

High-Redshift [NIII] 57 μm

Ordinary N/O in Normal Star-Forming Regions at $z=7.13$

Yuma Sugahara (Waseda Univ.)

Collaborators:

A. K. Inoue, Y. Fudamoto, T. Hashimoto, L. Colina, Y. Tamura,
J. Alvarez-Marques, R. Marques-Chaves, M. Pereira-Santaella,
T. Bakx, C. Blanco-Prieto, H. Algera, Y. Isobe, S. Arai

ALMA 2040



ESO/ALMA2040 papers

Already submitted to ESO

I. First galaxies ($z > 10$): dust and emission lines

II. Molecular surveys, dense gas and dust

III. Quiescent galaxies

IV. Resolved baryon cycle
(from star-forming clumps, to CGM)

V. Dynamics of L^* galaxies (i.e., Milky-Way
progenitors) at $z > 4$
& dark matter

T. Bakx & F. Rizzo

ALMA2040 papers (TBD)

First galaxies ($z > 10$): dust

First galaxies ($z > 10$): emission lines

Molecular surveys

Dense gas and dust

III. Quiescent galaxies

ALMA2040 papers (TBD)

Star-forming clumps

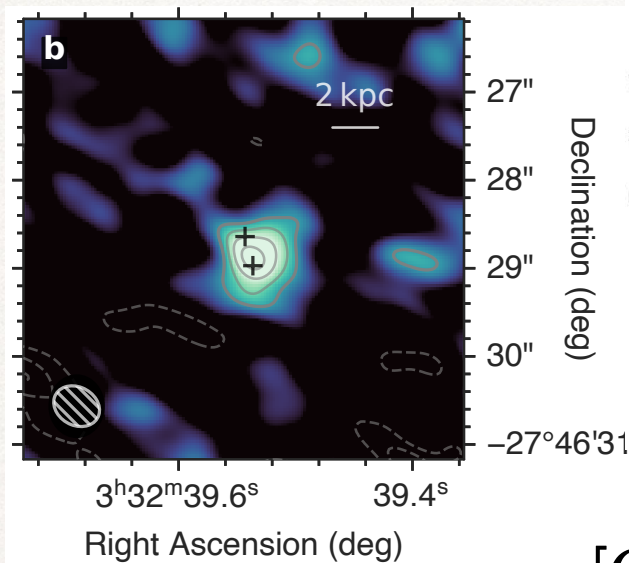
CGM

Disk kinematics, kpc-substructures (bar, spiral arms),
dark matter

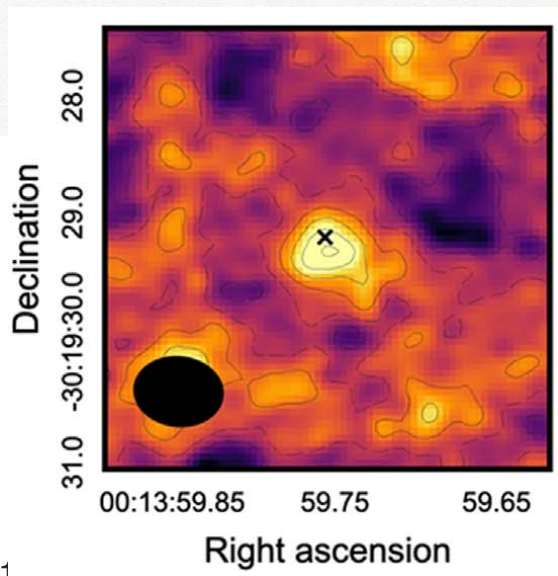
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Spec- z Frontier Pushed by [OIII]88 μ m

