UNIVERSITY OF MARYLAND

Crossing the Green Valleys with the Green Bank Telescope

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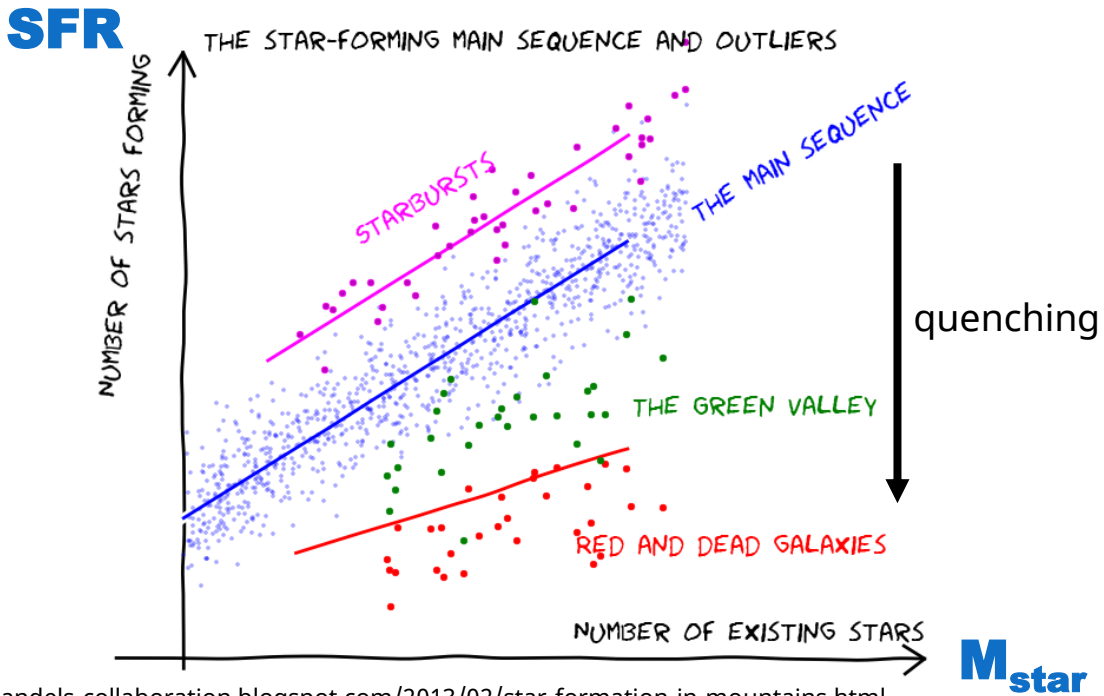
The EDGE-CALIFA Team

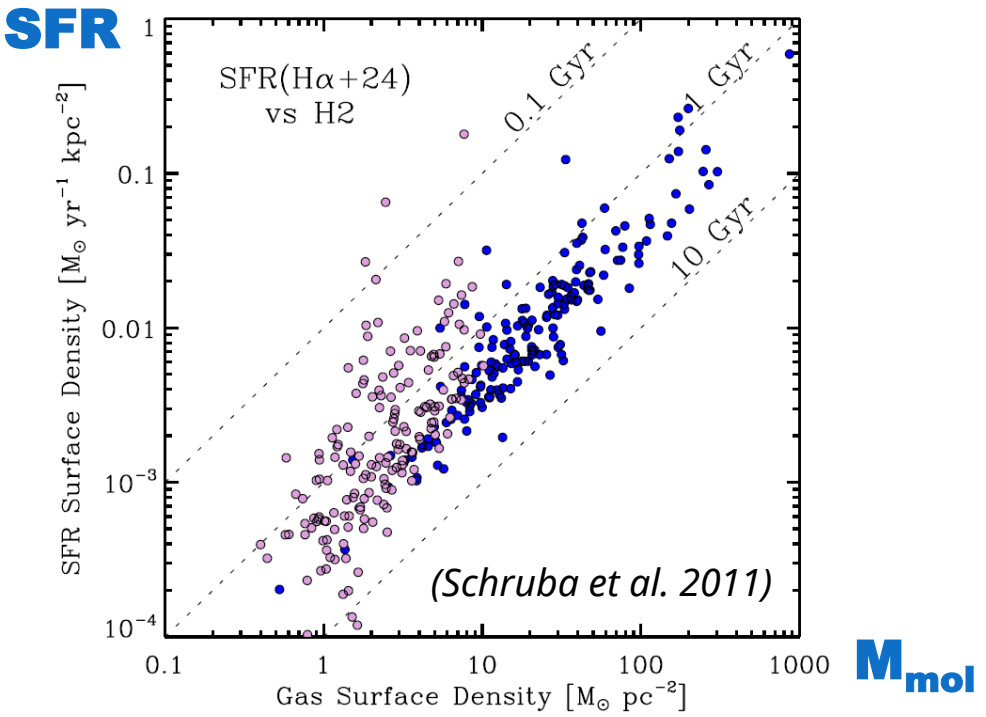
Motivation

- Galaxy quenching – the decline of star formation in galaxies
- What controls the level of star formation?

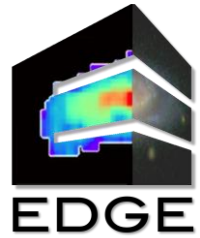
  → amount of molecular gas (M_{mol}) + star formation efficiency (SFE = SFR/M_{mol} = t_{dep}^{-1})

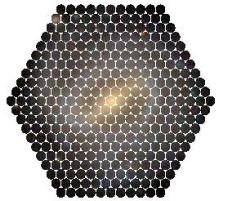


https://candels-collaboration.blogspot.com/2013/02/star-formation-in-mountains.html



The EDGE-CALIFA Collaboration





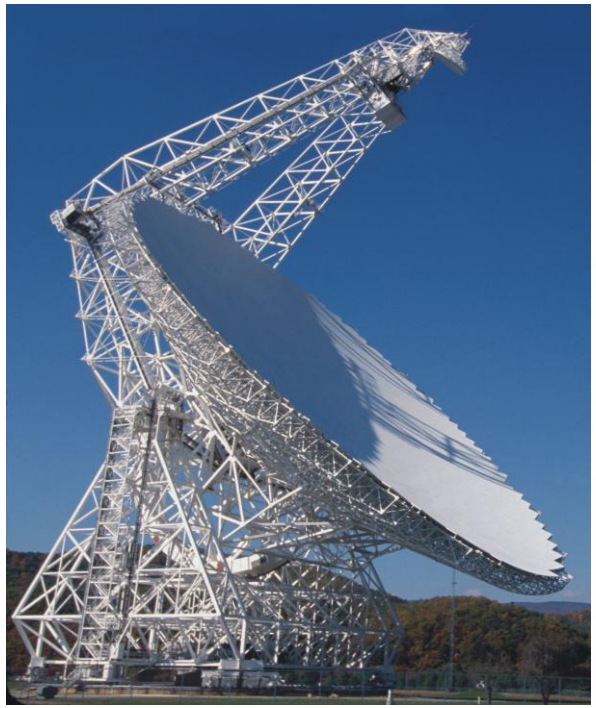
- CALIFA survey: ionized gas (e.g., Hα, Hβ, [NII], [OIII]) in ~700 galaxies
  - Optical IFU spectroscopy with the Calar Alto Observatory *(Sanchez+2012, 2016, 2023)*
  - *Pipe3D* data products: line emission properties, dust-corrected M_{star}, SFH, …, etc.
- EDGE survey: molecular gas via CO observations
  - **GBT CO *J*=1-0: 62 galaxies at 8" *(Teng+2026, to be submitted soon!)***
  - CARMA CO *J*=1-0: 126 galaxies at 7" *(Bolatto+2017, Wong+2024)*
  - APEX CO *J*=2-1: pointed spectra for ~500 galaxies at 26" *(Colombo+2020, 2025)*
  - ALMA ACA CO *J*=2-1: 60 galaxies at 12" *(Villanueva+2024)*

