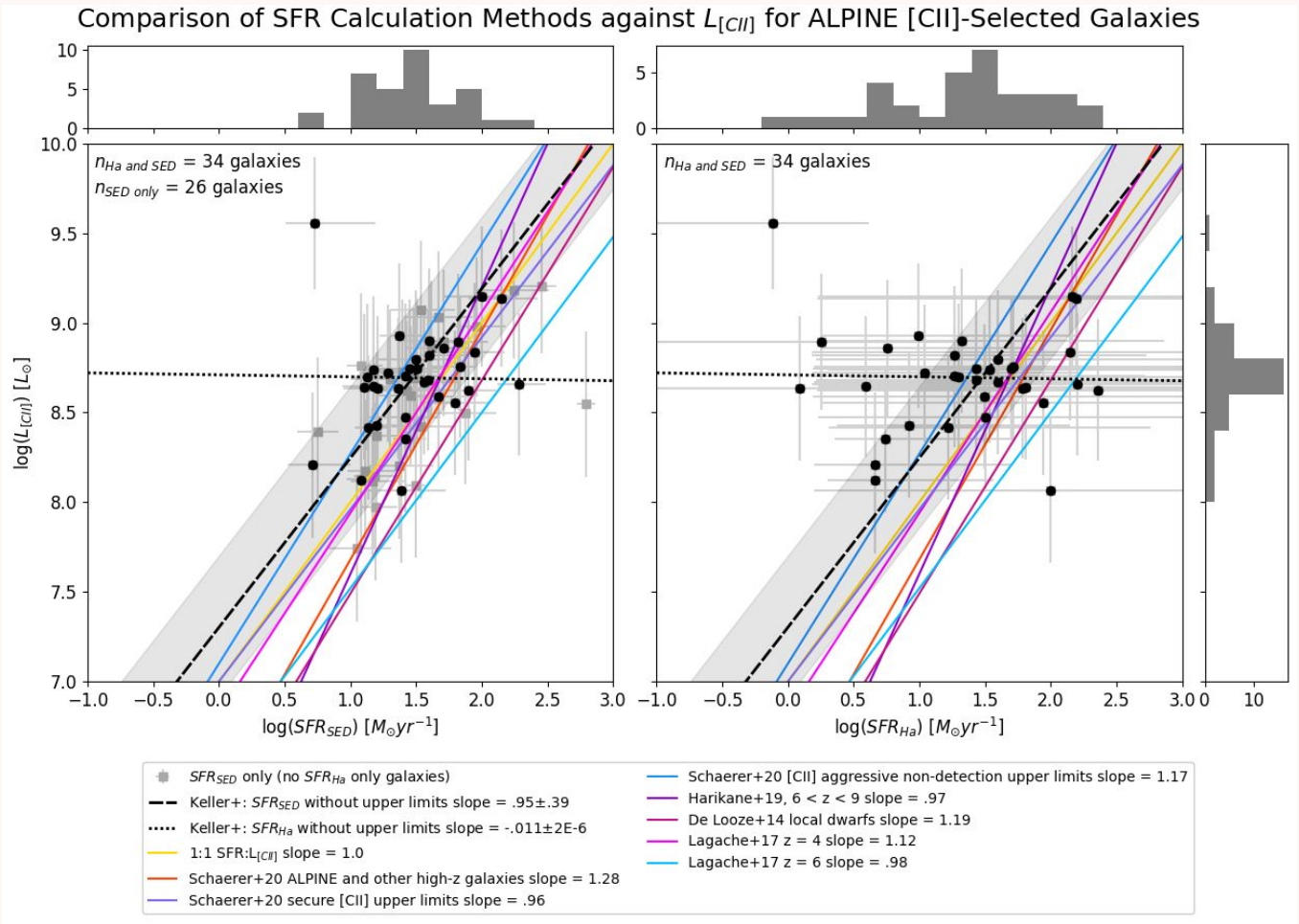


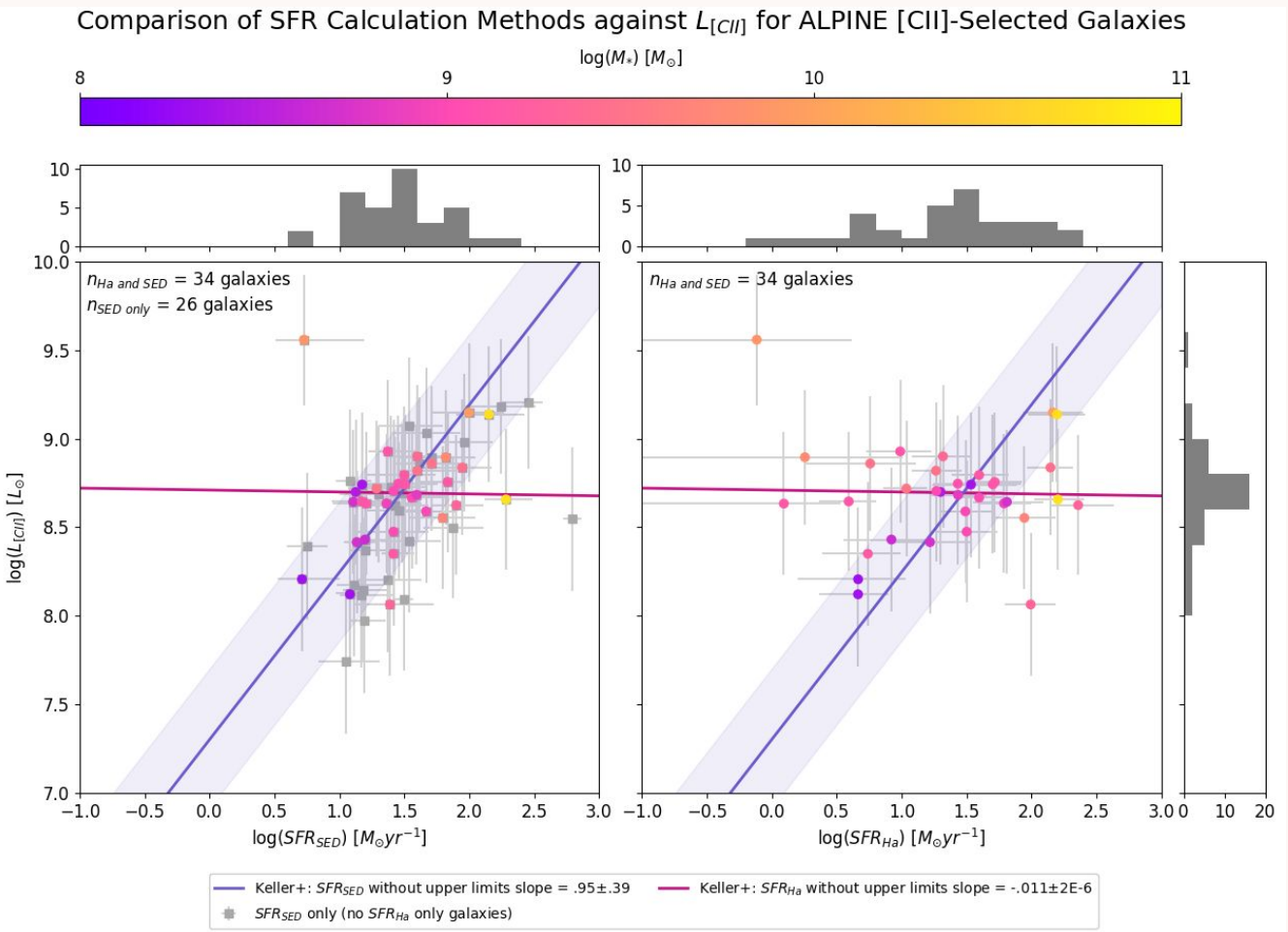



# Hα-derived SFR Relations




Comparison of SFR Calculation Methods against $L_{[CII]}$ for ALPINE [CII]-Selected Galaxies
$n_{Ha\ and\ SED}$ = 34 galaxies
$n_{SED\ only}$ = 26 galaxies
$n_{Ha\ and\ SED}$ = 34 galaxies
log($L_{[CII]}$) [$L_\odot$]
log($SFR_{SED}$) [$M_\odot yr^{-1}$]
log($SFR_{Ha}$) [$M_\odot yr^{-1}$]
$SFR_{SED}$ only (no $SFR_{Ha}$ only galaxies)
Keller+: $SFR_{SED}$ without upper limits slope = .95±.39
Keller+: $SFR_{Ha}$ without upper limits slope = -.011±2E-6
1:1 SFR:$L_{[CII]}$ slope = 1.0
Schaerer+20 ALPINE and other high-z galaxies slope = 1.28
Schaerer+20 secure [CII] upper limits slope = .96
Schaerer+20 [CII] aggressive non-detection upper limits slope = 1.17
Harikane+19, 6 < z < 9 slope = .97
De Looze+14 local dwarfs slope = 1.19
Lagache+17 z = 4 slope = 1.12
Lagache+17 z = 6 slope = .98


