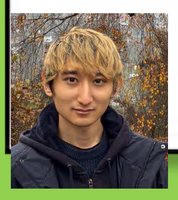
Nitrogen enhancement of GN-z11 due to the pollution from supermassive stars



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Abstract

GN-z11 shows high log(N/O)>-0.25 and supermassive stars' (SMS) stellar wind is suggested as possible origin of nitrogen (Isobe+23). Using the galaxy formation simulation, we added SMS pollution and tested whether SMS can realize GN-z11-like nitrogen-rich galaxy. We assumed SMS was formed at the galaxy center, formed the ionized bubble, polluted inside, and emitted emission lines. From star formation history, we assumed the central SMS weighed $10^{3-5}\ \mathrm{M}_\odot$. Mixing SMS ejecta with galactic gas by changing a pollution fraction, we found that 10—30 % pollution can reproduce GN-z11-like galaxy. This pollution fraction can be realized when SMS formed Strömgren sphere under $10^{4-5}\ \mathrm{cm}^{-3}$ gas density.

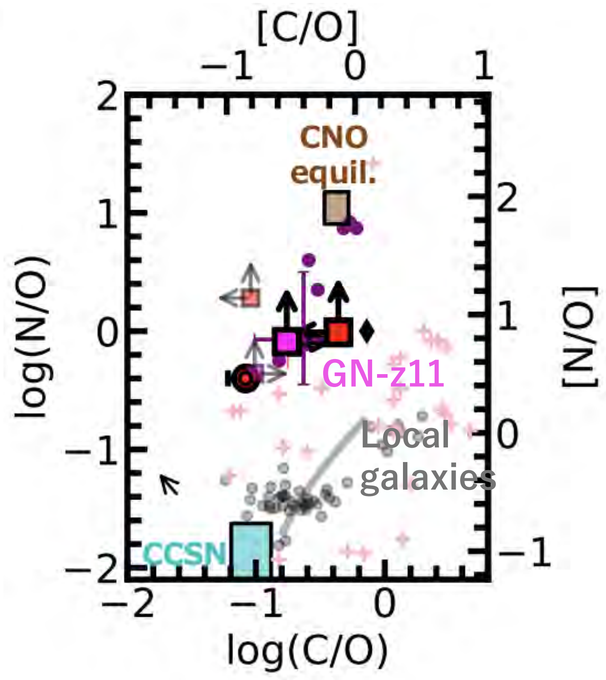


Fig.1: Chemical abundance ratio of GN-z11, local galaxies, CNO-cycle's equilibrium state, and core-collapse supernovae. (Isobe+23)

Introduction: GN-z11 is N/O-enhanced

GN-z11 shows log(N/O)>-0.25, which is higher than local galaxies' values, log(N/O)<-0.8 (Fig. 1).

GN-z11's chemical abundance is biased from the abundance of CCSN's ejecta, toward the abundance produced by the CNO cycle equilibrium state. (Fig. 1)

Introduction: possible origins of high N/O

- Wolf-Rayet stars (WR)
- Supermassive stars (SMS, $>10^4\ \mathrm{M}_\odot$)
- Tidal disruption events (TDE)

By using a one-zone model, Isobe+23 suggested these stellar events can produce GN-z11-like nitrogen-rich abundance (Fig. 2).
⇨Testing SMS pollution by more realistic galaxy simulation is a new approach.

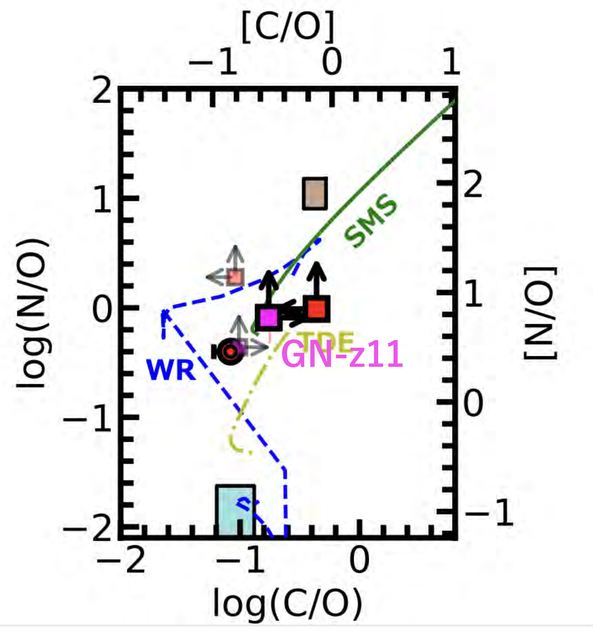


Fig.2: Possible chemical abundance ratio produced by WR, SMS, and TDE. (Isobe+23)

Method ~adding SMS to the simulation~

We used the N-body/SPH code ASURA (Saitoh+09) and the chemical evolution library CELib (Saitoh+17).