→ all EDGE data are processed and made public: https://pages.astro.umd.edu/~bolatto/EDGE/

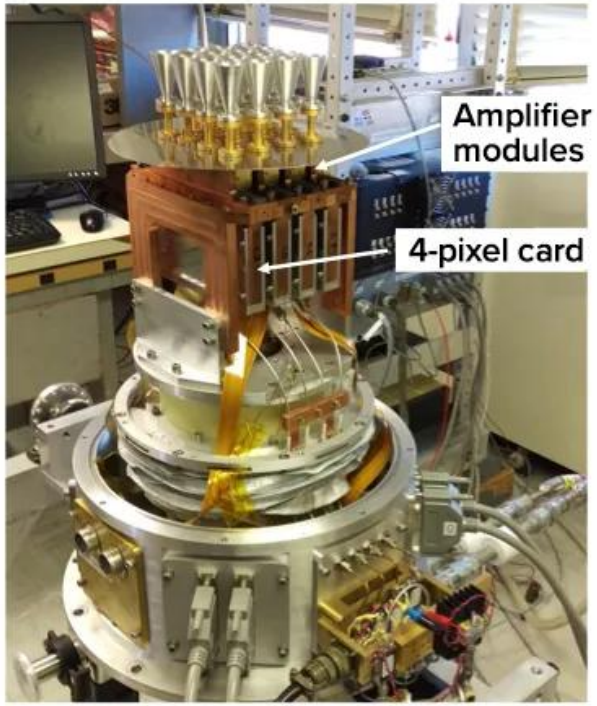
→ EDGE-CALIFA database also publicly available: https://github.com/tonywong94/edge_pydb

The GBT-EDGE Sample

Green Bank Telescope

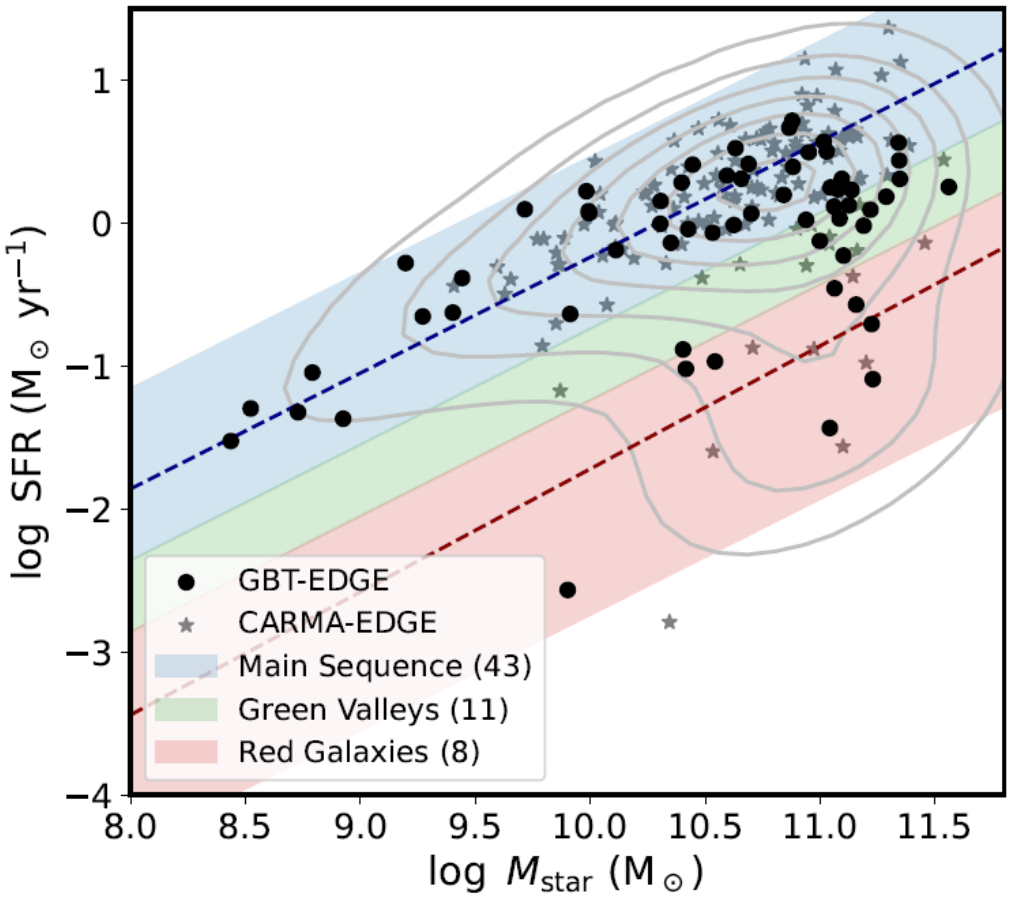


16-pixel Argus receiver



- CO(1-0) across 62 CALIFA galaxies
  - 344 hours; Nov 2021 – Mar 2025

The GBT-EDGE Sample



- CO(1-0) across 62 CALIFA galaxies
  - 344 hours; Nov 2021 – Mar 2025
  - 43 main sequence (MS)
  - 11 green valleys (GV)
  - 8 red galaxies (RG)
- Covers M_{star} down to $10^{8.5}$ $M_\odot$
- Representative of the full CALIFA sample (contour; 671 galaxies)
- No overlap with the 126 CARMA sample selection *(Bolatto+2017)*


NGC0001
NGC0014
NGC0169
NGC0776
NGC0932
NGC1056
NGC2449
NGC2540
NGC2596
NGC2691
NGC3057
NGC3106
NGC3353
NGC3395
NGC3406NED01
NGC3614
NGC3619
NGC3896
NGC4003
NGC5157
NGC5216
NGC5267
NGC5376
NGC5402
NGC5631
NGC5720
NGC5888
NGC5929
NGC5954
NGC6132
NGC6150B
NGC6154
NGC6338
NGC6497
UGC01659
UGC01938
UGC02134
UGC02222
UGC02239
UGC03960
UGC04136
UGC04245
UGC04262
UGC04659
UGC04730
UGC05326
UGC05396
UGC08004
UGC08231
UGC08234
UGC08322
UGC08733
UGC08781
UGC09598
UGC09629
UGC10097
UGC10905
CGCG163-062
CGCG536-030
IC0674
IC3598
Mrk1418
SDSS
g + r + i
R25 × FoV
S/N > 5
0
20
40

Data processing

- Data reduction pipeline (adapted from gbtpipe)
  - https://github.com/teuben/GBT-EDGE
- Map products – moment 0, 1, 2
  - Masking: CO-dilated mask + Hα velocity mask
  - Error estimation: data rms + baseline variation