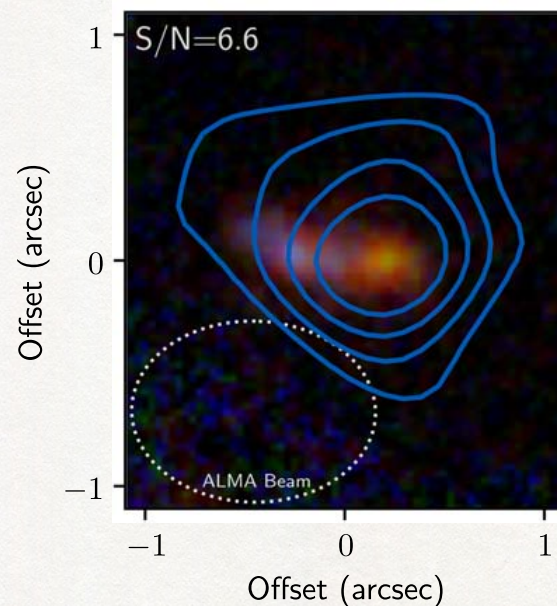
$z = 11.1$



$z = 12.3$



$z = 14.2$



[OIII] 88 μ m line detected even at $z > 10$

GREX-PLUS 2030s Mission Candidate

○ JAXA L-class mission candidate

- Primary mirror $D=1.0\text{m}$

○ Wide Field Camera

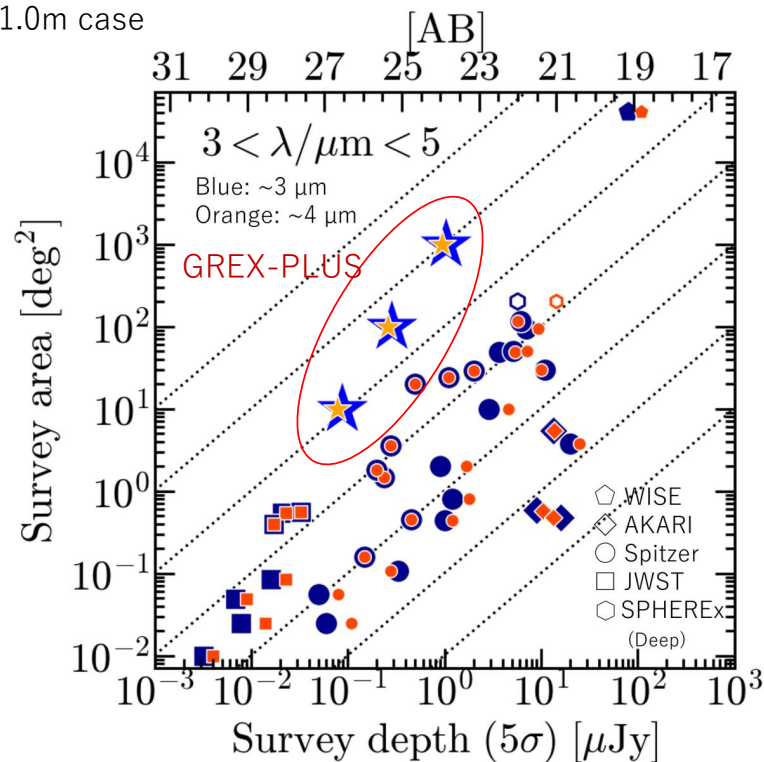
- NIR ($2\text{--}4.5\mu\text{m}$)
- MIR ($4.5\text{--}8\mu\text{m}$)

○ WFC surveys

- DEEP (10deg^2 , NIR 26.5mag)
- MEDIUM & WIDE

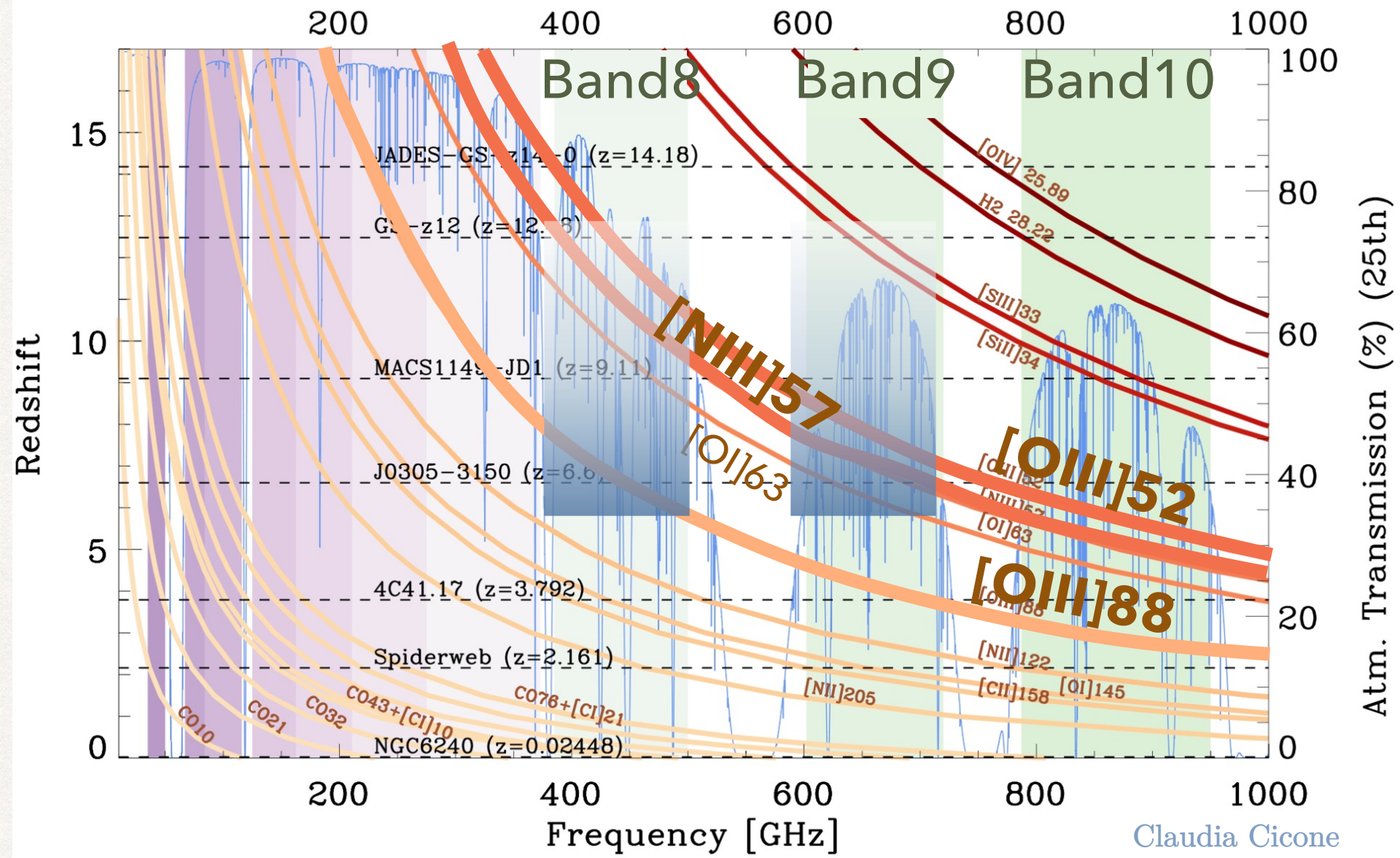
○ Goal: Finding $z > 14$ galaxies!

