Puzzlingly High N/O and N/C Galaxies at $z \sim 6-10$: Any Mechanisms for Insufficient C and O Enrichments

Kuria Watanabe

(National Astronomical Observatory of Japan /The Graduate University for Advanced Studies)

Collaborater: M. Ouchi, N. Tominaga, Y.Isobe,
JWST-Tokyo Chemical Evolution Team

Watanabe et al. 2024 ApJ.962.50W

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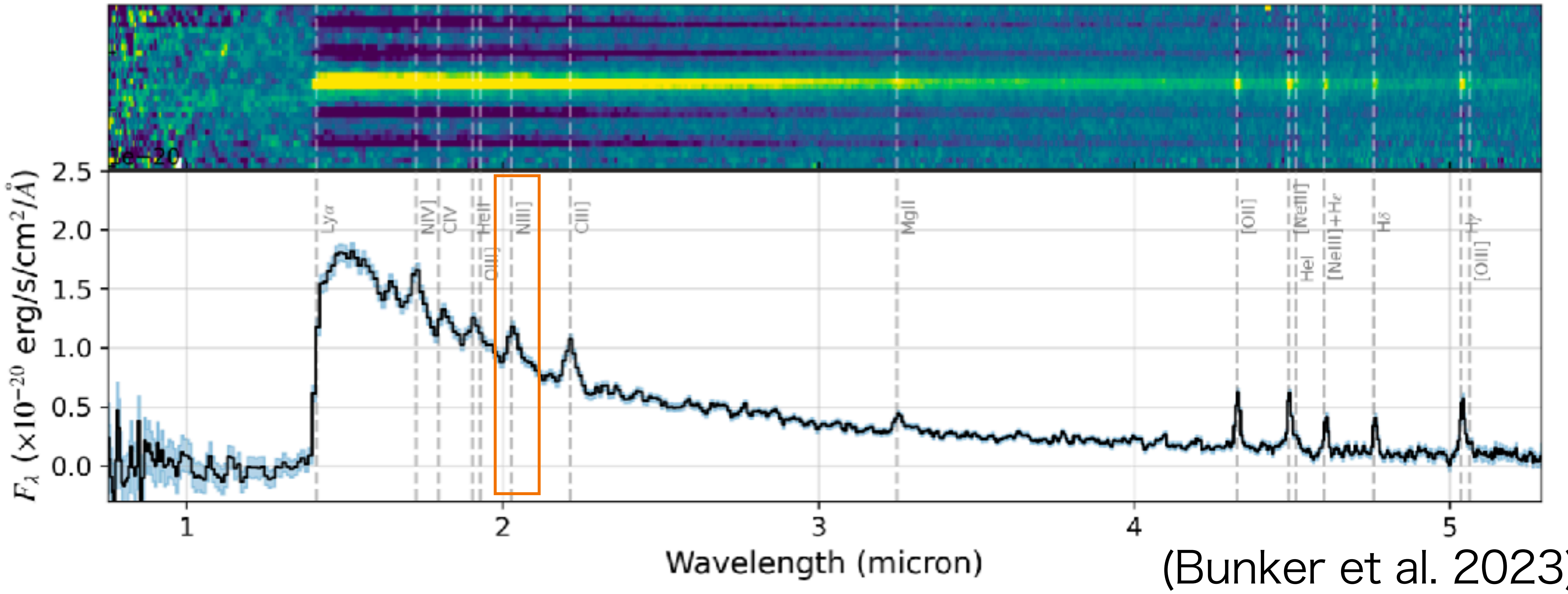
Nitrogen Abundance in GN-z11

The luminous galaxy at $z = 10.6$



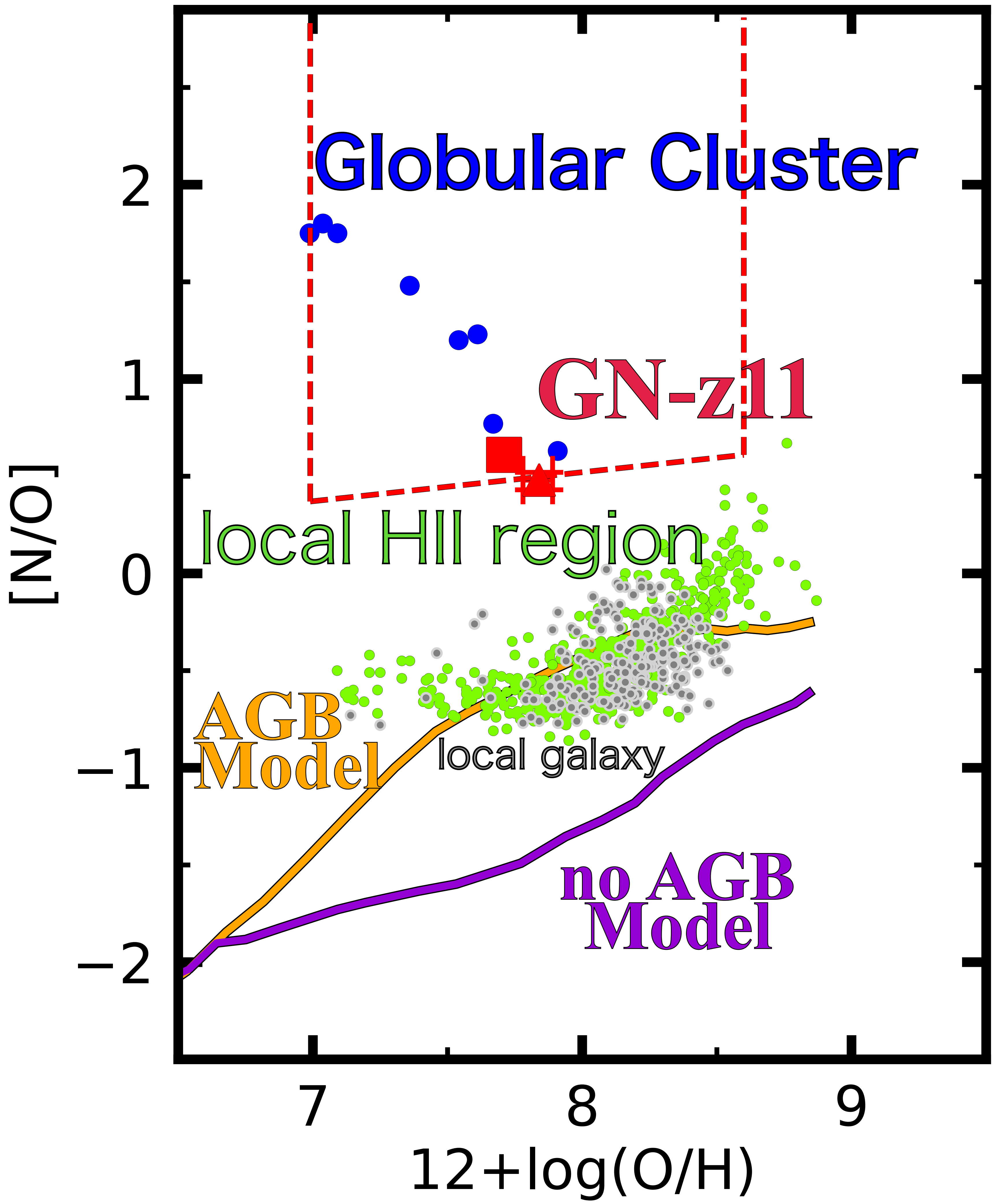
(Bunker et al. 2023)

The strong nitrogen emission line

[N/O]=0.52

(Cameron et al. 2023)

$$[X/Y] = \log\left(\frac{N_X/N_{X\odot}}{N_Y/N_{Y\odot}}\right)$$



(Watanabe et al. 2024)

High N/O cannot be reproduced by models including AGB stars.

The site of Globular cluster formation?