→ post-processing & analysis code to be released soon

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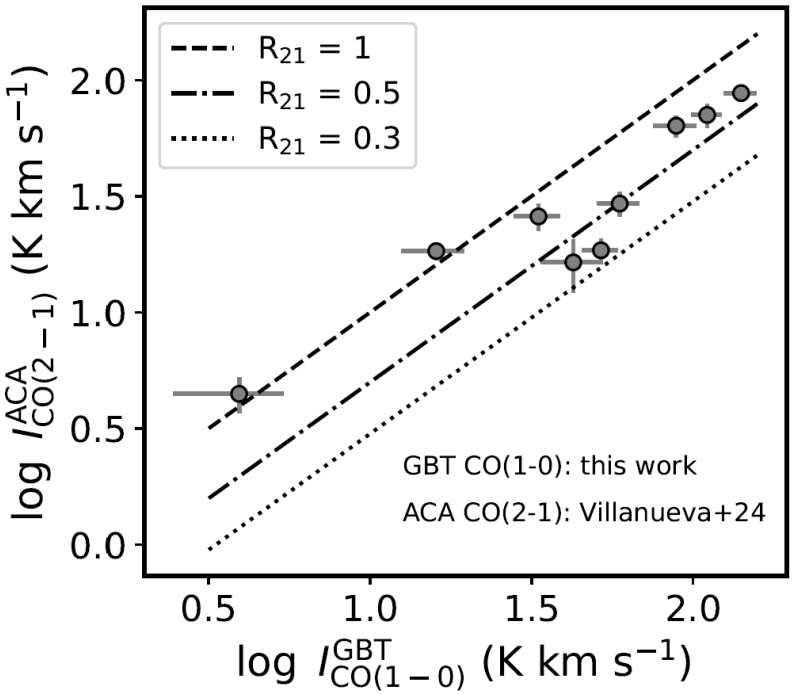
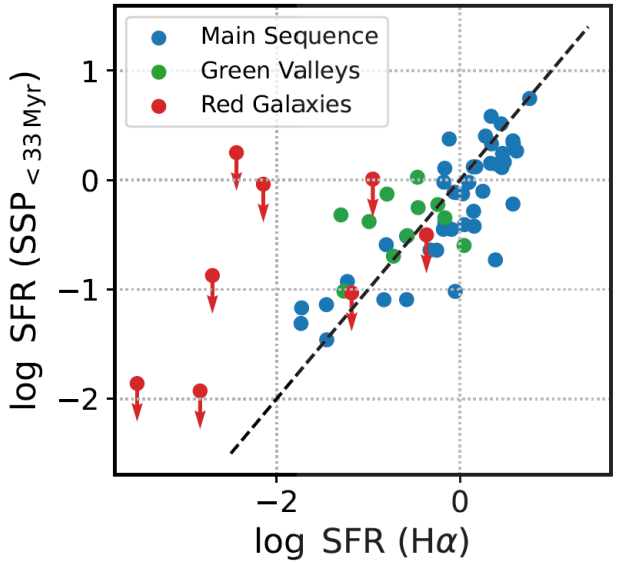
- Flux comparison with ACA data
  - 9 galaxies overlap with the ACA sample *(Villanueva+2024)*
  - CO 2-1/1-0 line ratio (R21) = 0.70 ± 0.27 ☑



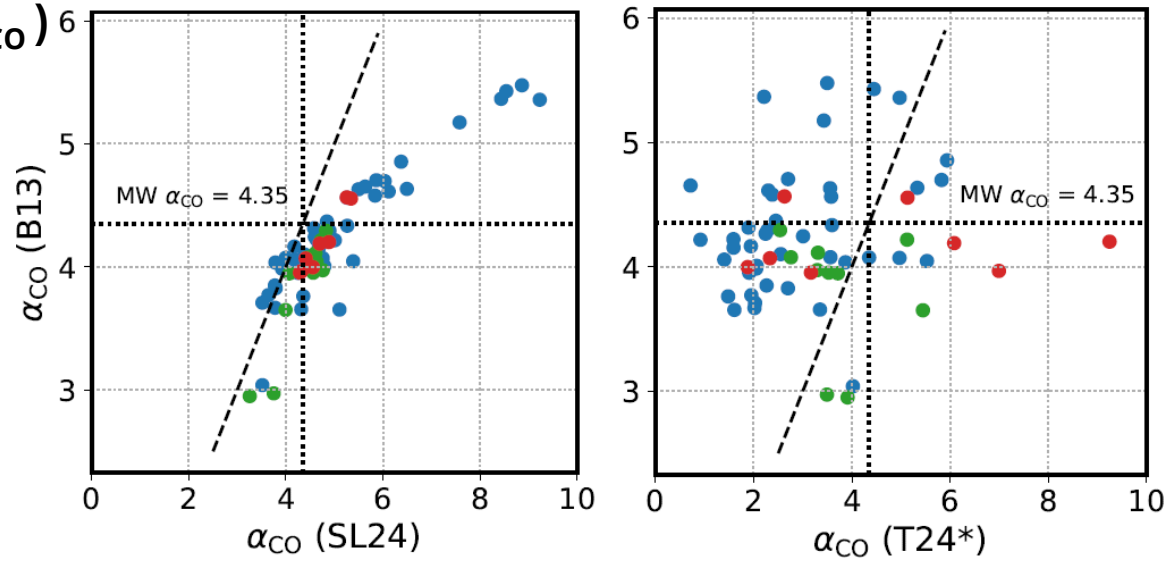
SFE = SFR / M_{mol}

- SFR estimation: **Hα** vs. **star formation history**
  - Consistent SFRs for MS and GV galaxies
  - Hα provides better constraints for RGs



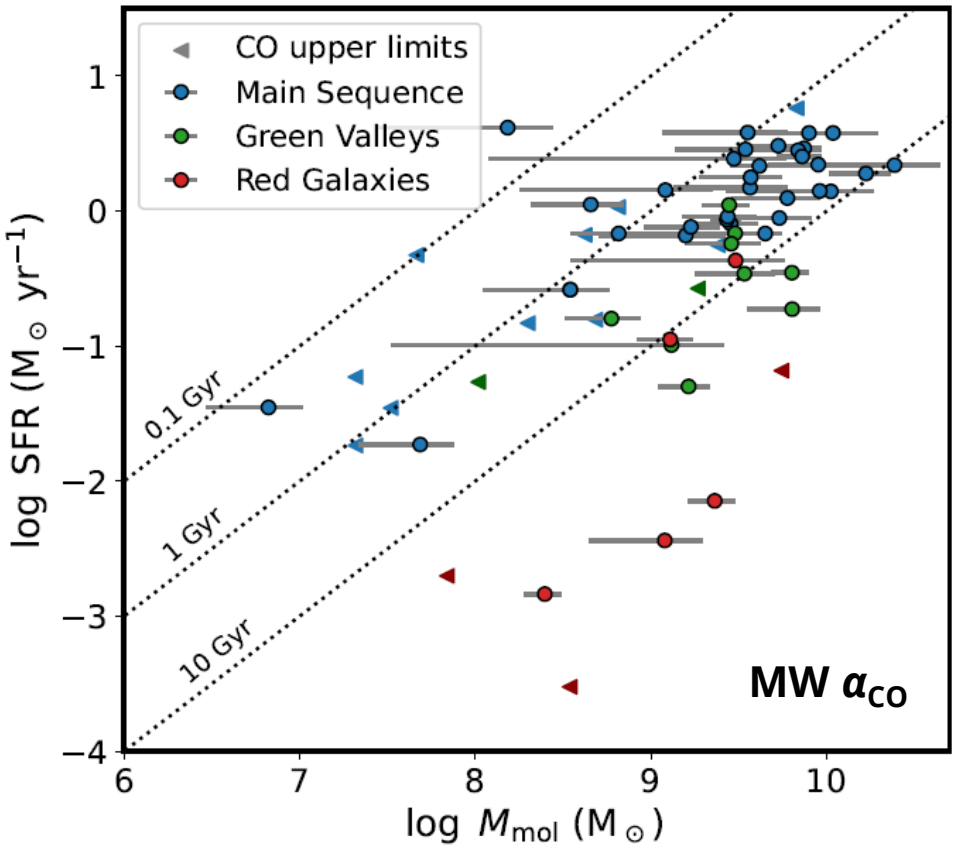
- M_{mol} estimation: **CO-to-H2 conversion (α_{CO})**
  - Constant MW α_{CO} : 4.35 $M_\odot$ $(K\,km\,s^{-1})^{-1}pc^{-2}$
  - Bolatto et al. (2013) : Z' + Σ_{star}
  - Schinnerer & Leroy (2024) : Z' + Σ_{star}
  - Teng et al. (2024)* : $\Delta v_{CO,\,2kpc}$