$\Phi 1.0\text{m case}$



ALMA will play a key roll in determining z in 2040

How is in studying galaxy physics at high redshift?



Claudia Cicone

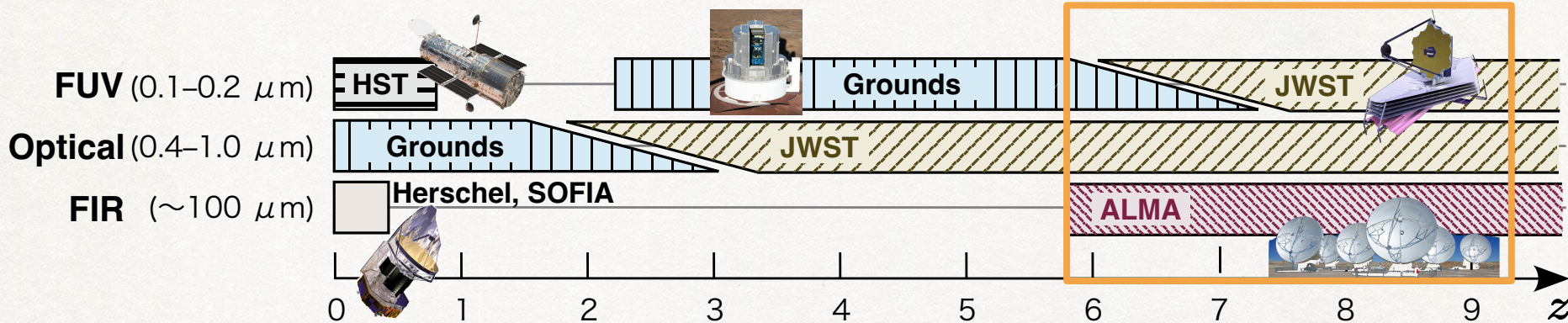
$z > 6$ — Best z for Ionized ISM studies

$z > 6$ is only the redshift covered in rest-UV, opt, FIR lines
with active telescopes

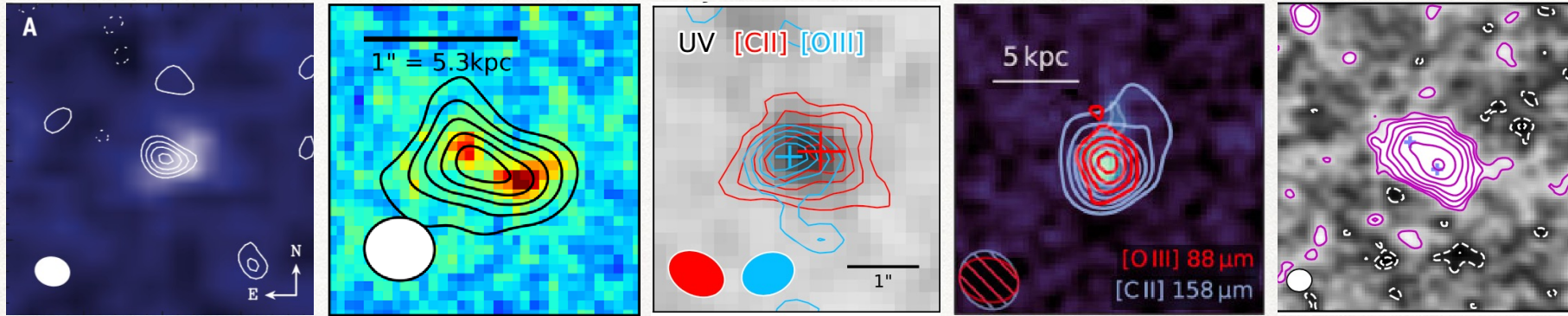
○ Multi-Wave Emission Lines

- UV: $\text{OIII}] \lambda\lambda 1660, 1666$
- opt: $[\text{OIII}] \lambda 4364, [\text{OIII}] \lambda\lambda 4960, 5008$
- FIR: $[\text{OIII}] 52, 88 \mu\text{m}$