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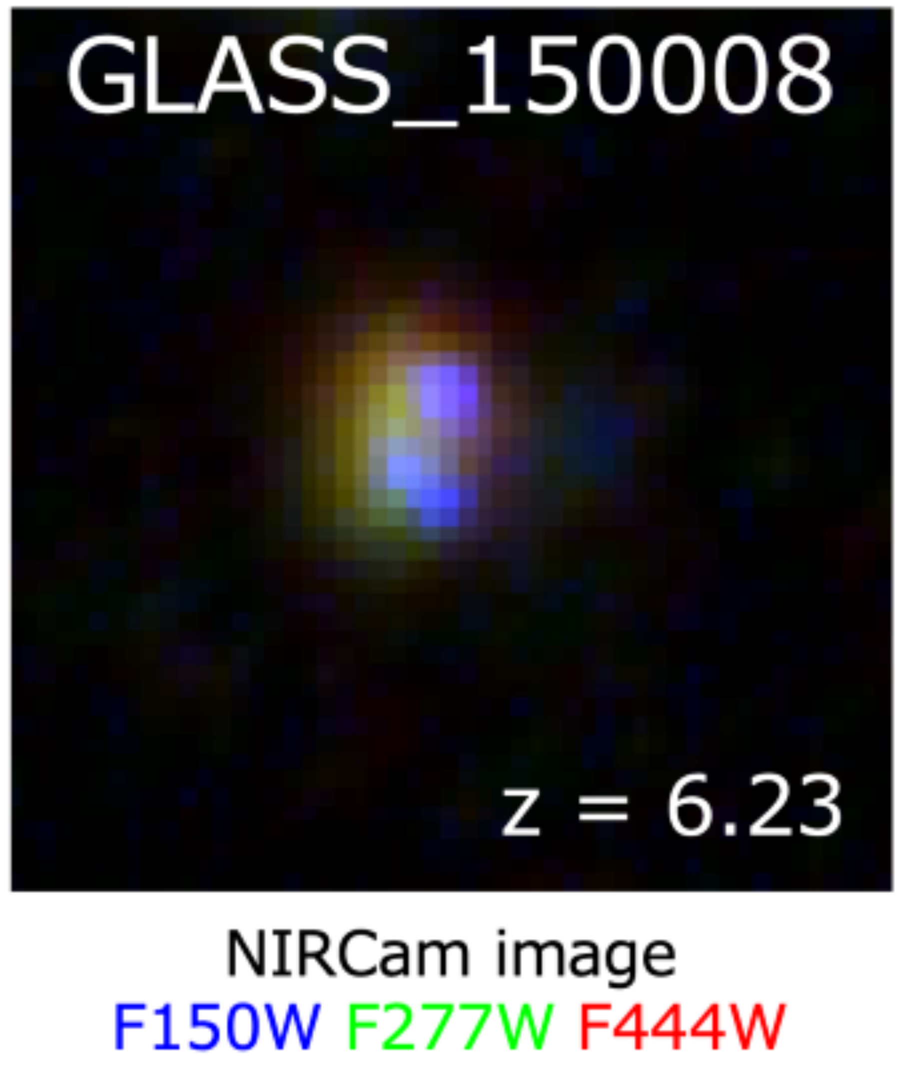
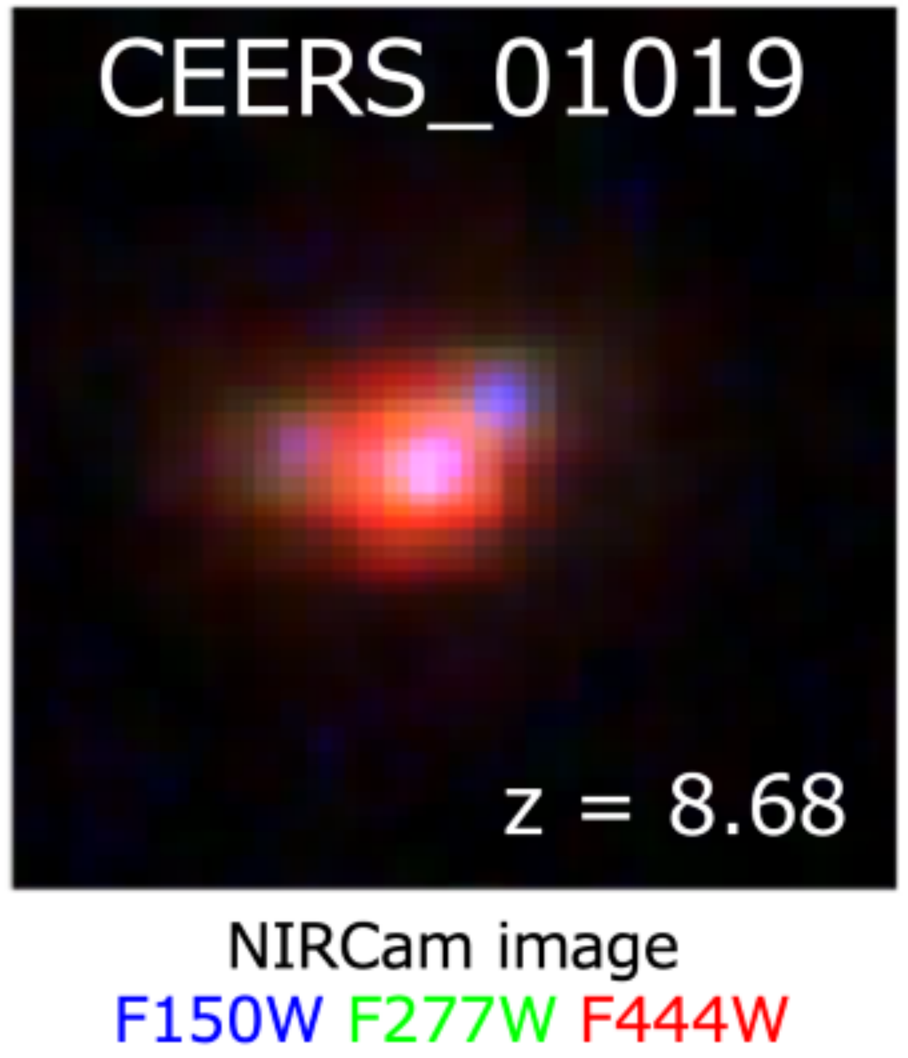
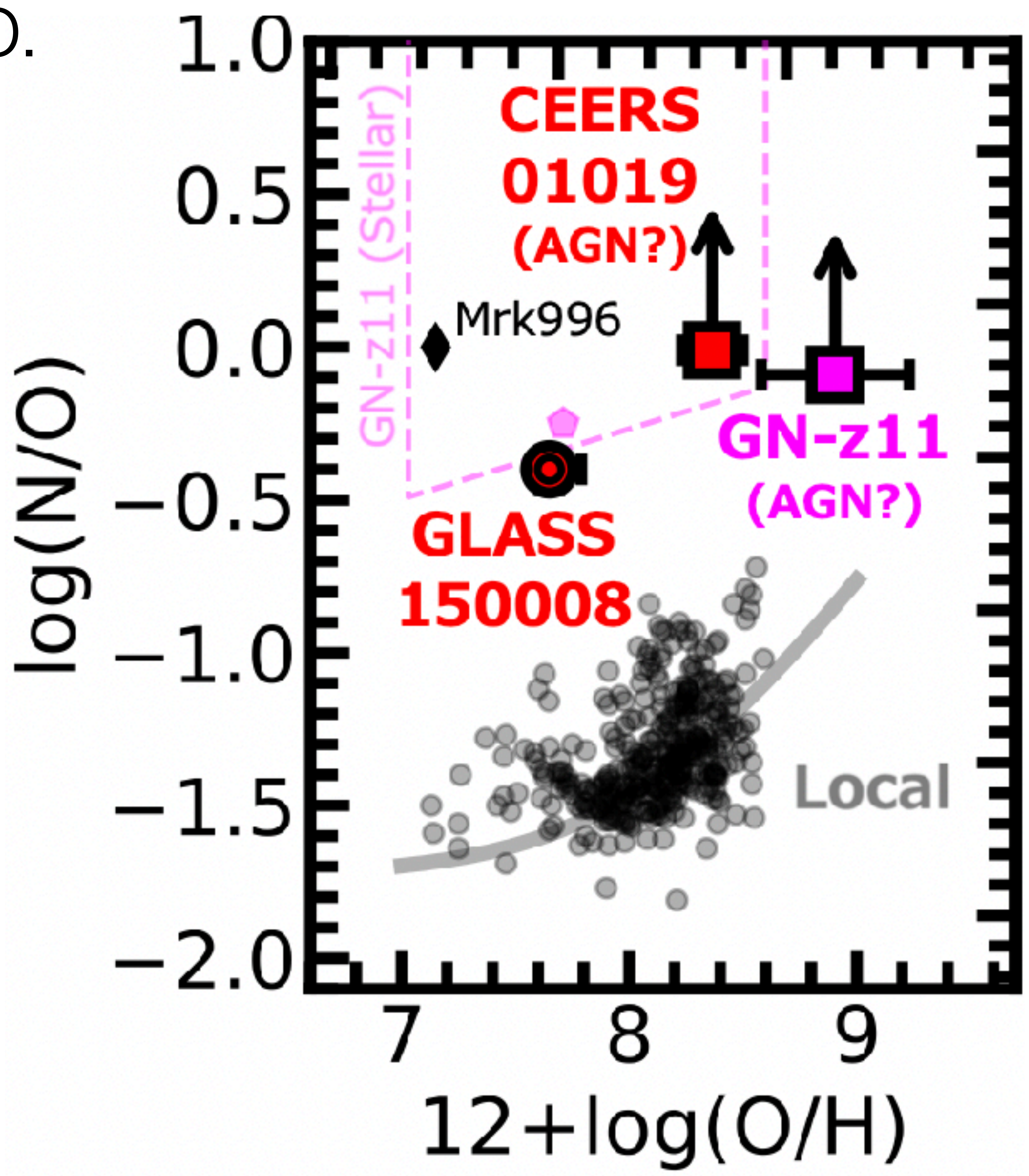
Nirtrogen Rich Galaxies

Isobe et al. (2023) report the two galaxies with high N/O.





(Isobe et al. 2023)



[N/O]=0.46

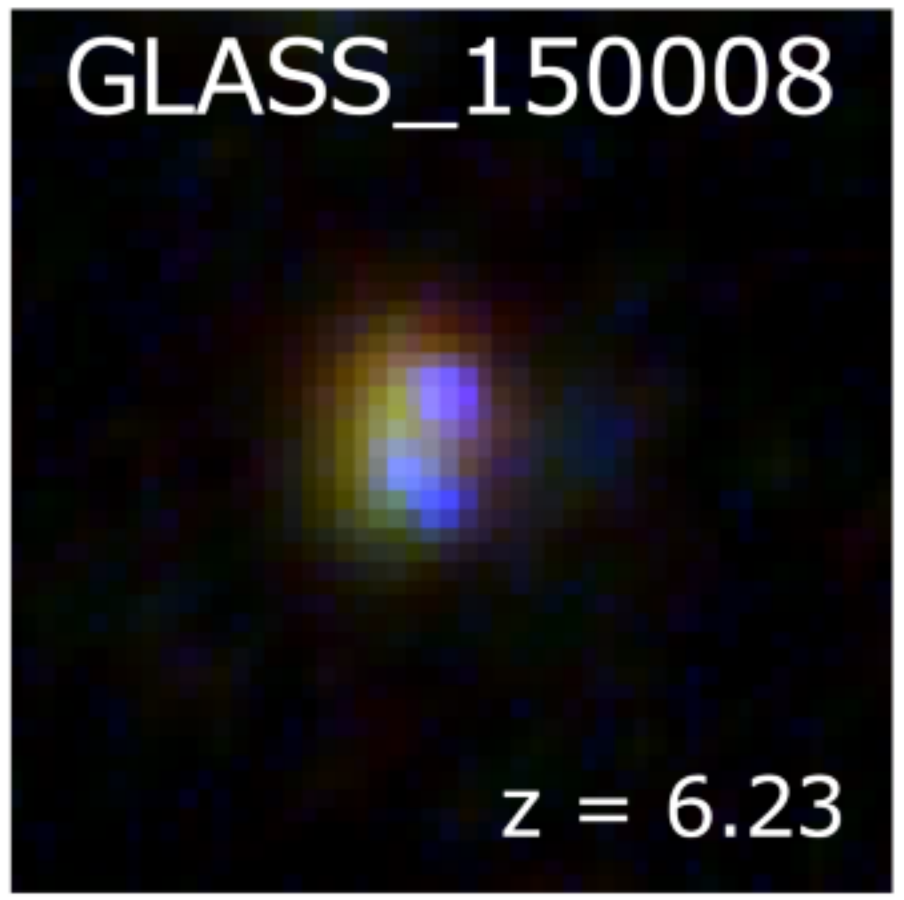
[N/O]>1.14

3 N-rich galaxies are found at high redshift.

(Isobe et al. 2023)