→ α_{CO} differs, but variations are within 2-3x



*modified 2-kpc version *(Teng et al. in prep)*

The SFR-M_{mol} Relation



- MS galaxies
  - M_{mol} ~ $10^{7\text{-}10}$ $M_\odot$
  - t_{dep} ~ 2 Gyr

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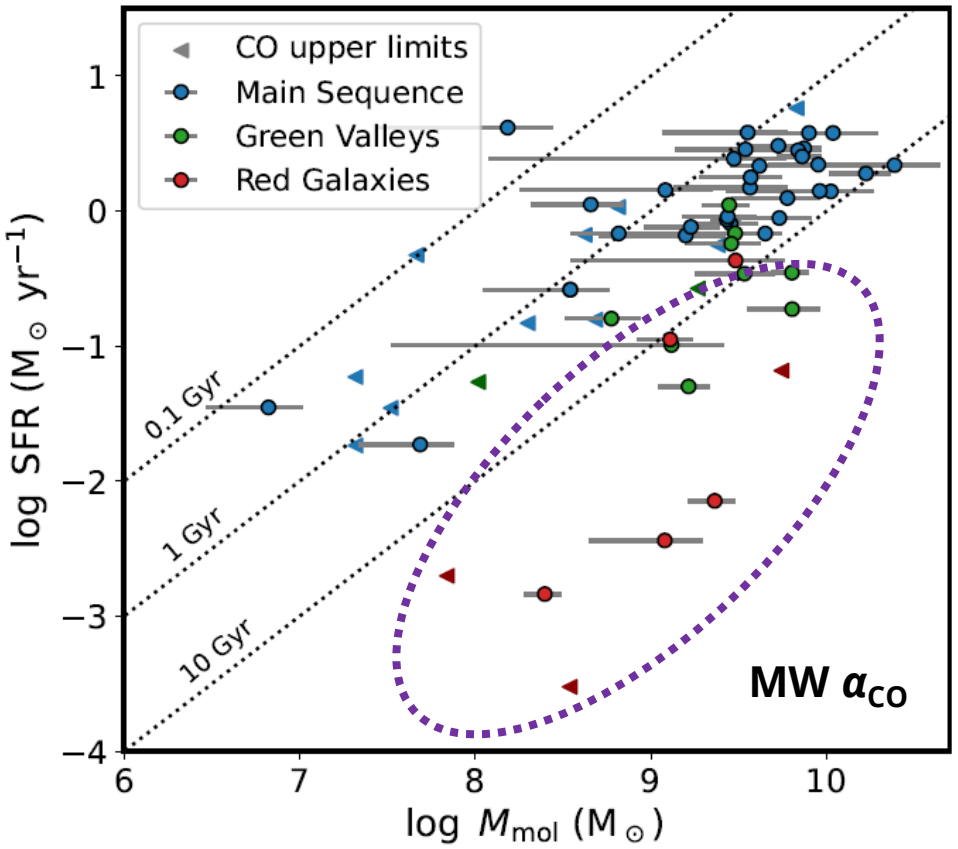


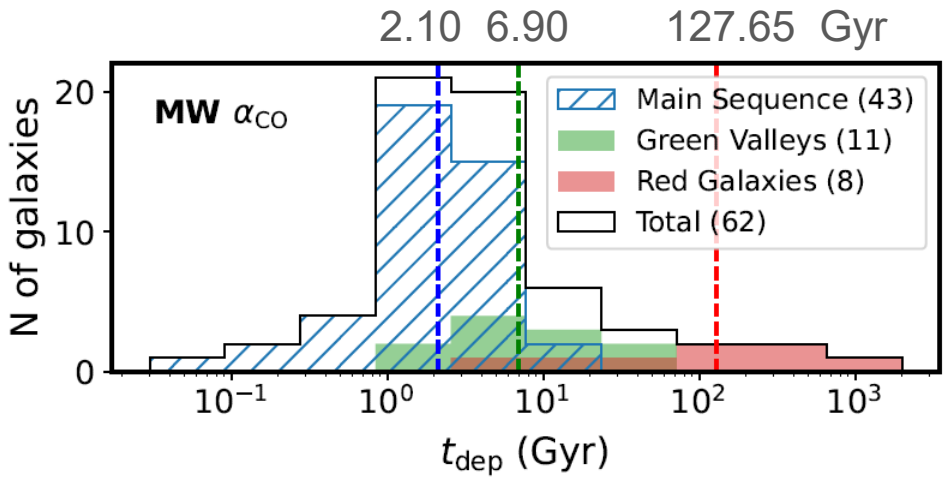
- MS galaxies
  - M_{mol} ~ $10^{7\text{-}10}$ $M_\odot$
  - t_{dep} ~ 2 Gyr
- GV and RGs
  - M_{mol} > 10^8 $M_\odot$!!
  - t_{dep} > 10 Gyr for most RGs