Precise determination
of ISM properties



Bright Galaxies Detected in [OIII]88 μ m

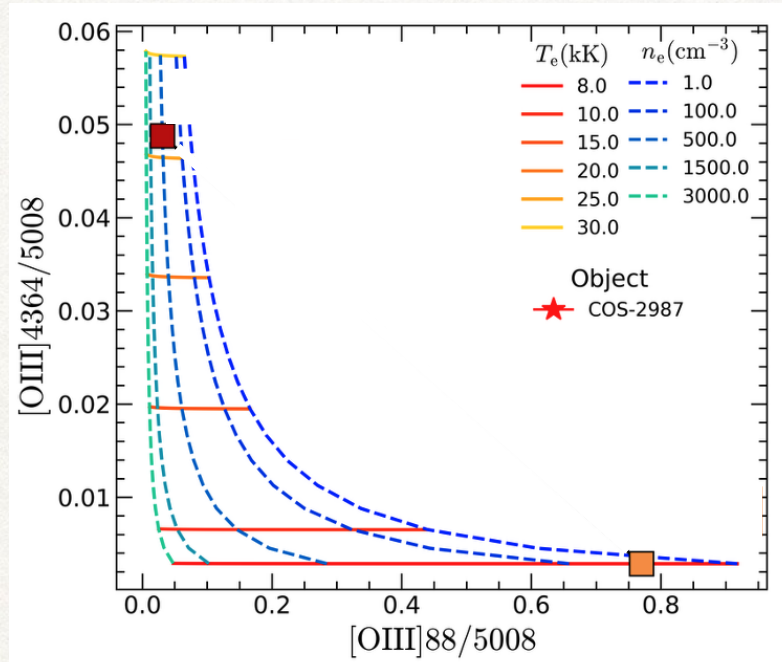


○ Many detection of [OIII]88

...but too bright?

Too Strong [OIII]88 Line?

○ COS-2987 at $z=6.81$

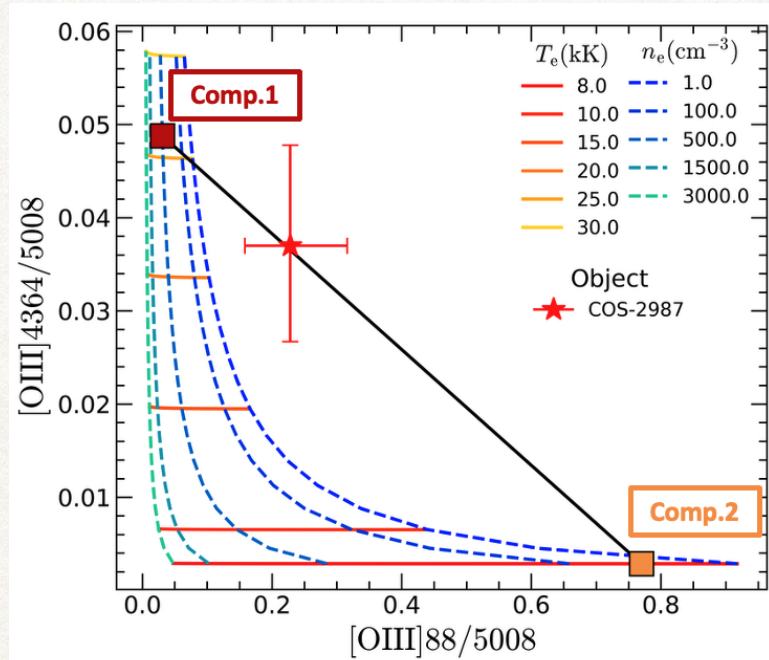


Usui, ..., YS et al. (2025)

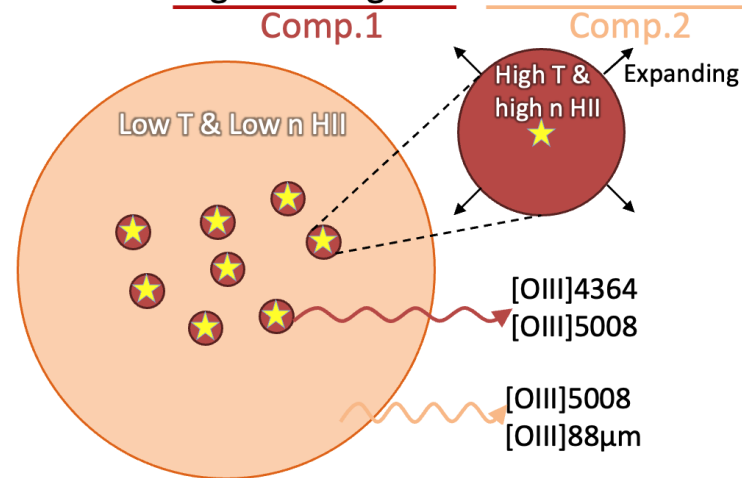
Mawatari, ..., YS et al. (2025)

Too Strong [OIII]88 Line?