Comparison of SFR Calculation Methods against $L_{[CII]}$ for ALPINE [CII]-Selected Galaxies
log($M_*$) [$M_\odot$]
8
9
10
11
$n_{Ha\ and\ SED}$ = 34 galaxies
$n_{SED\ only}$ = 26 galaxies
$n_{Ha\ and\ SED}$ = 34 galaxies
log($L_{[CII]}$) [$L_\odot$]
log($SFR_{SED}$) [$M_\odot yr^{-1}$]
log($SFR_{Ha}$) [$M_\odot yr^{-1}$]
Keller+: $SFR_{SED}$ without upper limits slope = .95±.39
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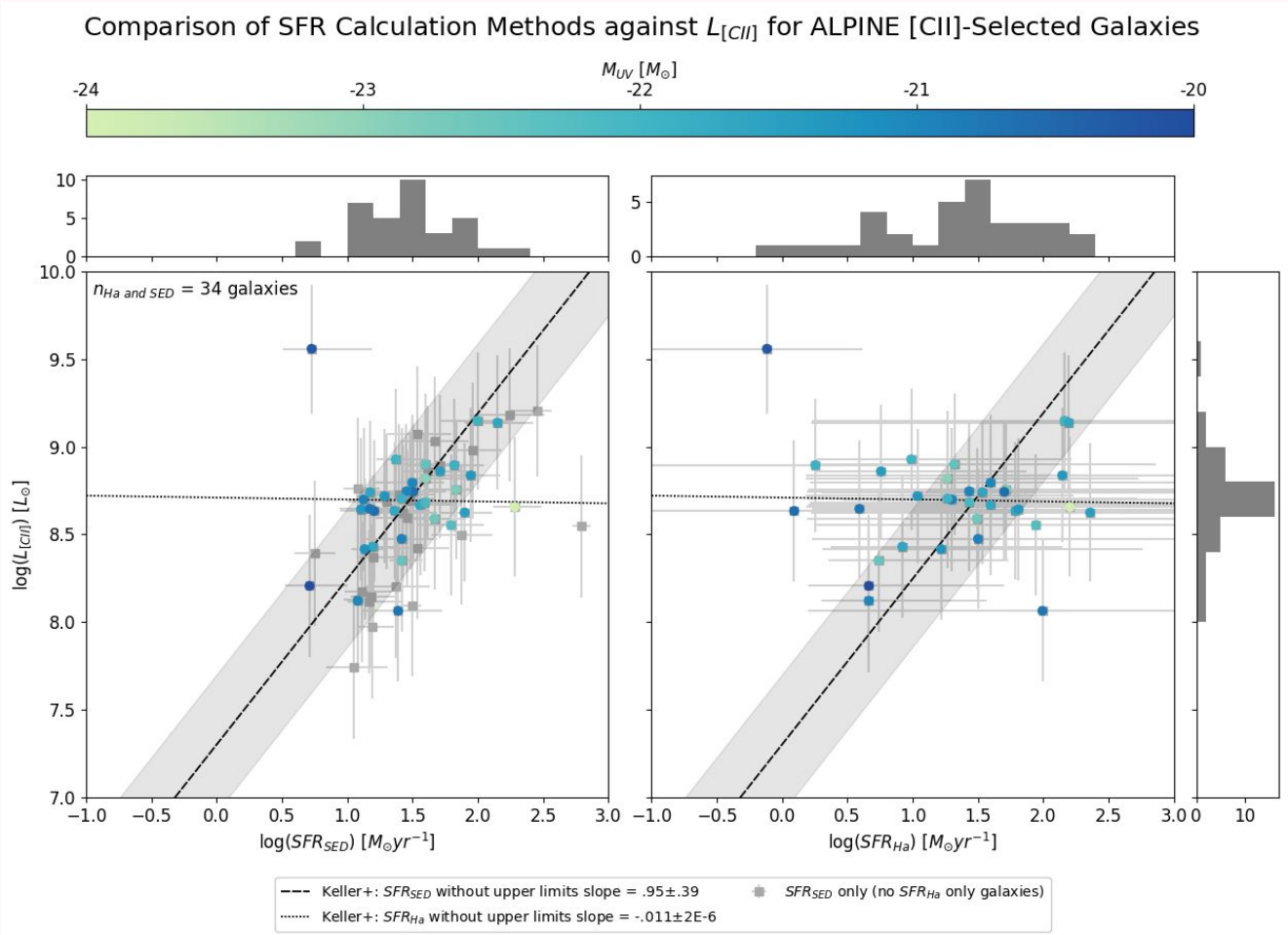
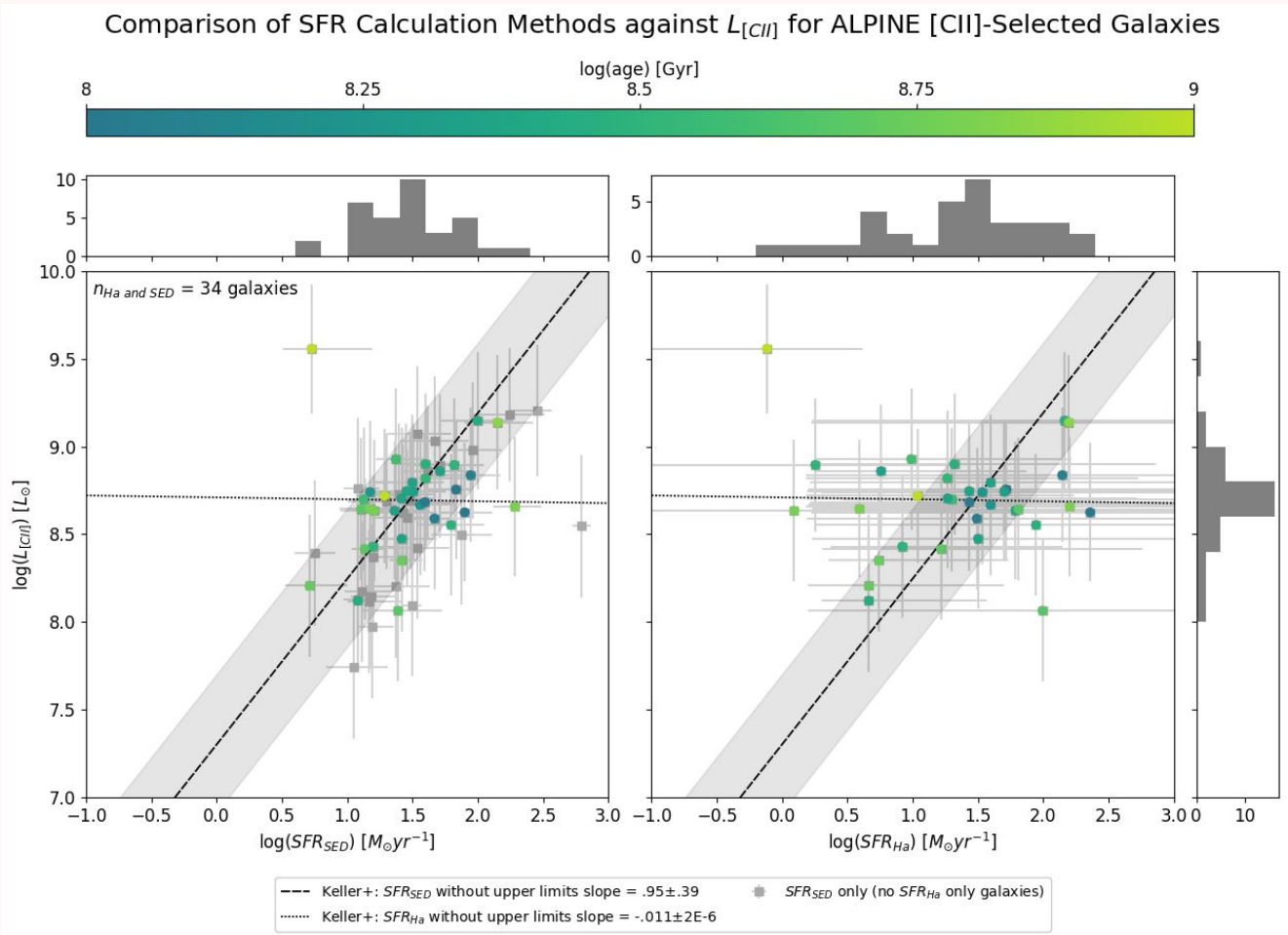
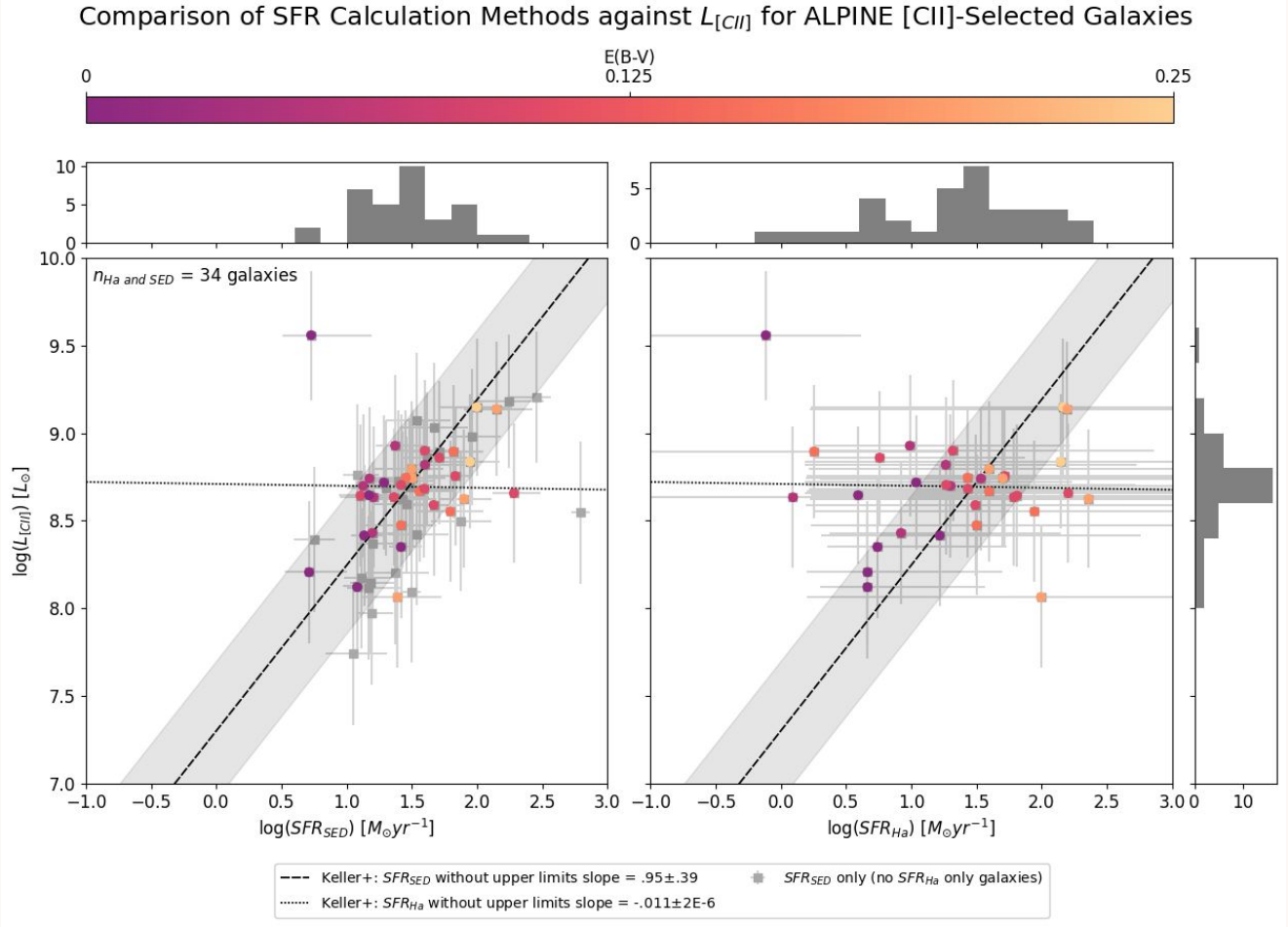
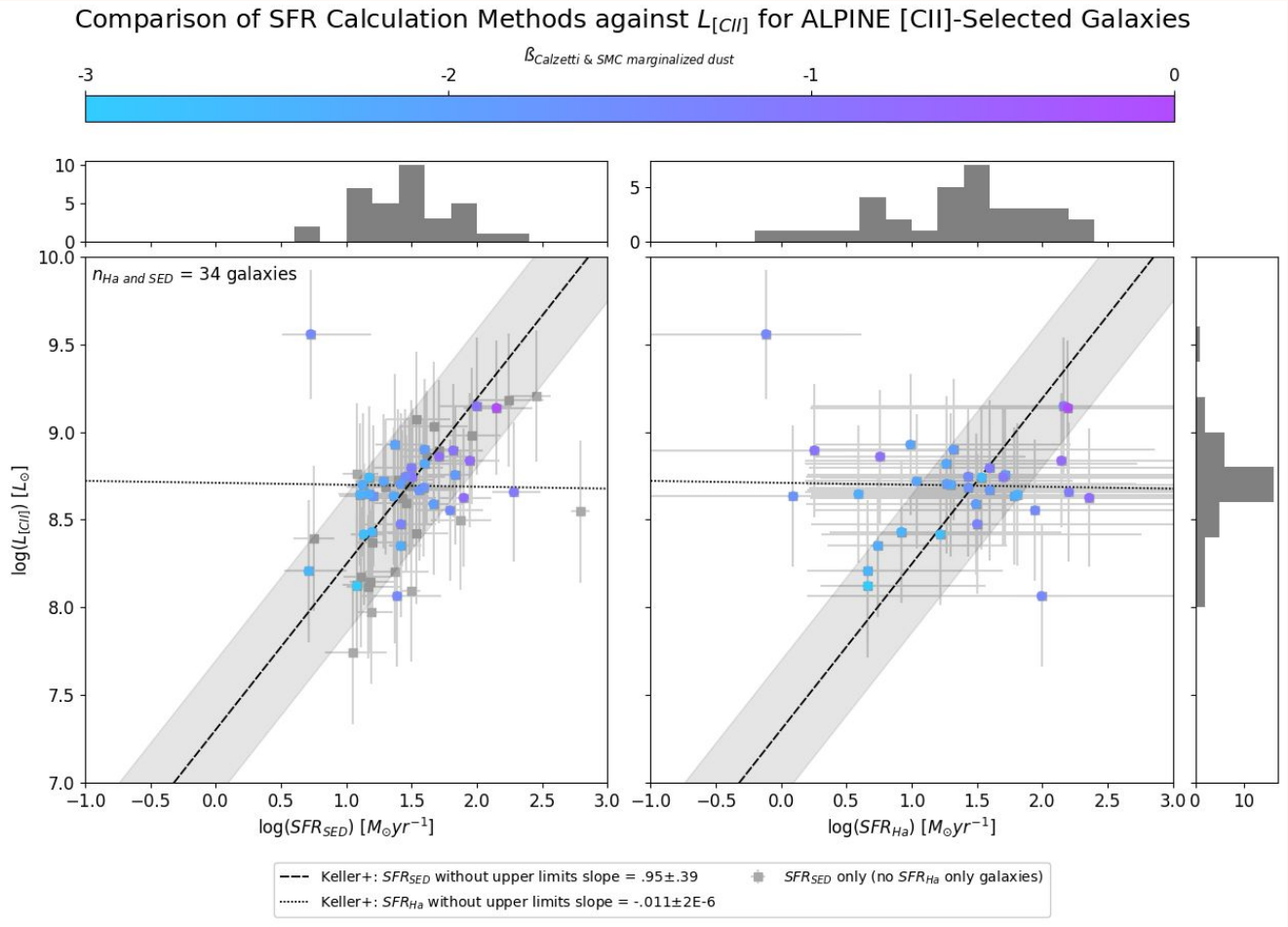
$SFR_{SED}$ only (no $SFR_{Ha}$ only galaxies)