→ Substantial quiescent gas in RGs

→ Gradual t_{dep} increase from MS → GV → RG

t_{dep} across galaxy stages

MW α_{CO} shows distinctly increasing t_{dep} range from MS to GV and RGs



t_{dep} across galaxy stages

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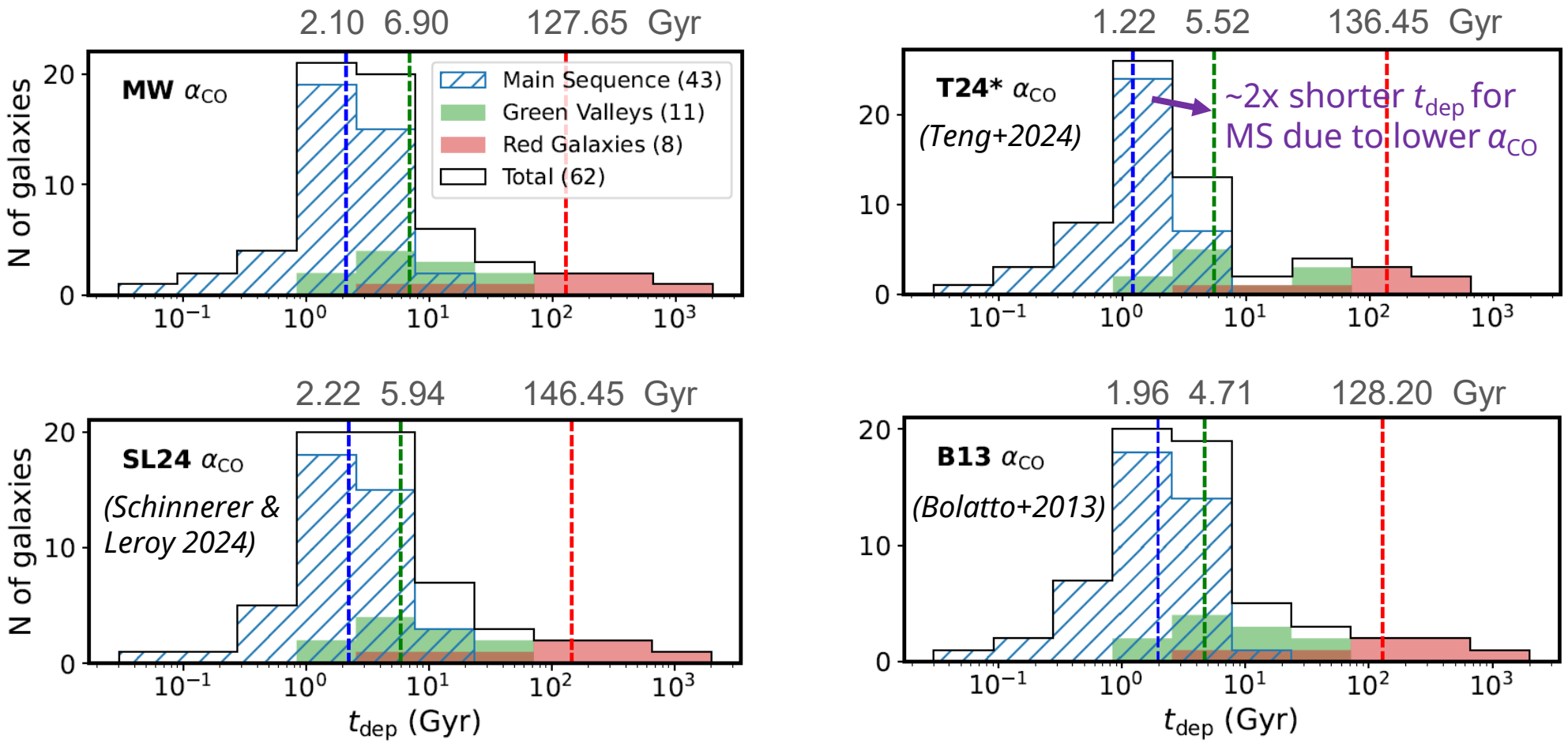
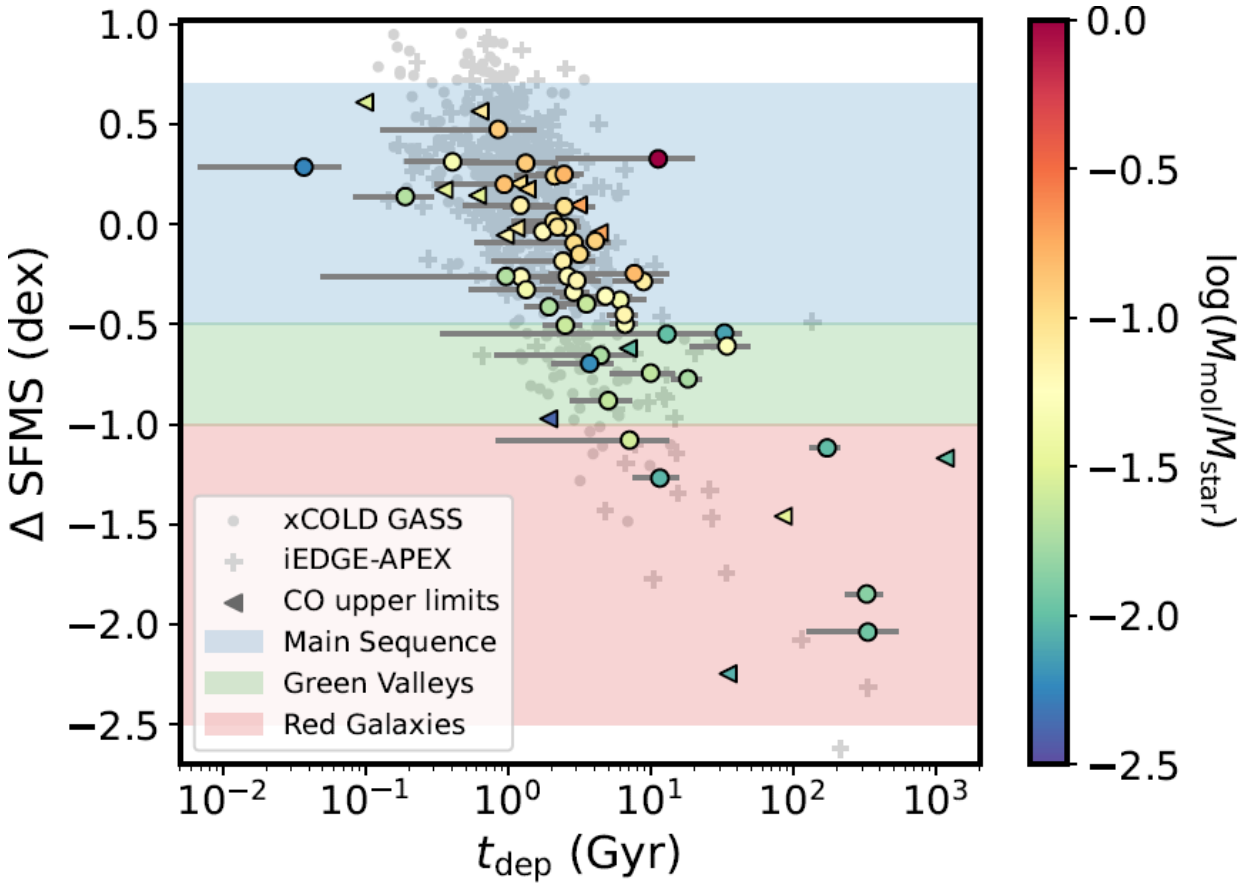