○ COS-2987 at $z=6.81$



Proposed scenario. High T_e & high n_e + Low T_e & low n_e



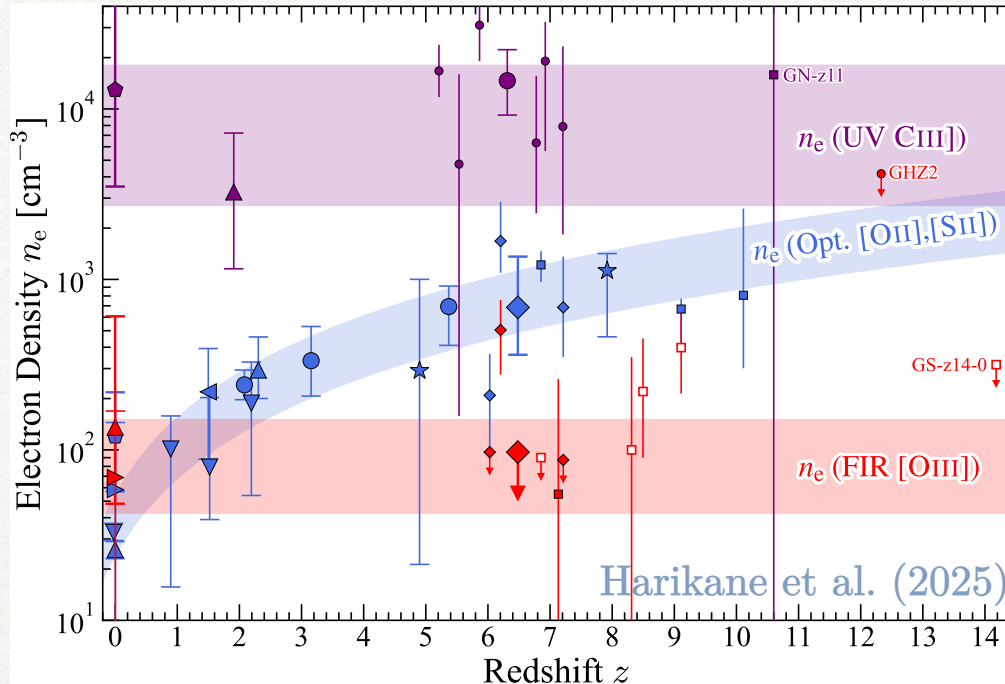
Usui, ..., YS et al. (2025)

Mawatari, ..., YS et al. (2025)

□ Strong [OIII]4364 (**high- T_e**) & [OIII]88 μ m (**low- T_e , n_e**)