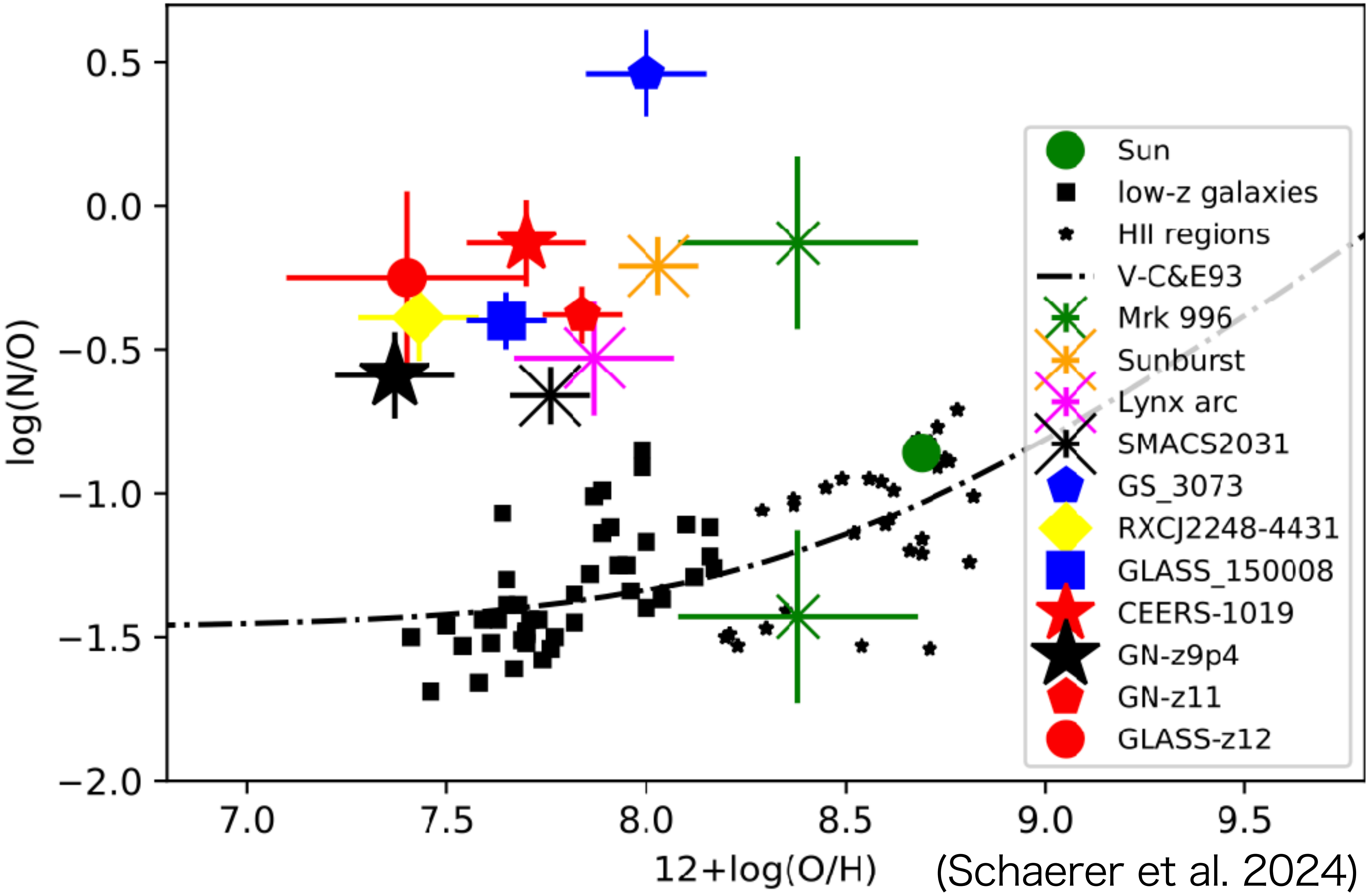
Nirtrogen Rich Galaxies

Isobe et al. (2023) report the two galaxies with high N/O.

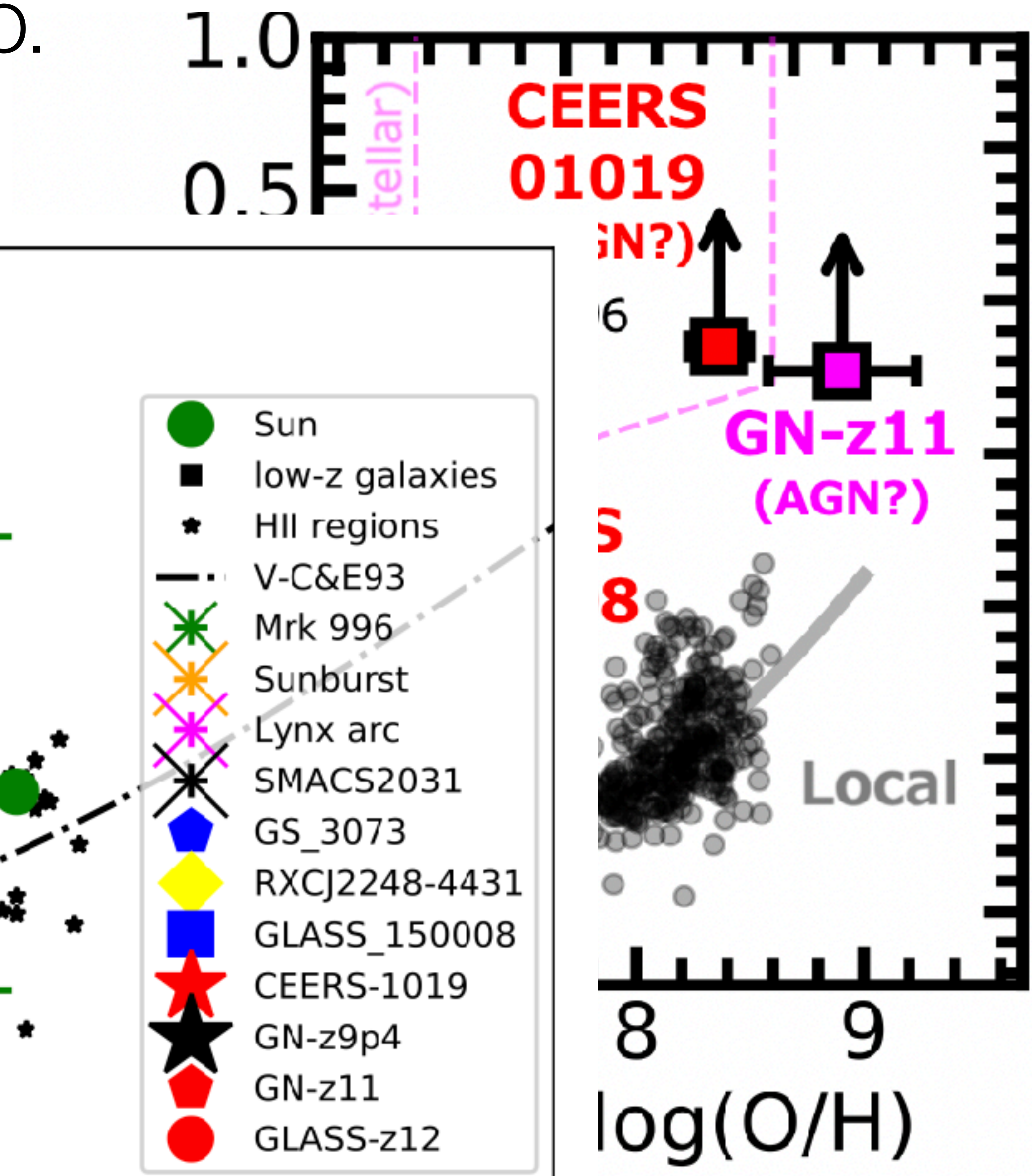


NIRCam image
F150W F277W F444W

[N/O]=0.46



(Schaerer et al. 2024)



(Isobe et al. 2023)

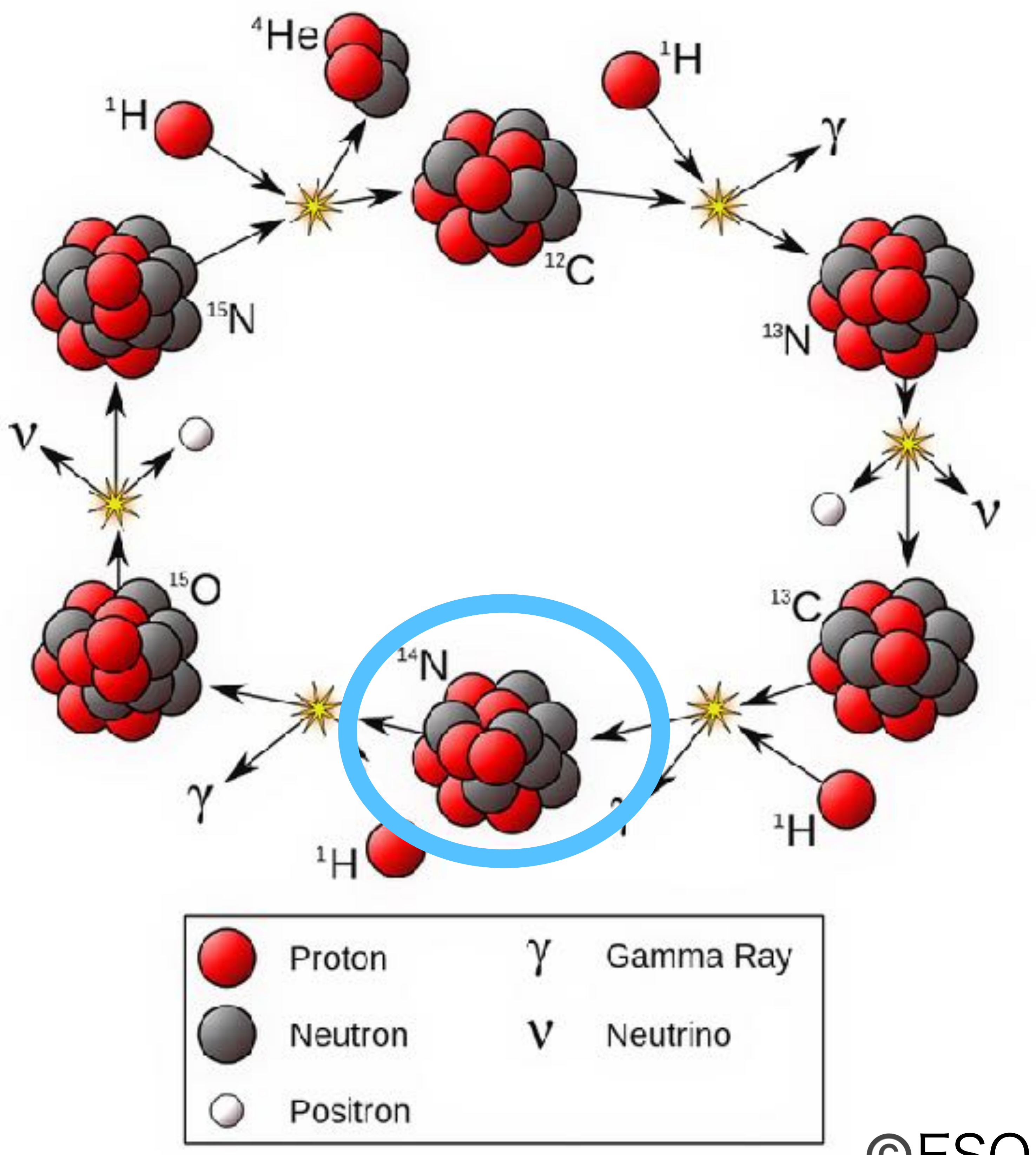
Investigating the physical origin of N-rich galaxies.