SFE vs. offset from main sequence



- A significant t_{dep} increase as ΔSFMS drops

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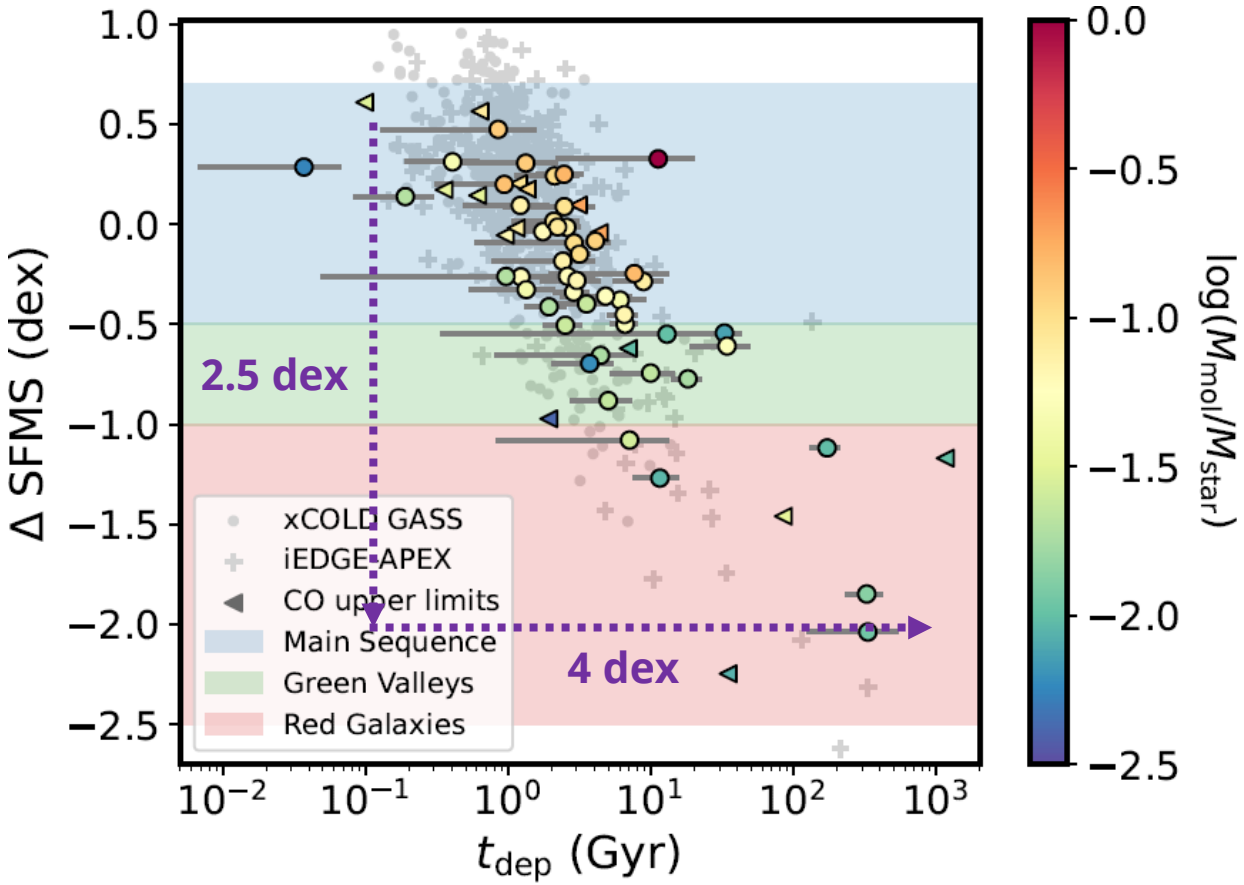
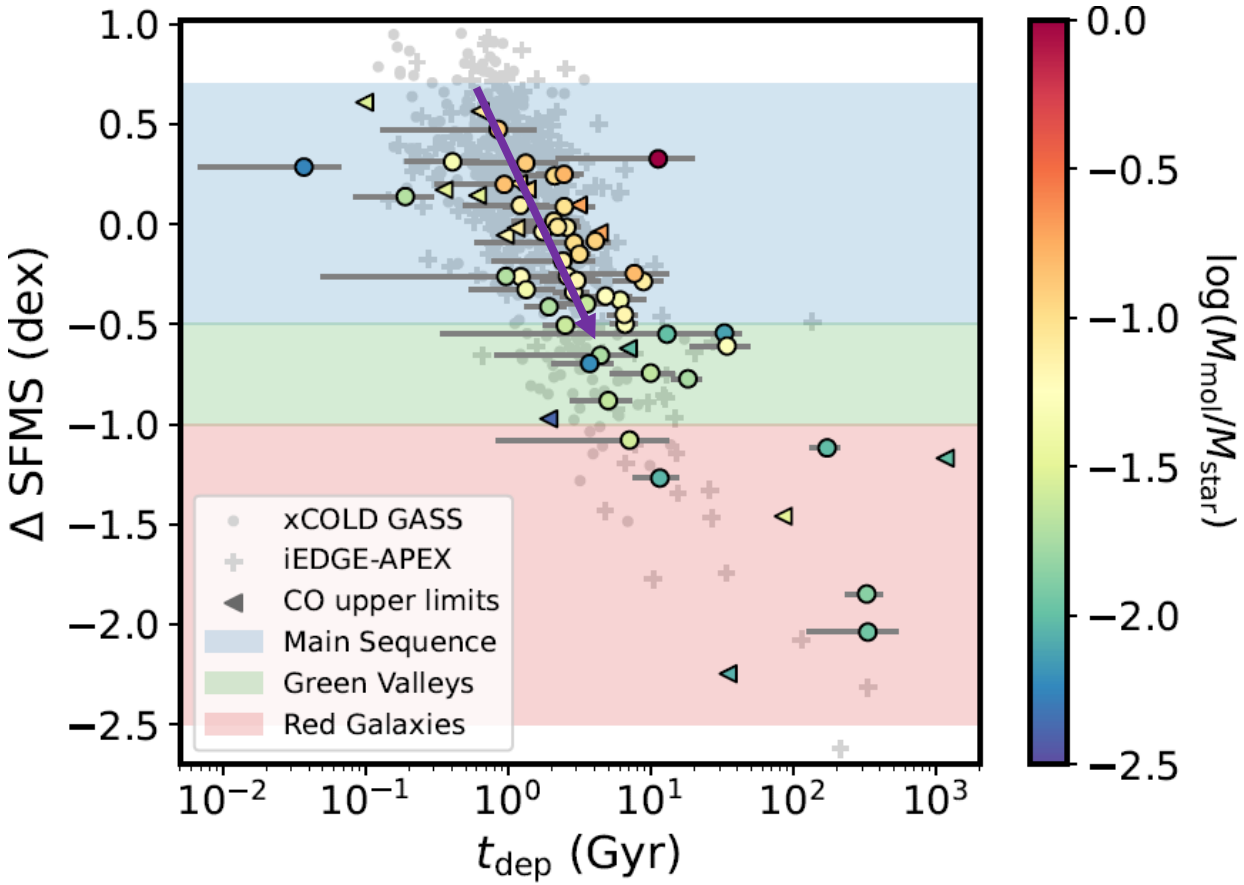


- A significant t_{dep} increase as ΔSFMS drops
  - 4 dex in t_{dep} vs. 2.5 dex in ΔSFMS

SFE vs. offset from main sequence

xCOLD GASS: Saintonge+2017
iEDGE: Colombo+2025



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- Compared to *xCOLD GASS* & *iEDGE*
  - MS trends are in good agreement

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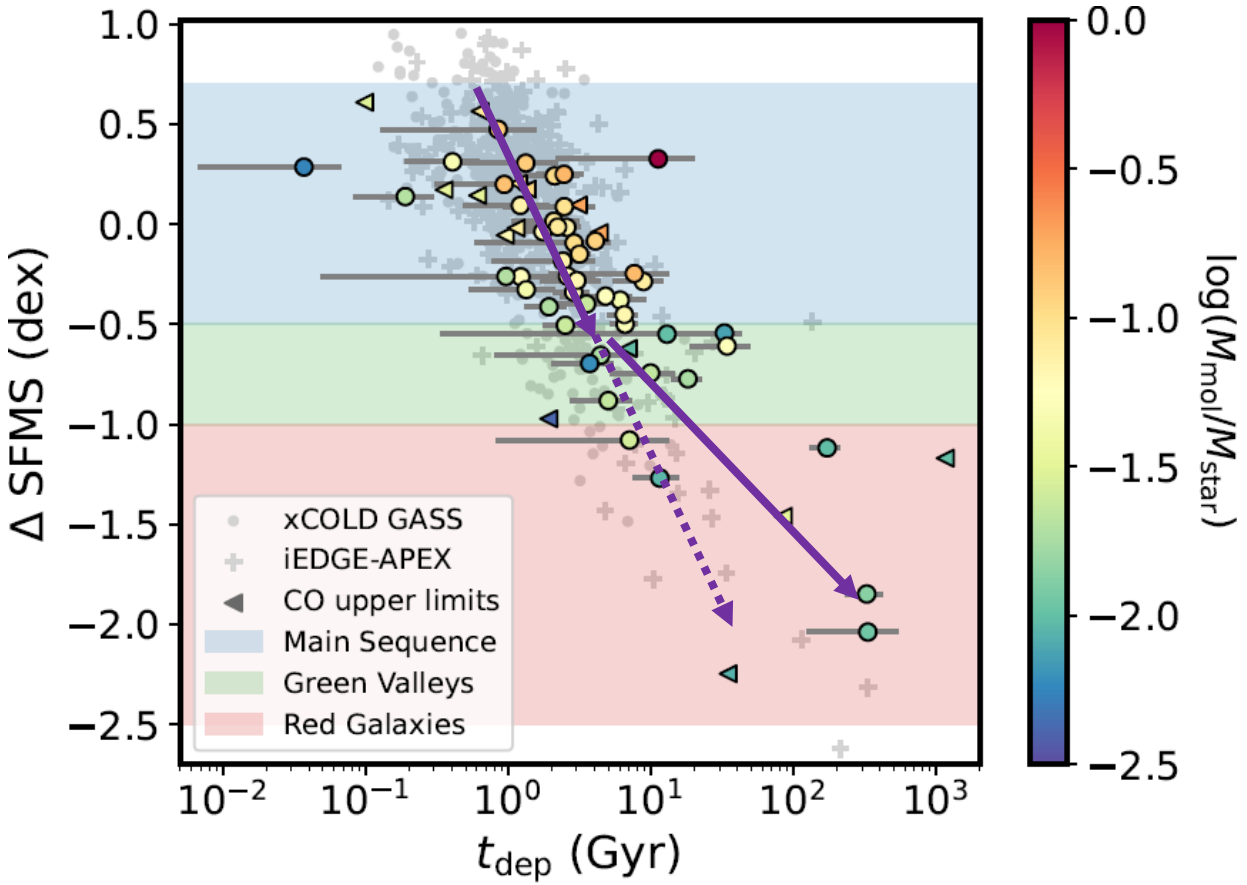