Multi-Wave Obs. Trace Different Gas

○ Redshift evolution of electron density n_e



High- n_e

opt. [OII]3727,3729

Low- n_e

FIR [OIII]52&88 μm

FIR emission lines trace diffuse/normal SF regions

JWST has detected NIII] and NIV] lines



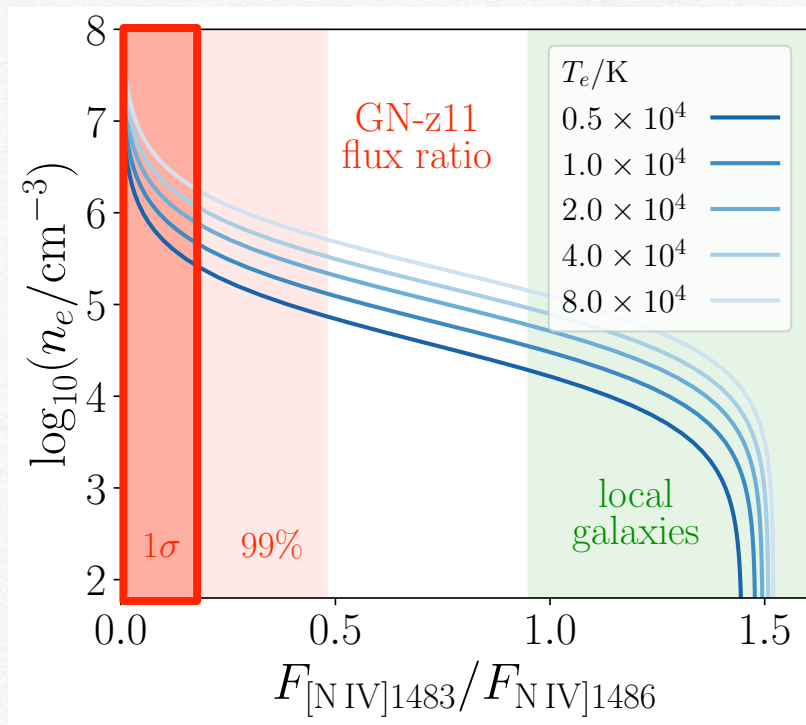
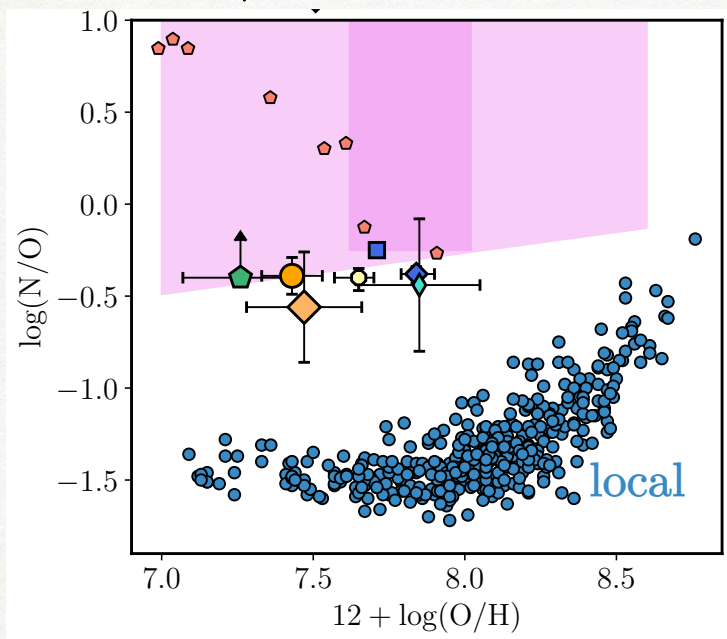
Bunker+24

- GN-z11 detected in NIV] and NIII]
 - Are they really nitrogen lines?
 - What is an origin of the high-ion lines?

N-rich, Compact Star-formation

○ UV NIV] emitters

□ High N/O & $n_e > 10^5 \text{ cm}^{-3}$



How enriched in normal/diffuse star-forming regions?

Target: ALMA [NIII] 57 μm

○ [NIII] 57 μm

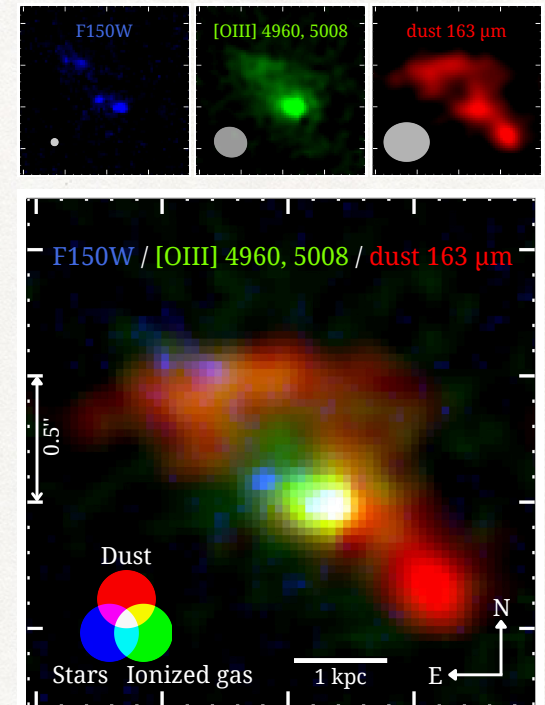
- Precise N/O with [OIII] 52, 88 μm lines
- Critical density $n_e \sim 2000 \text{ cm}^{-3}$

○ A1689-zD1

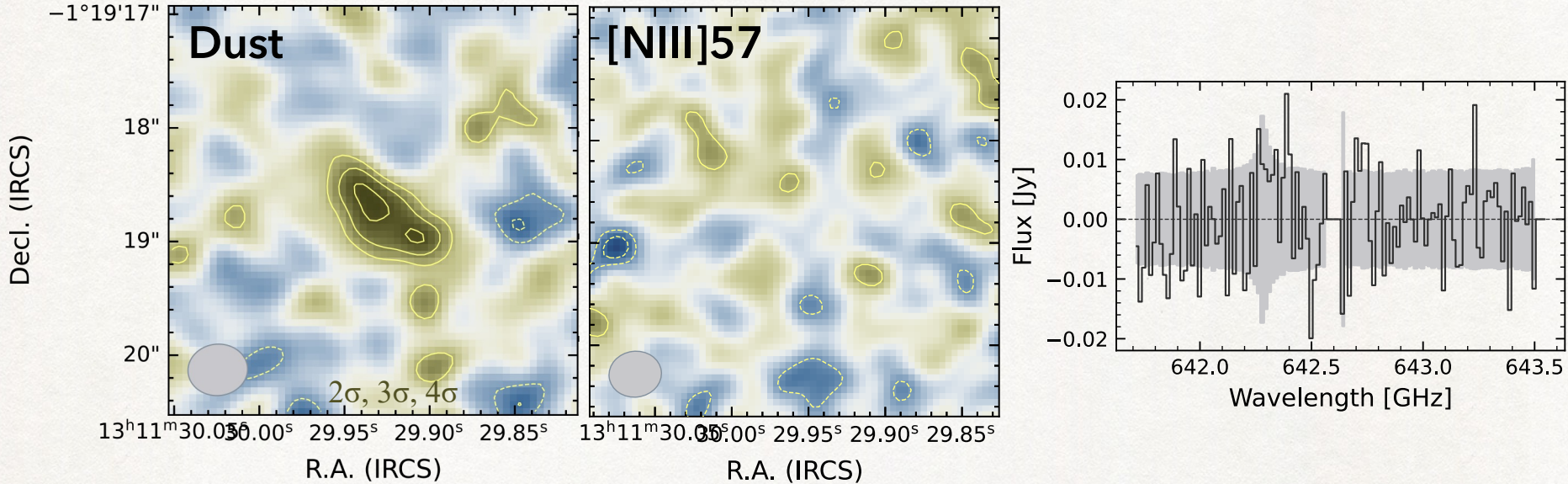
- Bright, gravitationally lensed target
- Previous ALMA obs.
 - [CII], [OIII]88, [OIII]52, [NII]122,