The C/N values of N-rich Galaxies

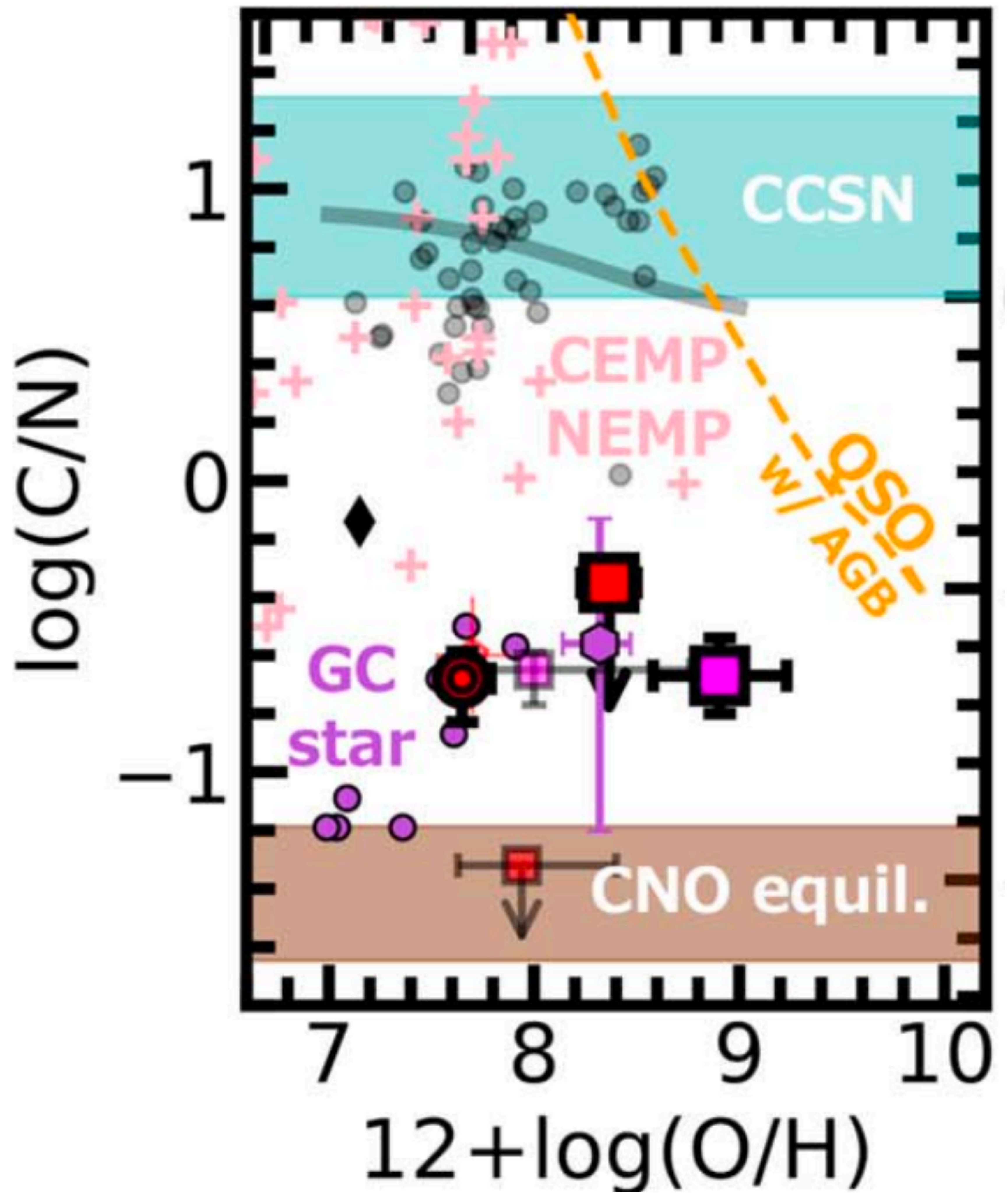
The N-rich galaxies have low C/N ratios.

→ The equilibrium of the CNO cycle

N-rich galaxies are enriched by CNO cycle?



©ESO Supernova



(Isobe et al. 2023)

The Candidates of Nitrogen Origin

In rotating stars, CNO cycle is active at the surface.

→ Nitrogen increase at the stellar surface

- **Wolf-Rayet star (WR)**

  → ejected by stellar winds

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- **Tidal disruption events (TDE)**

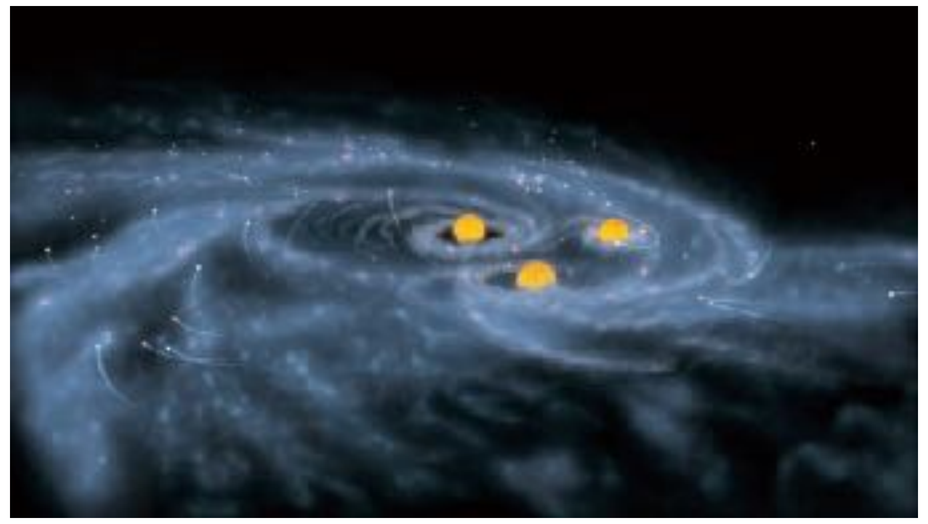
  → pulled apart by black hole

©ESA/C. Carreau

- **Supermassive star (SMS)** with $10^3 - 10^5\ M_\odot$

  The inflowing gas triggers the CNO cycle in SMS.

  → ejected by stellar winds



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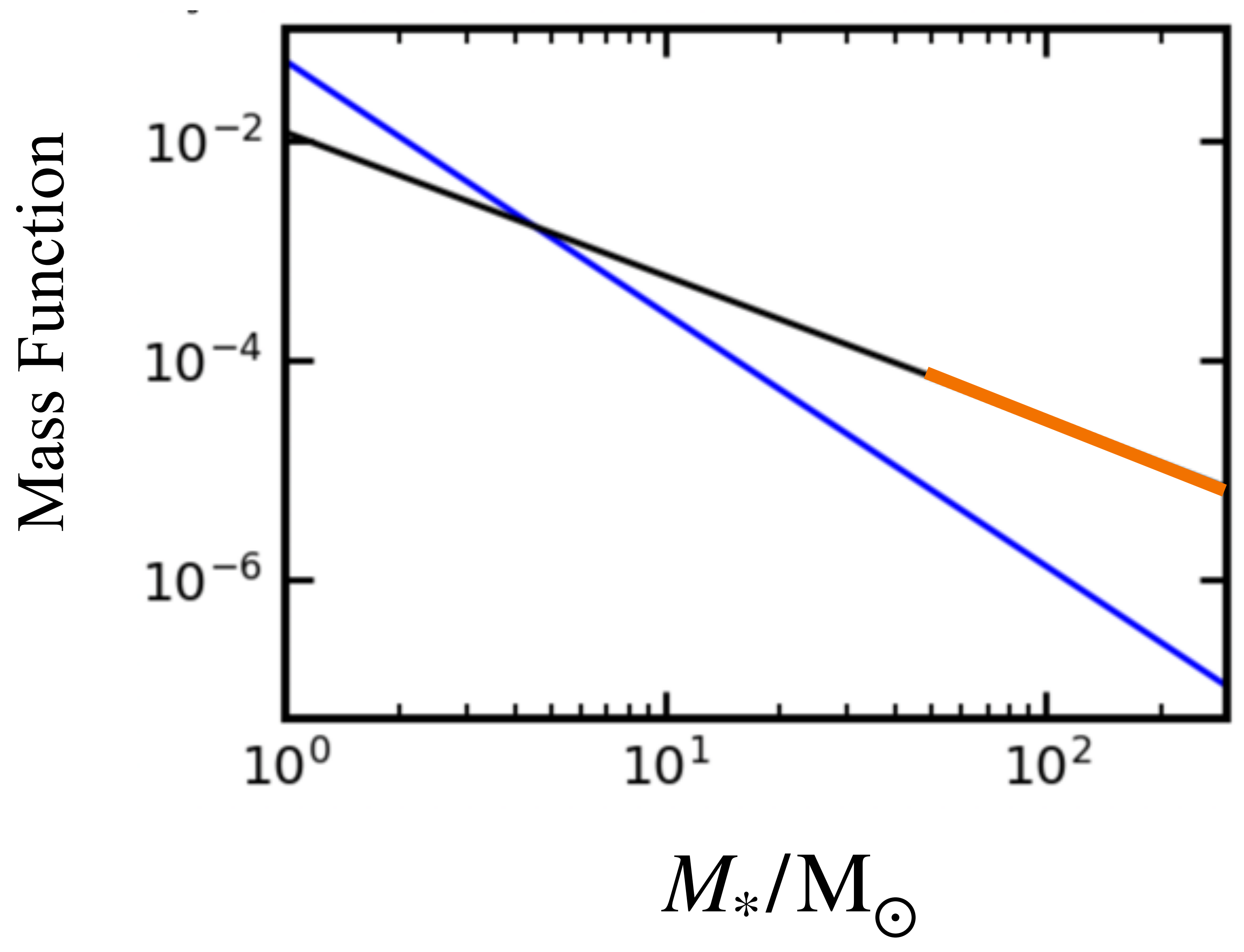
Developing chemical evolution models

Developing Chemical Evolution Models

1. Star formation based on IMF



Kroupa IMF (Kroupa 2000)

Top heavy (Marks et al. 2012)