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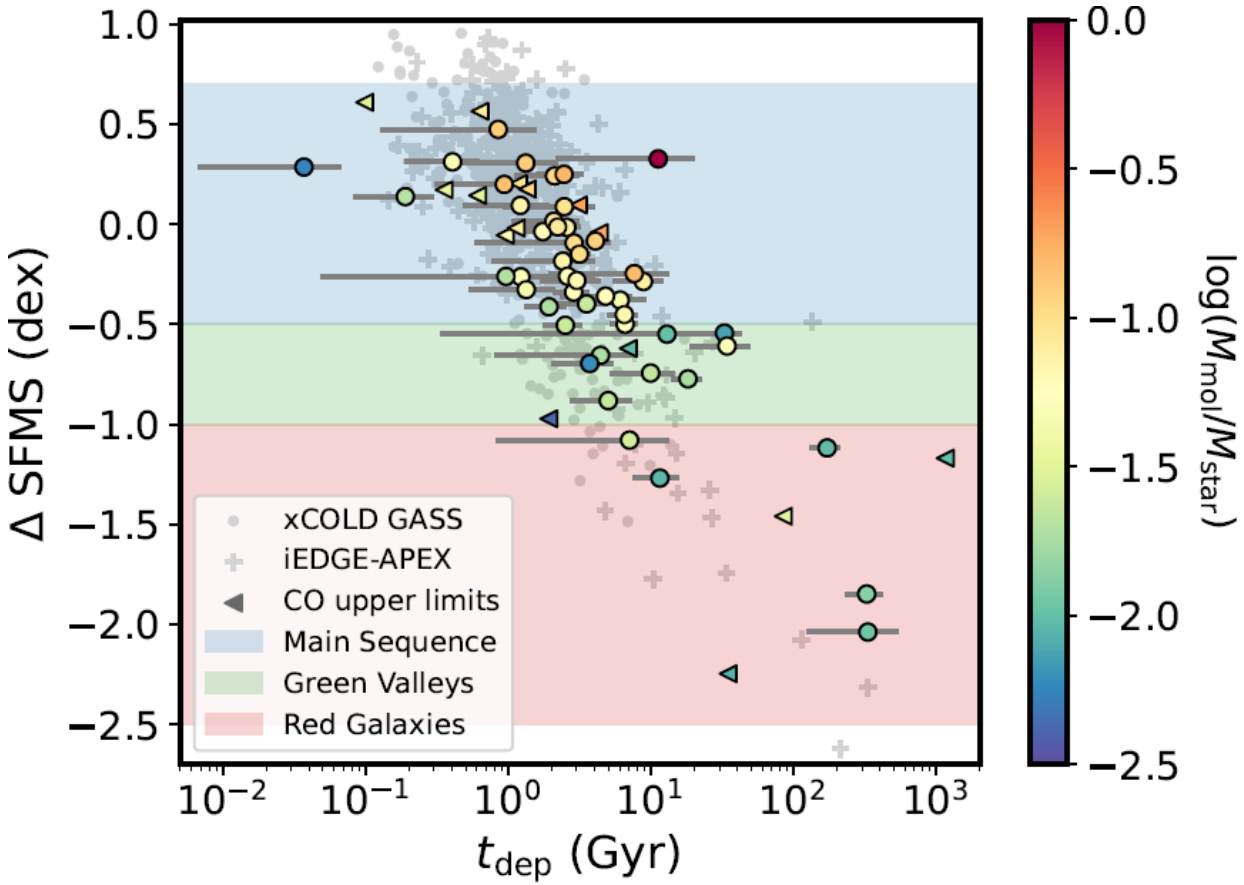

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  - MS trends are in good agreement
  - Our GV/RGs deviate toward longer t_{dep} but mostly compatible with iEDGE (S/N > 5)
- M_{mol}/M_{star} drops from MS → GV, but remains similarly low for GV and RGs

→ Reduced gas fraction affects the initial quenching stages (MS → GV), but a strong suppression of SFE is seen across all stages!

Remaining questions

- What physical processes cause the reduced SFE in GV/RGs?
- What prevents the substantial gas reservoir from forming stars?

☹ • Environmental quenching (e.g. galaxy interactions)

→ Gas removal without SFE change cannot explain our sample

☹ • AGN feedback

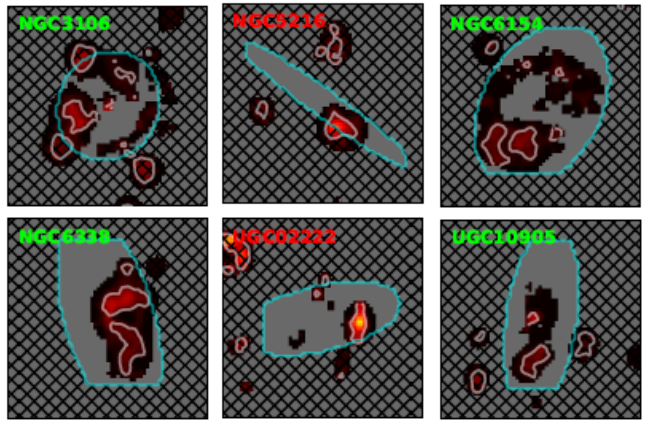
→ Only 2 of our galaxies have confirmed AGNs

😟 • Morphological quenching (e.g. bulges, bars)