○ This work

- ~8.5h observations in Band 9



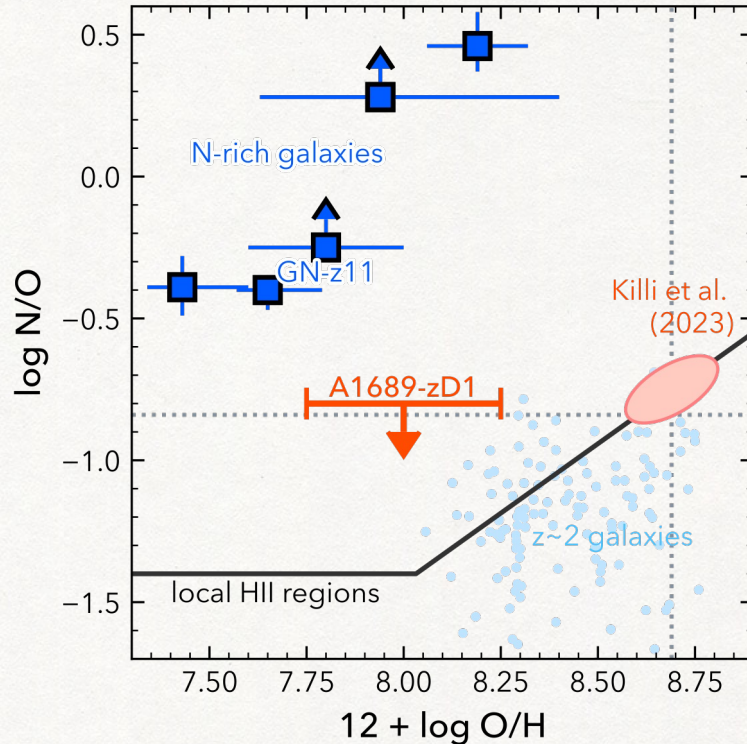
[NIII] 57 μm observations



○ No detection of [NIII] 57

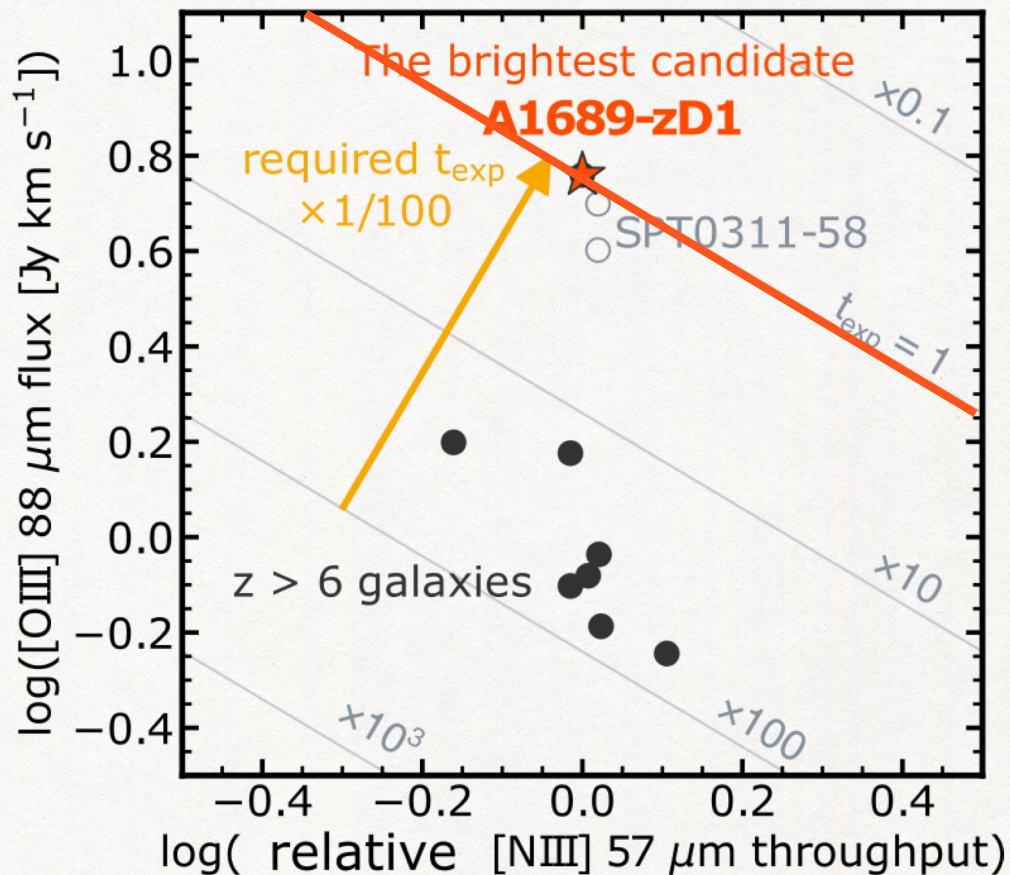
→ Stringent constraint on [NIII] and thus N/O