Very Top heavy: Mass range > $50 M_\odot$

2. Adding up Nitrogen rich ejecta

- **WR models**

  yields: Limongi & Chieffi (2018)

  mass range: $25 - 120\ M_\odot$

- **TDE models**

  yields: Calculating yields

  mass range: $9 - 100\ M_\odot$

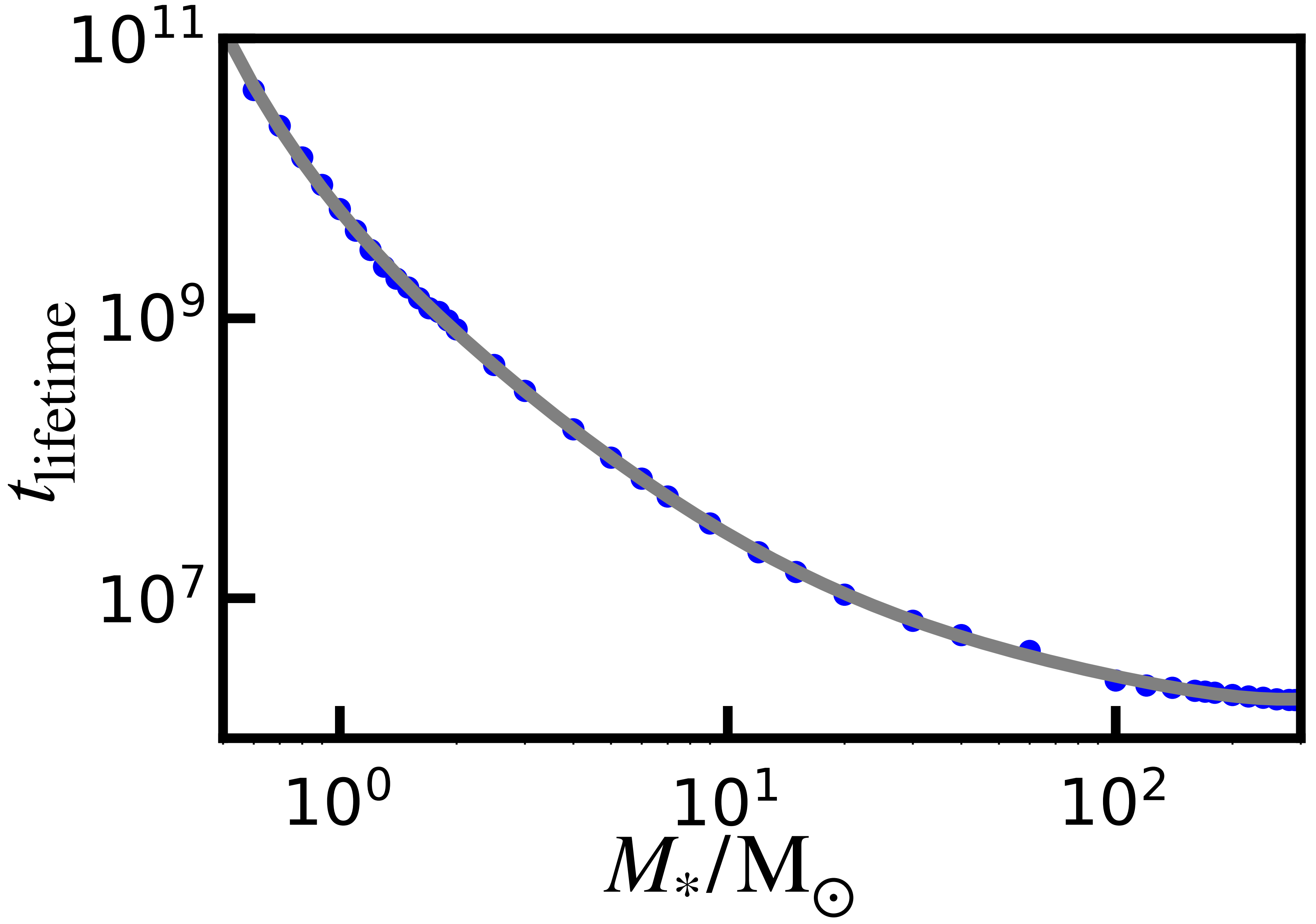
- **SMS models**

  yields: Nagele & Umeda (2023)