Comparison of SFR Calculation Methods against $L_{[CII]}$ for ALPINE [CII]-Selected Galaxies
$M_{UV}$ [$M_\odot$]
-24
-23
-22
-21
-20
$n_{Ha\ and\ SED}$ = 34 galaxies
log($L_{[CII]}$) [$L_\odot$]
log($SFR_{SED}$) [$M_\odot yr^{-1}$]
log($SFR_{Ha}$) [$M_\odot yr^{-1}$]
Keller+: $SFR_{SED}$ without upper limits slope = .95±.39
Keller+: $SFR_{Ha}$ without upper limits slope = -.011±2E-6
$SFR_{SED}$ only (no $SFR_{Ha}$ only galaxies)


Comparison of SFR Calculation Methods against $L_{[CII]}$ for ALPINE [CII]-Selected Galaxies
log(age) [Gyr]
8
8.25
8.5
8.75
9
$n_{Ha\ and\ SED}$ = 34 galaxies
$\log(L_{[CII]})\ [L_\odot]$
$\log(SFR_{SED})\ [M_\odot yr^{-1}]$
$\log(SFR_{Ha})\ [M_\odot yr^{-1}]$
Keller+: $SFR_{SED}$ without upper limits slope = .95±.39
Keller+: $SFR_{Ha}$ without upper limits slope = -.011±2E-6
$SFR_{SED}$ only (no $SFR_{Ha}$ only galaxies)