We assumed that SMSs are located at the center of globular clusters through runaway collisions (Fujii+24).

We also assumed that (1) the central SMS formed an ionized sphere, (2) the SMS polluted inside the sphere, and (3) we observed the emission lines from the sphere.

The next step is… to estimate the mass of the central SMS and the size of the ionized bubble.

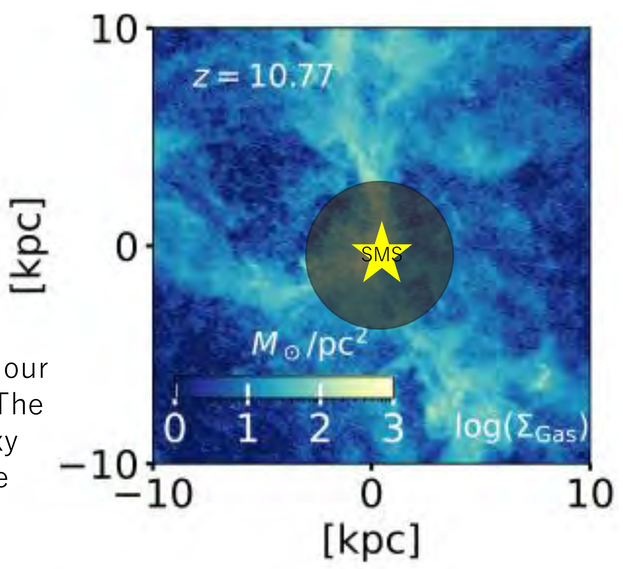


Fig.3: The concept picture of our SMS formation assumption. The SMS was formed at the galaxy center and pollutes inside the Strömgren sphere it made, resulting in emission lines.

Result ~How does the central SMS weigh?~

From Fujii+24, $3-5\ \%$ of a star formation rate (SFR) of the system can be transferred to the SMS mass increase. We found that the SFR around the galaxy center ($<10\ \mathrm{pc}$) is $0.3-3\times10^{1}\ \mathrm{M}_\odot\ \mathrm{yr}^{-1}$. Thus,

Mass increase rate: $3-5\ \%$ of $0.3-3\times10^{1}\ \mathrm{M}_\odot\ \mathrm{yr}^{-1}$⇨ 9.0×10^{-3}–$1.5\ \mathrm{M}_\odot\ \mathrm{yr}^{-1}$.

In contrast, according to Vink+18, the SMS's mass loss follows:
$\log\dot{M} = -9.13 + 2.1\log(M_{\mathrm{SMS}}/\mathrm{M}_\odot) + 0.74\log(Z/Z_\odot)\ [\mathrm{M}_\odot\ \mathrm{yr}^{-1}]$,

where adopted our galaxy's metallicity $Z = 0.1\ Z_\odot$.

SMS reaches its maximum mass when mass increase and mass loss rate are balanced. Under our accretion rate range, 9.0×10^{-3}–$1.5\ \mathrm{M}_\odot\ \mathrm{yr}^{-1}$, our SMS grows to $10^{3-5}\ \mathrm{M}_\odot$ (see Fig. 4).