  mass range: $10^5\ M_\odot$

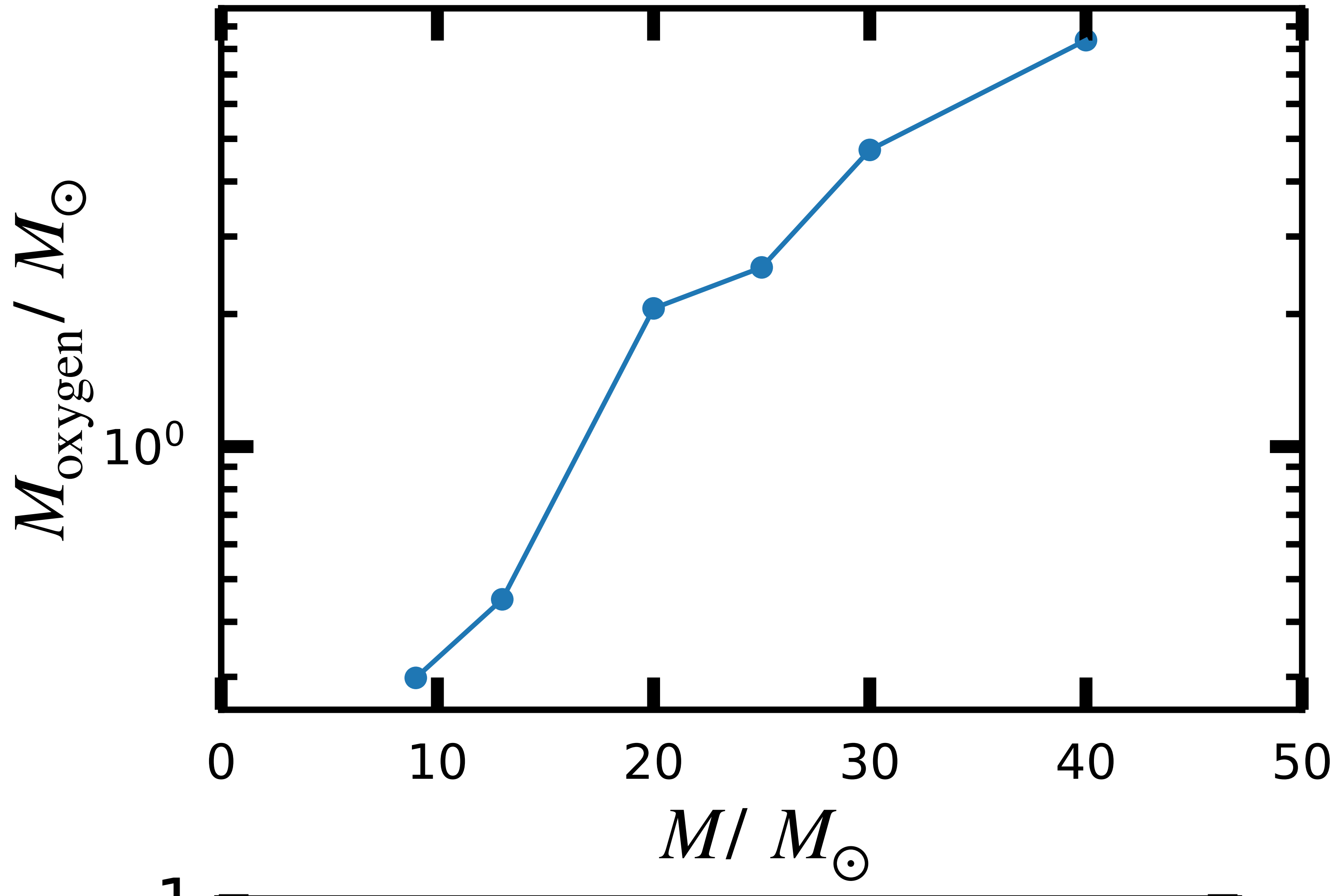
Developing Chemical Evolution Models

3. Life time of stars

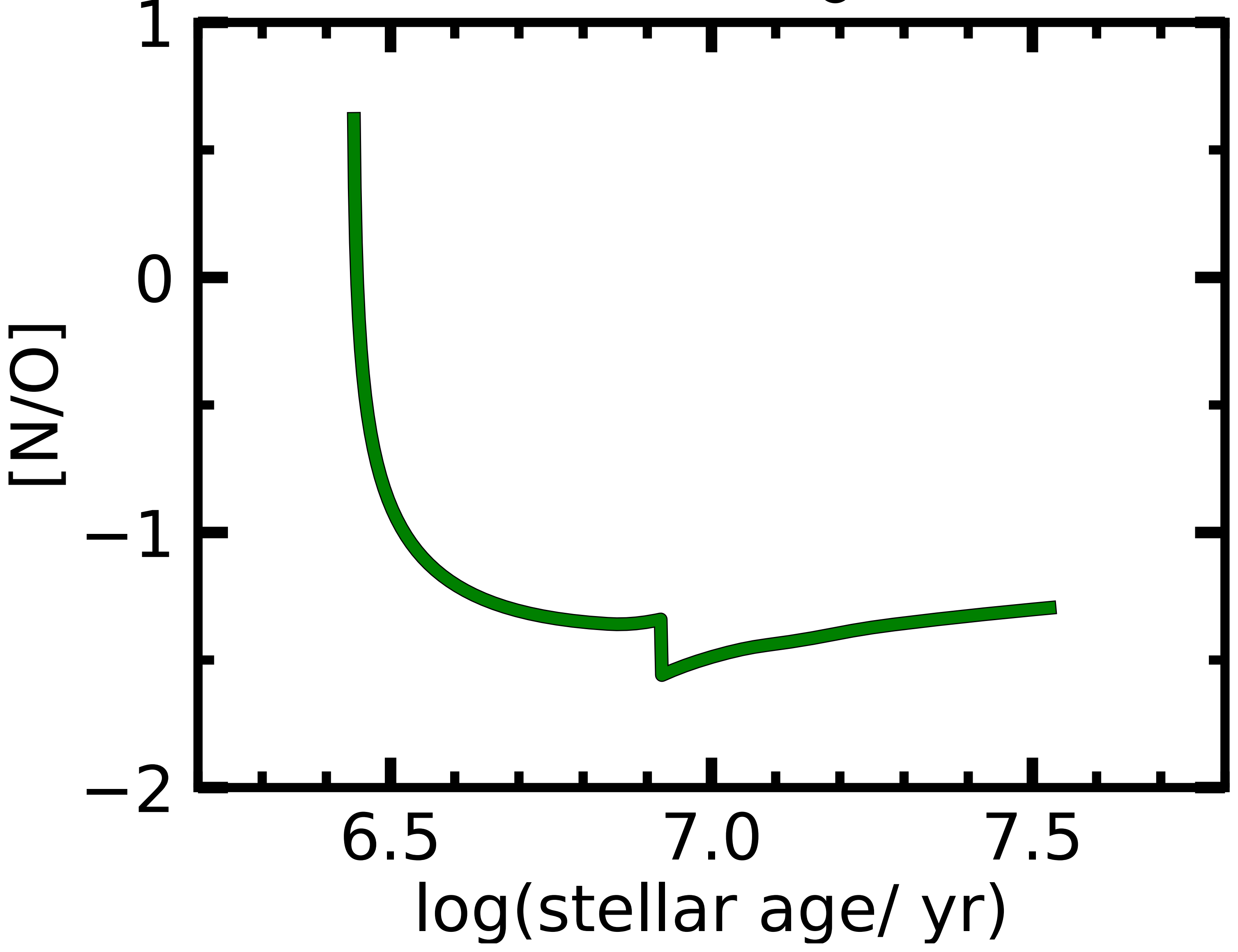


4. Adding up CCSN ejecta

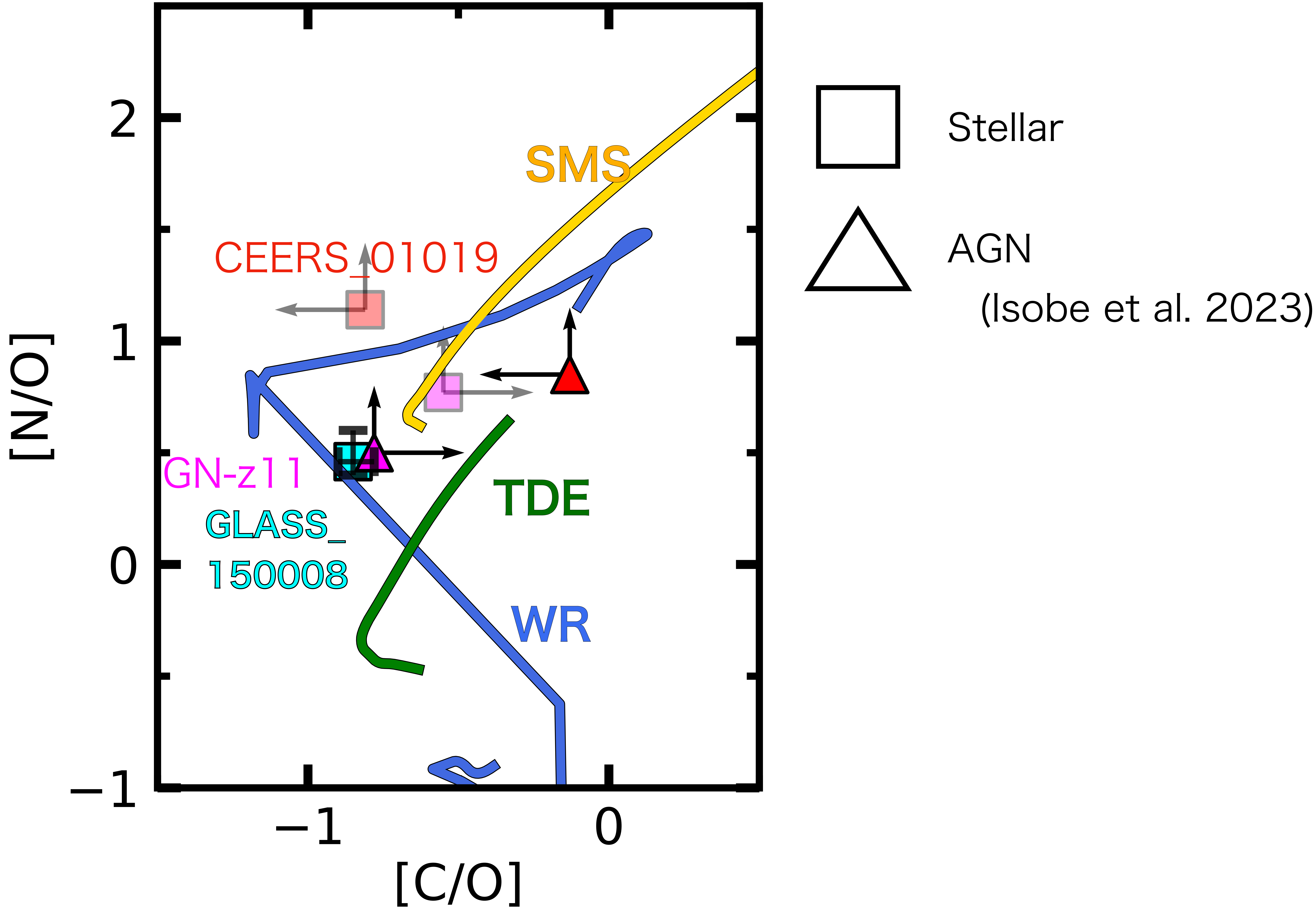
(Nomoto et al. 2013)



5. Abundance ratios as a function of time



C/O and N/O



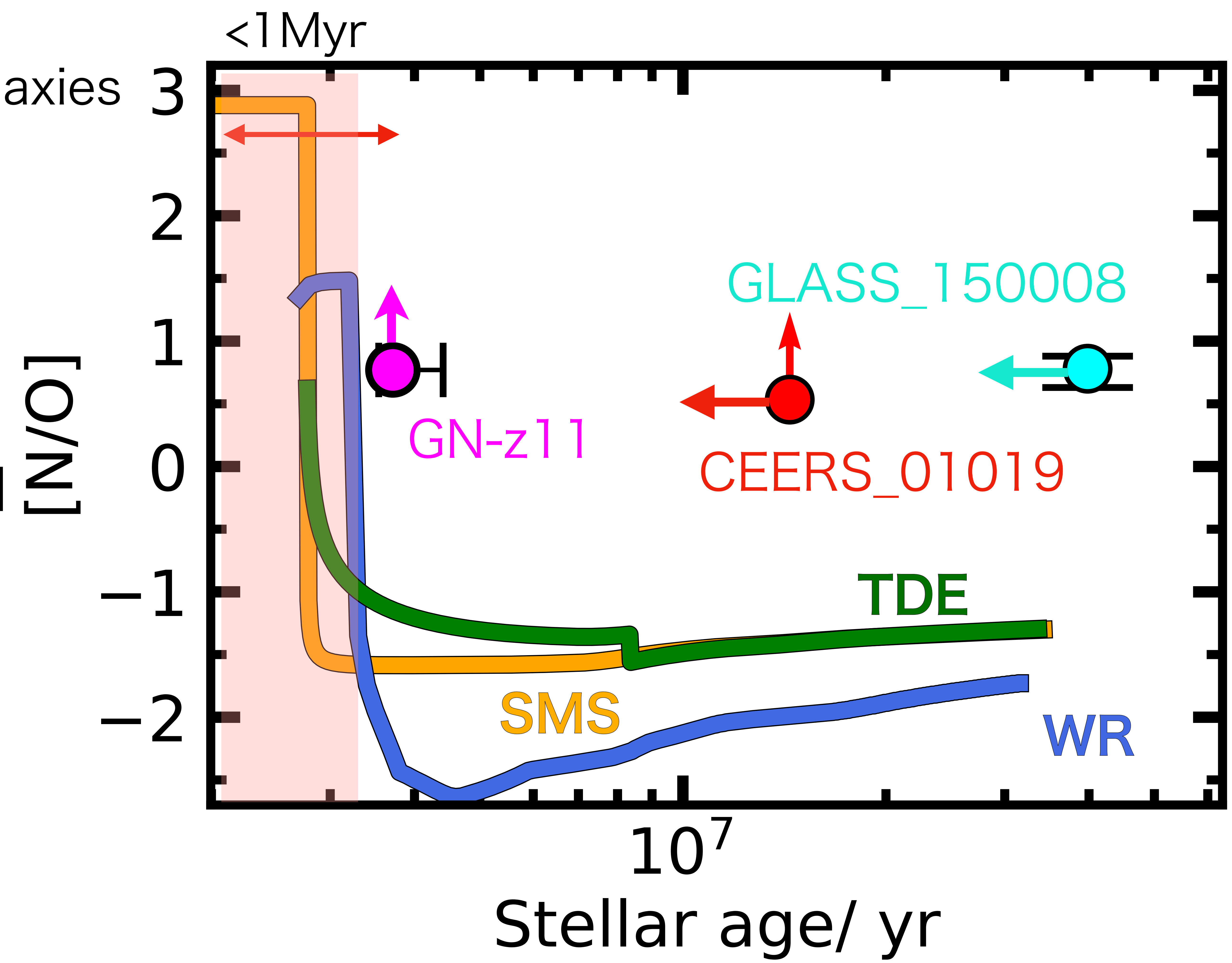
Our model is consistent with the N/O and C/O ratios of N-rich galaxies

WR, SMS, and TDE Models

Our models are as nitrogen-rich as the N-rich galaxies

When CCSNe take place,
a large amount of oxygen is ejected.

→ Short time period (< 1 Myr) for high [N/O]



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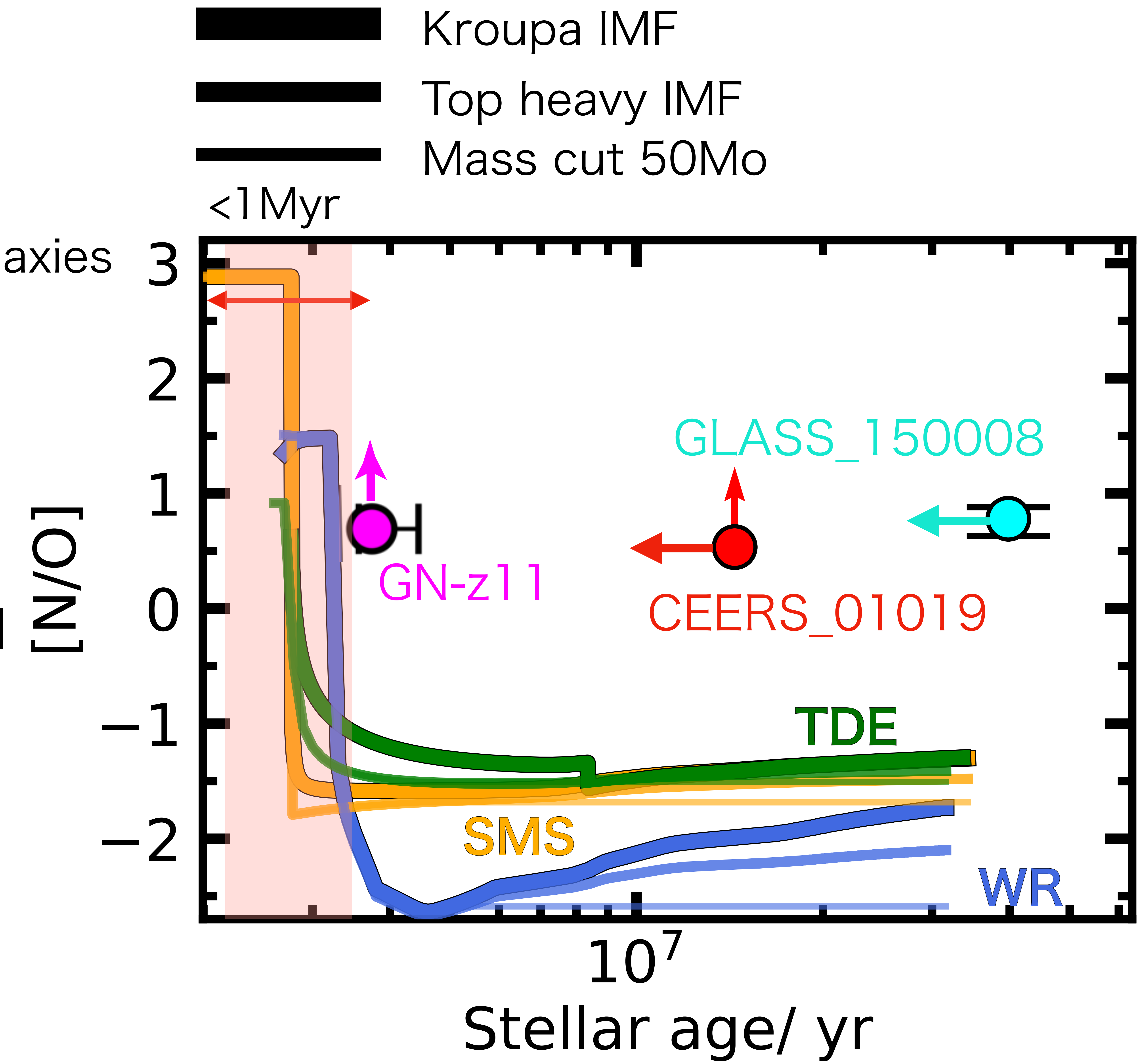
IMF: Kropua, Top-heavy, Very top-heavy