→ Many GV/RGs show CO near their outer radii

🙂 • Our CO detects low-density gas in the GV/RGs

Selected GV/RGs



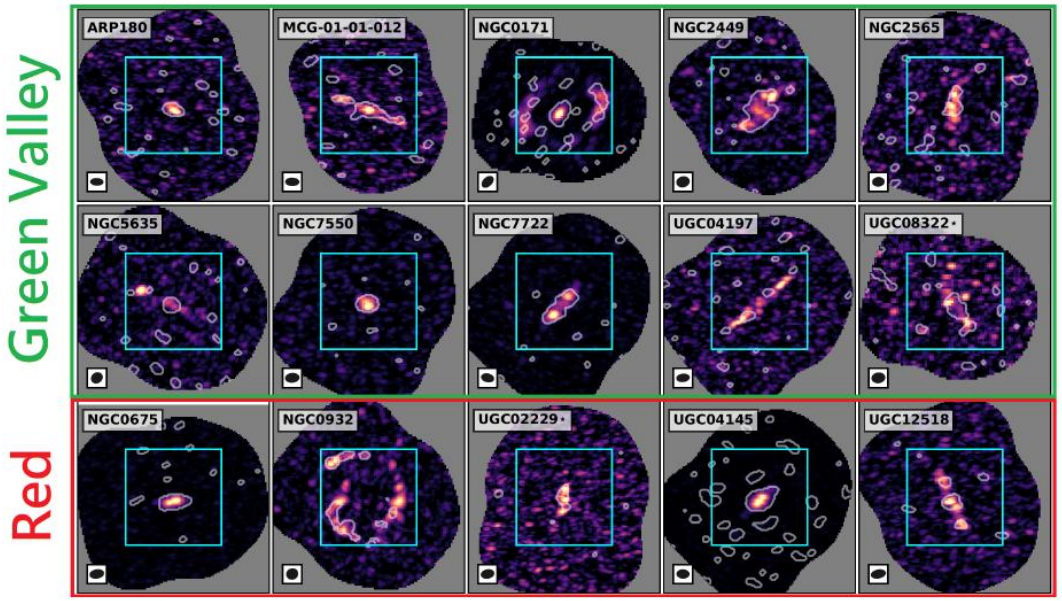
Ongoing ALMA Observations

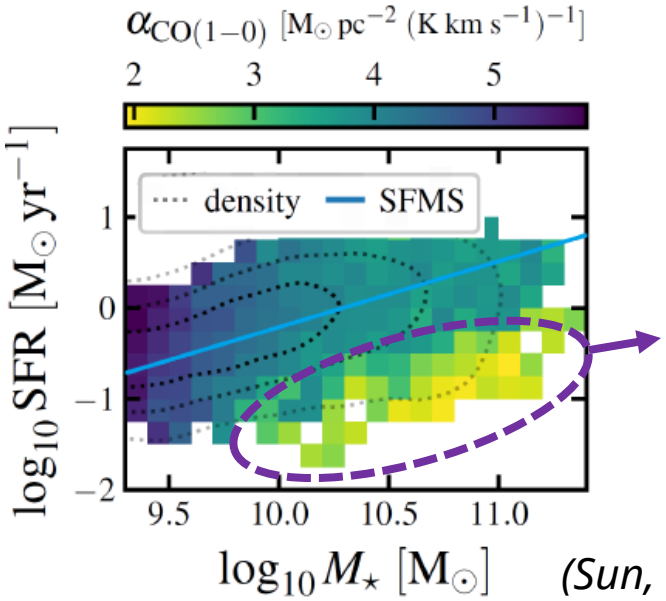
- CO(3-2) + ^{13}CO(2-1) mapping in 15 GV/RGs with existing CO(2-1)

  → What gas conditions cause the systematic drop in SFE? Is gas density low?

  → First resolved α_{CO} **measurements** for a sample of quenched galaxies

ALMA Cycle 12 in progress *(PI: Teng) – 1/3 complete!*





SL24 **predicts** lower α_{CO} below the SFMS ?

(Sun, Teng et al. 2025)

Summary

Paper coming out soon *(Teng+2026)*!

- We present GBT-EDGE, a new CO(1–0) survey across 62 nearby massive galaxies, including 43 main sequence, 11 green valley, and 8 red galaxies.
- We measure molecular gas mass and star formation efficiency across the sample using different SFR indicators and α_{CO} prescriptions.

  → Hα-based SFRs provide better constraints than using star formation history

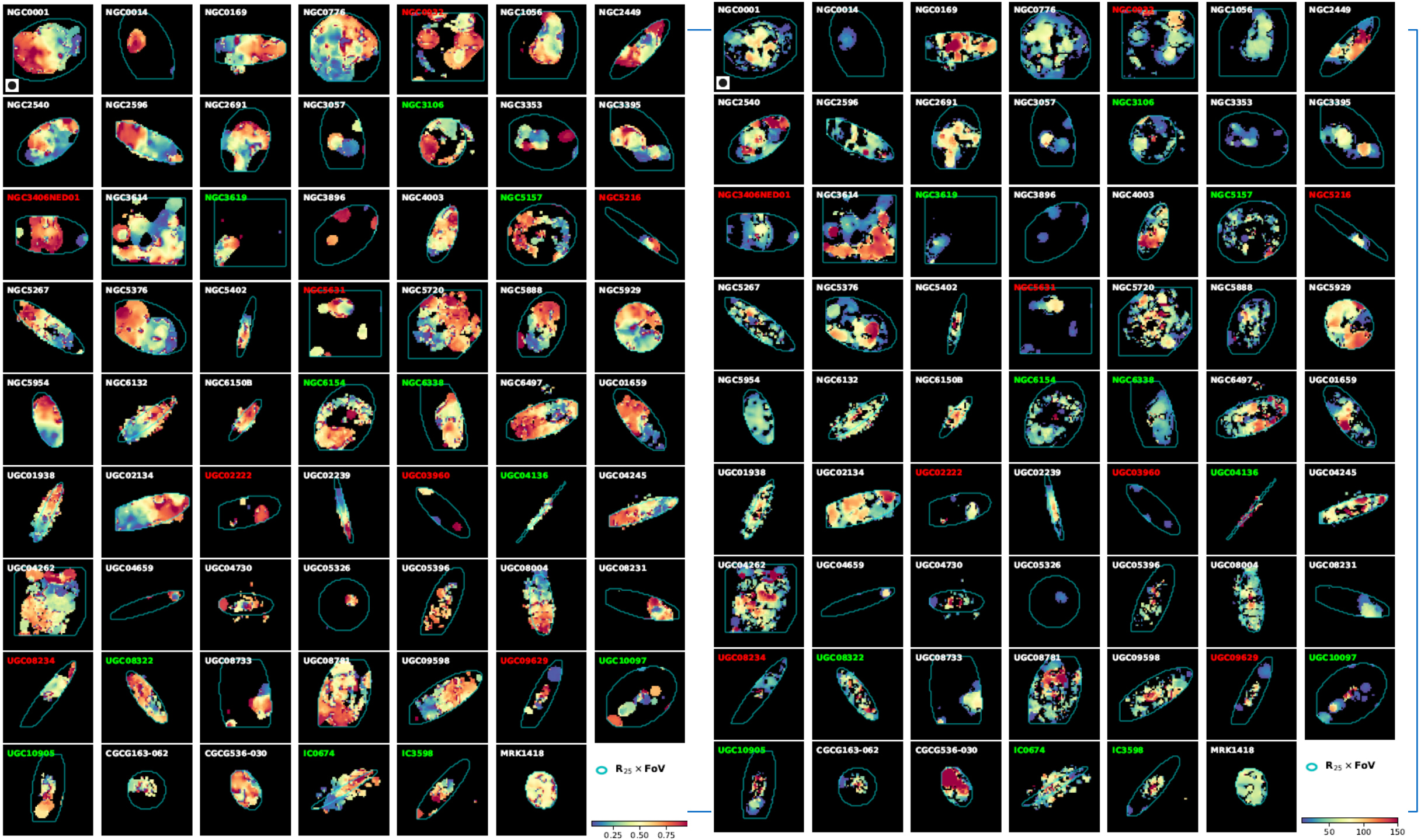
  → Global α_{CO} values vary by a factor of 2 within and among different prescriptions

- We find a systematic increase of t_{dep} across MS, GV, and RG populations

  → Quenched galaxies retain substantial gas reservoir comparable to MS galaxies

  → Quenching can be primarily driven by suppressed SFE rather than a lack of gas

- Low gas density could be the main cause for reduced SFE, but further observations with multiple dense gas tracers are needed to clarify the situation.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CGCG163-062
CGCG536-030
IC0674
IC3598
MRK1418
R25 × FoV
0.25 0.50 0.75
50 100 150