Comparison of SFR Calculation Methods against $L_{[CII]}$ for ALPINE [CII]-Selected Galaxies
E(B-V)
0
0.125
0.25
$n_{Ha\ and\ SED}$ = 34 galaxies
$\log(L_{[CII]})$ $[L_\odot]$
$\log(SFR_{SED})$ $[M_\odot yr^{-1}]$
$\log(SFR_{Ha})$ $[M_\odot yr^{-1}]$
Keller+: $SFR_{SED}$ without upper limits slope = .95±.39
Keller+: $SFR_{Ha}$ without upper limits slope = -.011±2E-6
$SFR_{SED}$ only (no $SFR_{Ha}$ only galaxies)


Comparison of SFR Calculation Methods against $L_{[CII]}$ for ALPINE [CII]-Selected Galaxies
$ß_{Calzetti\ \&\ SMC\ marginalized\ dust}$
-3
-2
-1
0
$n_{Ha\ and\ SED}$ = 34 galaxies
$\log(L_{[CII]})\ [L_\odot]$
$\log(SFR_{SED})\ [M_\odot yr^{-1}]$
$\log(SFR_{Ha})\ [M_\odot yr^{-1}]$
Keller+: $SFR_{SED}$ without upper limits slope = .95±.39
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$SFR_{SED}$ only (no $SFR_{Ha}$ only galaxies)

# Outcomes + Next Steps

## Disagreement

2 possible confounding variables showed some differing impact on SED- and Hα-derived SFRs.

## Literature Relations

The best-fit line for $SFR_{SED}$ agrees with the slope of all literature relations, including those for low-mass local dwarfs, and agrees with the *y*-intercept of two.

## Additional Galaxies

As is always the case in astronomy...

Upcoming missions will contribute to available data!

## Investigate ALPINE

There is a possibility that something in how ALPINE data was compiled is causing the disagreement.

# Thank You!

**Questions?**

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