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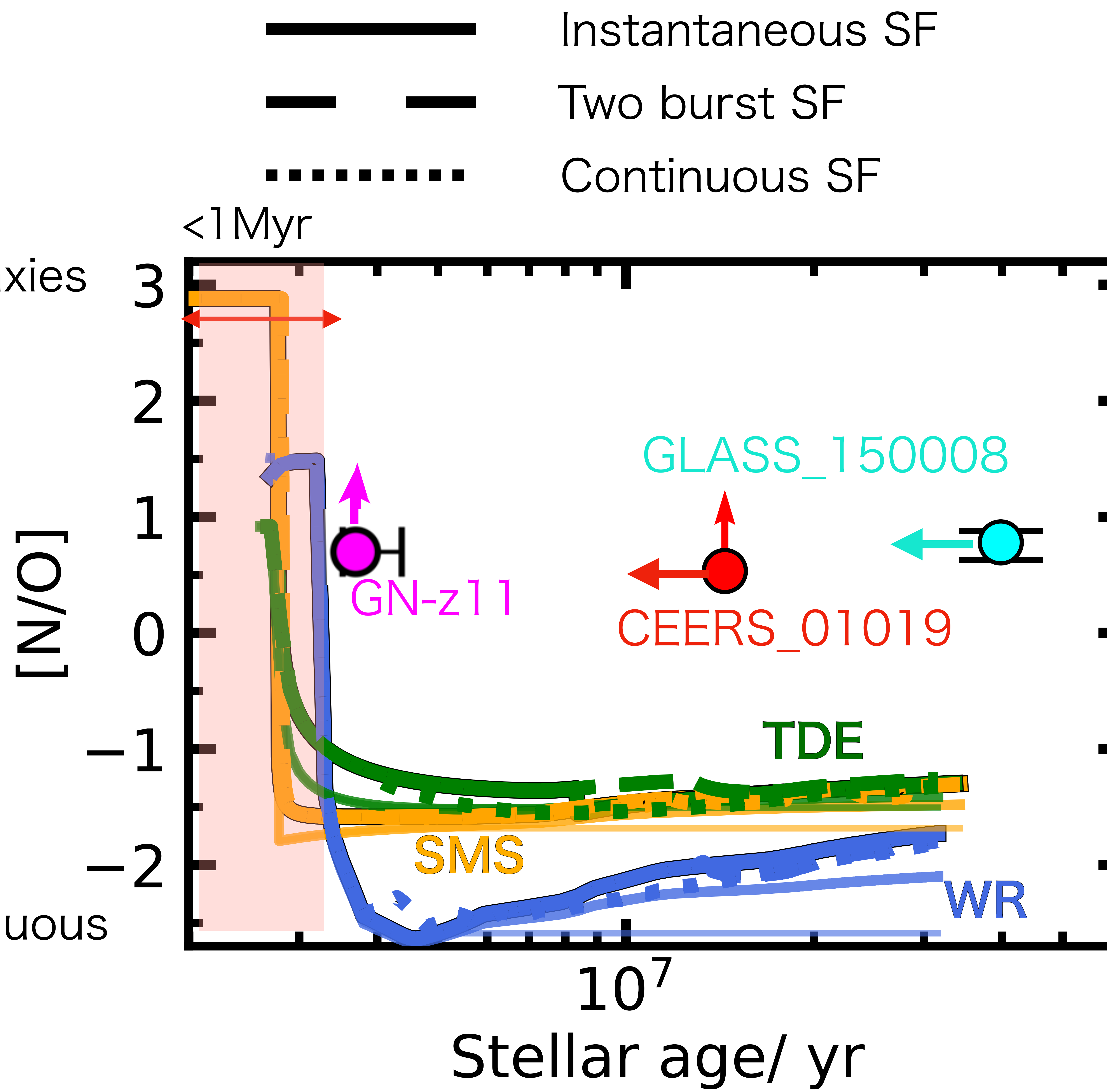
Star formation: Instantaneous, Two bursts, Continuous

→ They do **not** affect the changes in N/O



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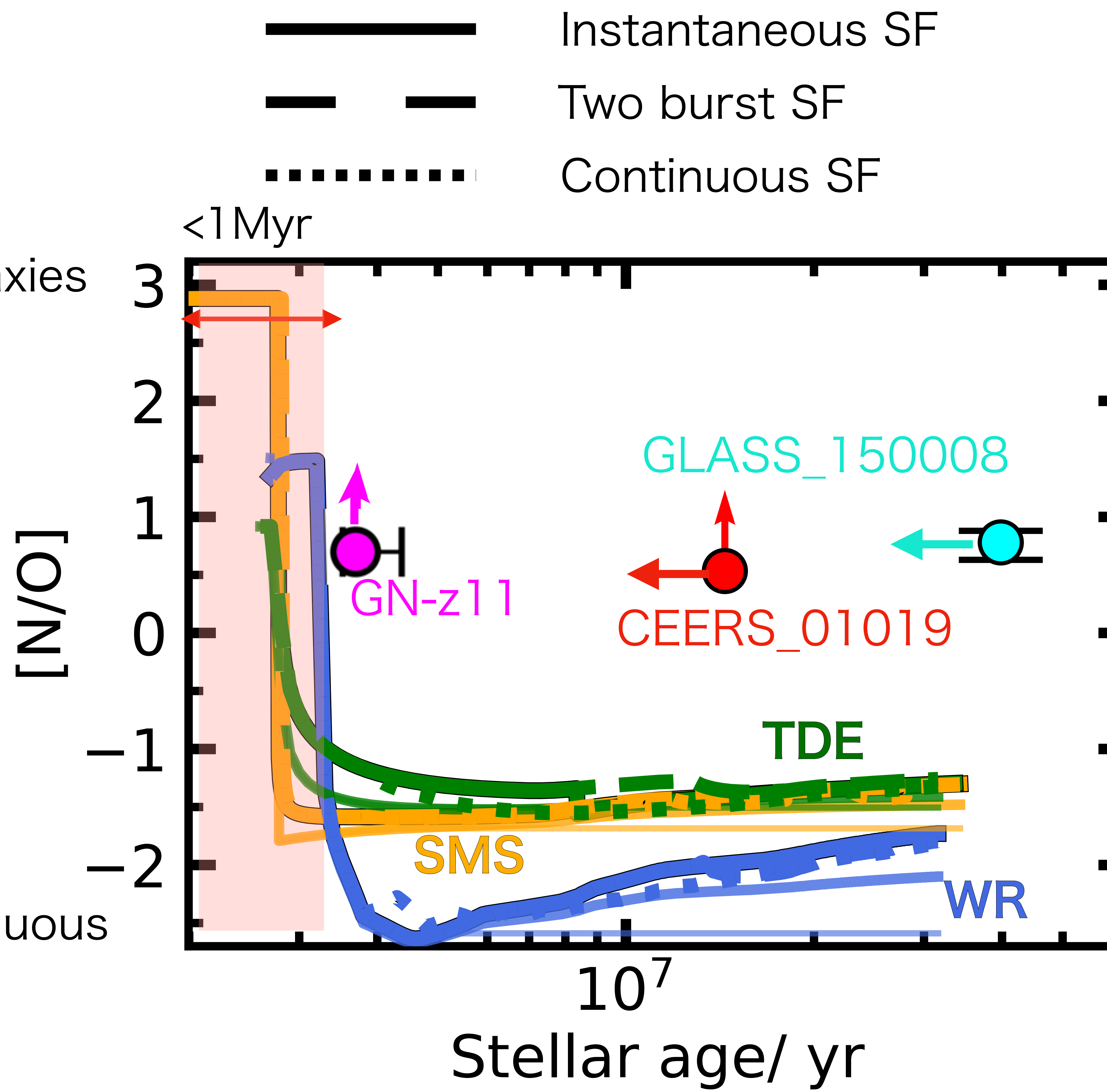

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If CCSNe don't take place, [N/O] will remain high?

Direct collapse

We introduce direct collapse(DC) models.