A1689-zD1: Ordinary N/O at $z \sim 7$

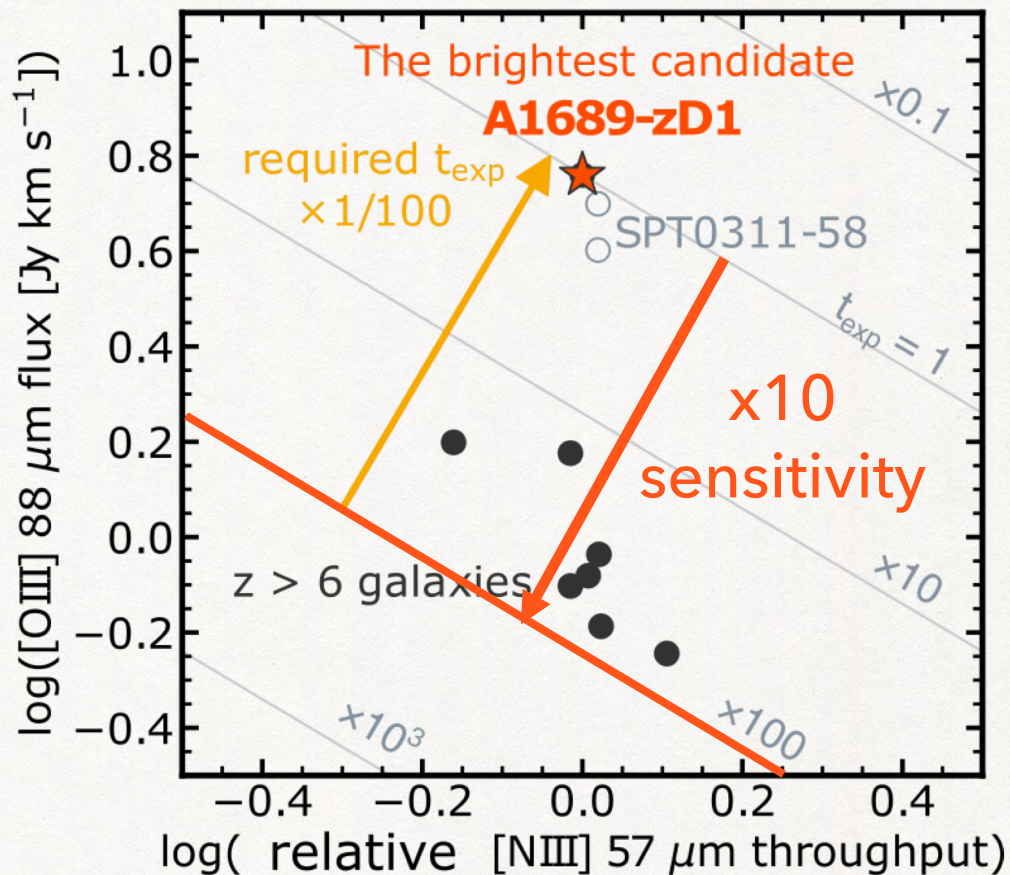


Constraint on N/O at FIR, tracing $n_e < 2000 \text{ cm}^{-3}$

Towards ALMA 2040



Towards ALMA 2040



Summary

- ALMA can be a “redshift machine” even in 15 years
- $z > 6$ is only the redshift covered in rest-UV, opt, FIR lines
 - Enables investigation of high- z ionized ISM
- High- z star-forming galaxies with multi-phase ionized gas
 - Optical and FIR lines would trace different ionized gas.
 - Case study: [NIII]57 μ m trace N/O of normal SF regions.