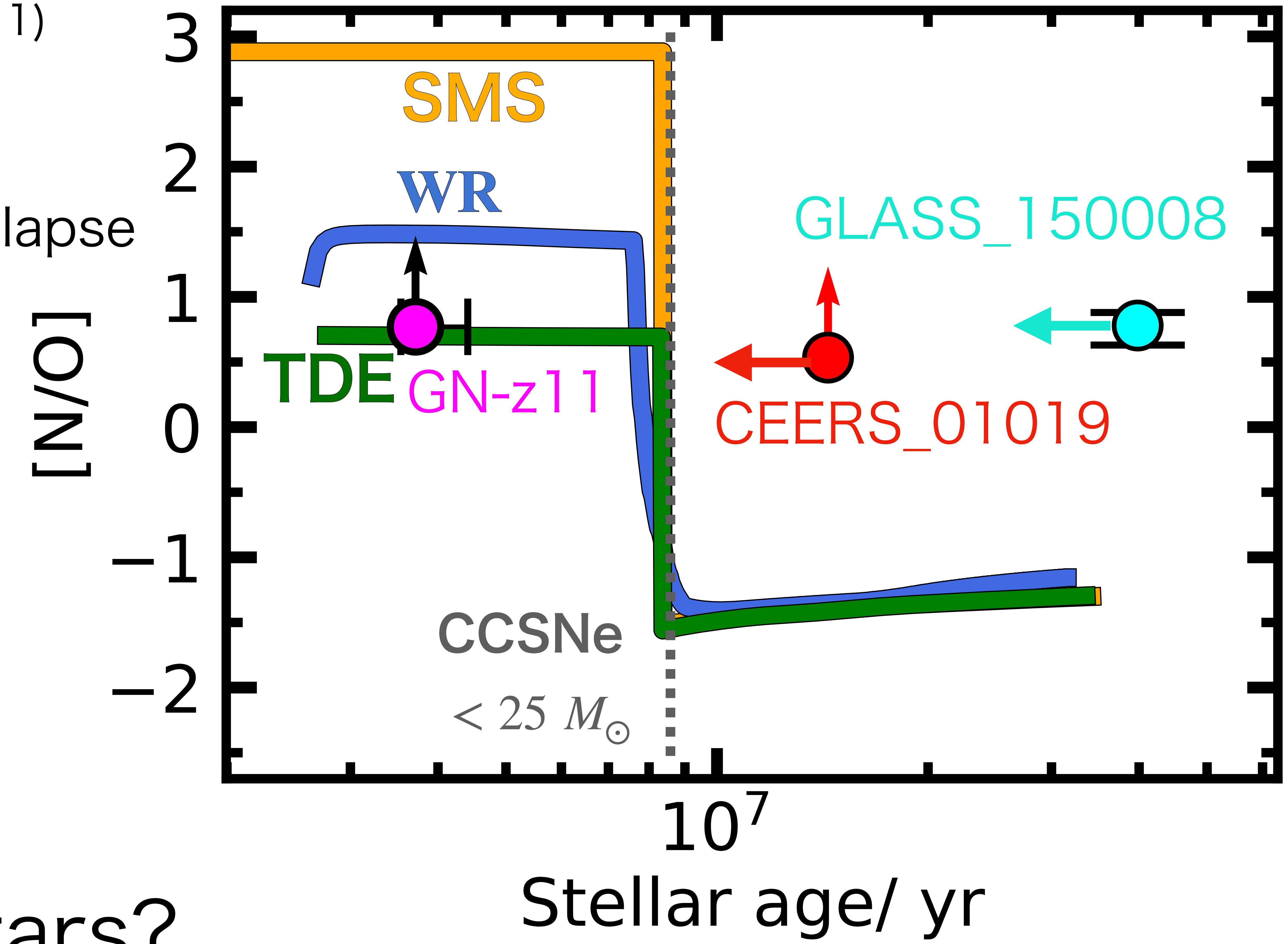
Massive stars tend to cause DC because they have massive Fe cores.

(Woosley et al. 2002, O'Connor & Ott 2011)

Assuming that massive stars ($\geq 25\ M_\odot$) directly collapse into a black hole without CCSNe.

DC does not eject oxygen.

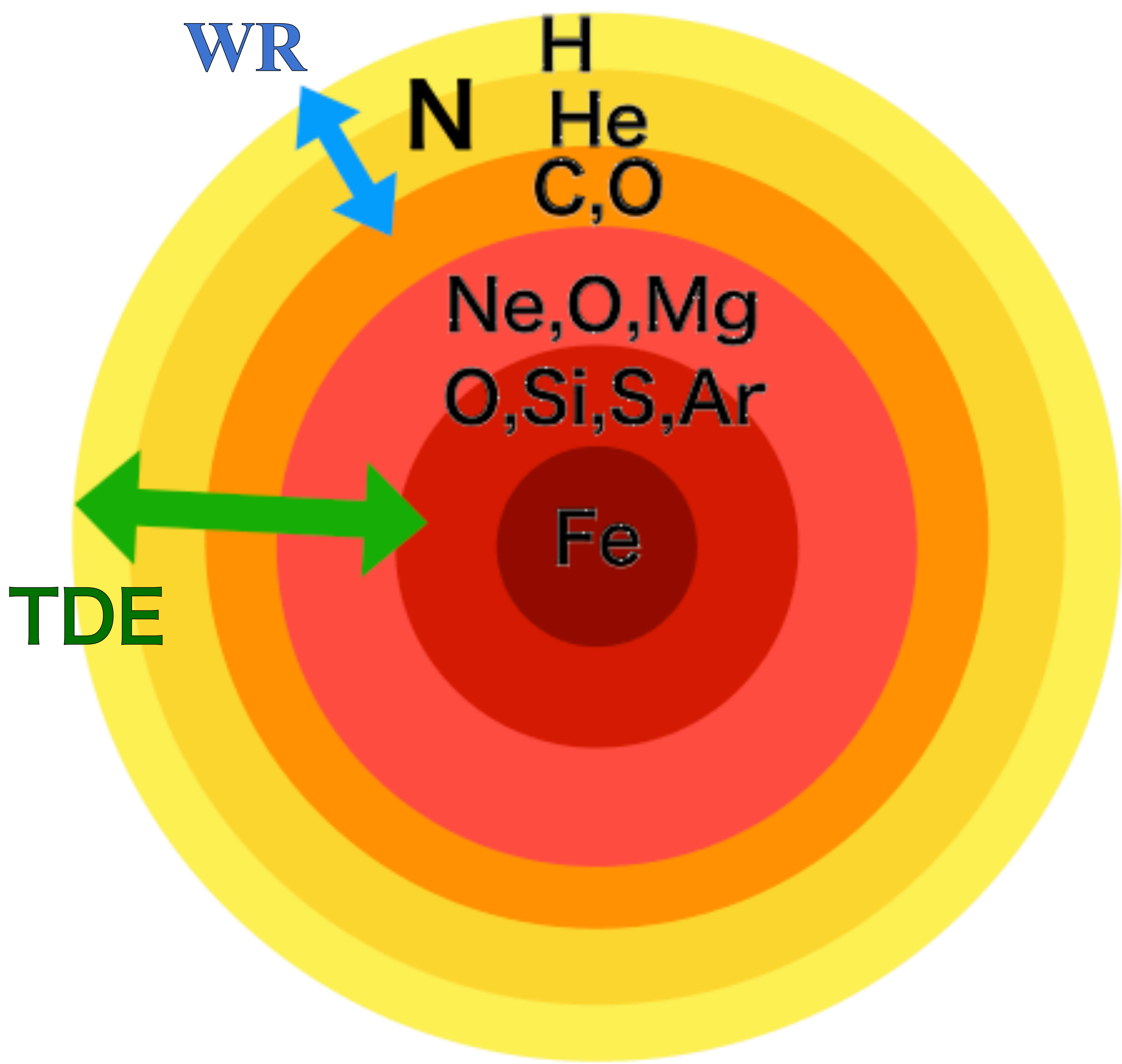
→ [N/O] is high for a long time.

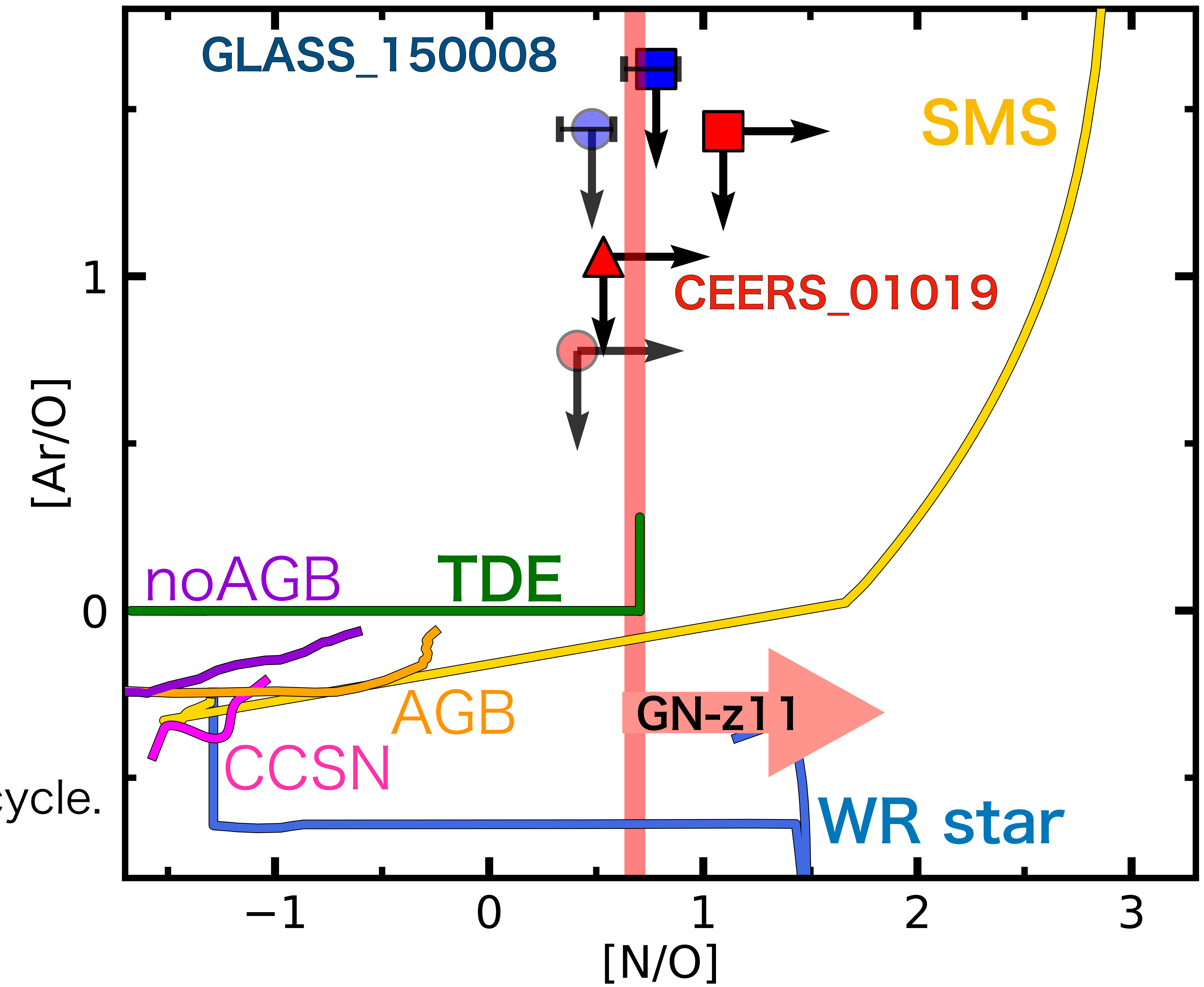


In N-rich galaxies,

DCs for majority of massive stars?

Differentiating models





All models extract a N-rich surface layer due to CNO cycle.

The interior elements can distinguish between models.

Watanabe et al. in prep

Ar can be used to determine the origin of rich nitrogen.

→ Observations are challenging.

Summary

- N-rich galaxies are found at $z \geq 6$

- The abundance ratios of N-rich galaxies are consistent with the equilibrium of the **CNO cycle**

→ **Wolf-Rayet star, Supermassive star, and Tidal disruption event?**

- We develop the chemical evolution models of 3 candidates

→ **Direct collapse** is necessary to retain N-rich conditions

IMF and SFH do **not** affect the changes in N/O.

- We can distinguish models with **Ar/O** and restrict the origin of N ?