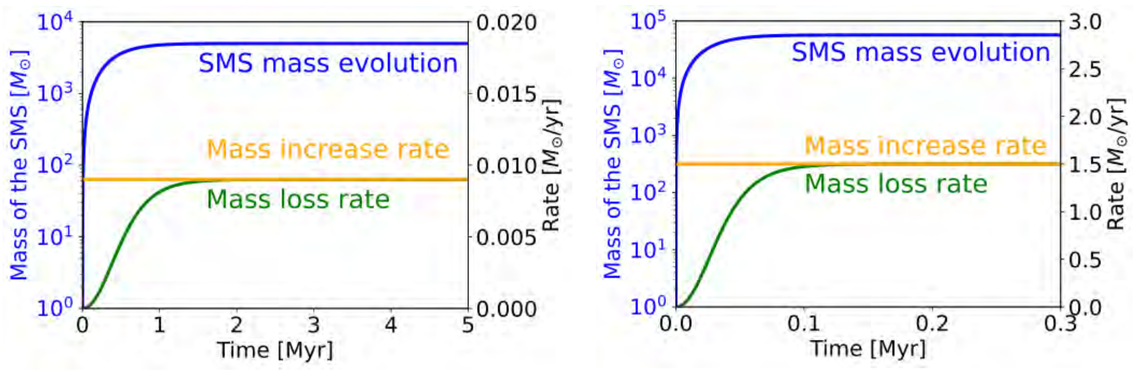
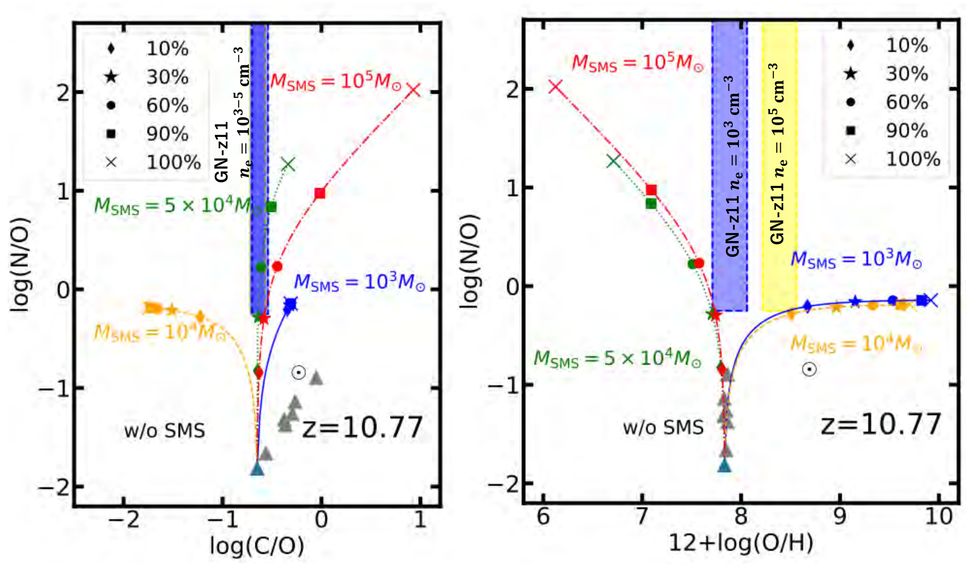
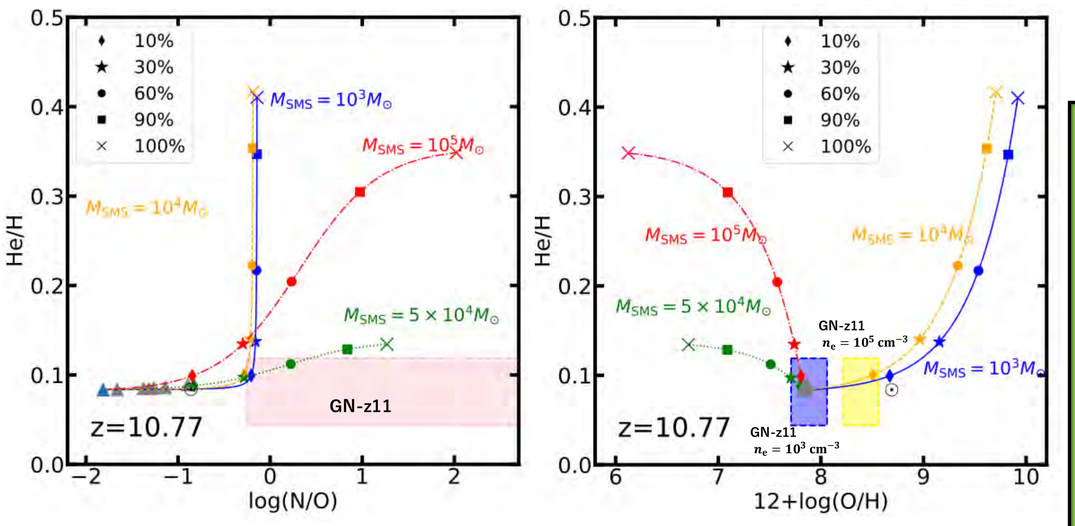


Fig.4: The SMS mass evolution under the constant mass increase rate, $9.0\times10^{-3}\ \mathrm{M}_\odot\ \mathrm{yr}^{-1}$ (left) and $1.5\mathrm{M}_\odot\ \mathrm{yr}^{-1}$(right).

Result ~SMS changes chemical abundance~

Fig.5: The chemical abundance change if SMS ejecta was mixed to our galaxy's gas at z=10.77 (the blue triangle). The grey triangle show our simulated galaxy's abundance between z=10.6 to z=10.77. The blue and yellow shaded region is GN-z11 by Isobe+25 for $n_{\mathrm{e}} = 10^3$ and $10^5\ \mathrm{cm}^{-3}$, respectively.





Nagele+23 calculated ejecta from $10^{3-5}\ \mathrm{M}_\odot$ SMSs. We mixed the ejecta to our result by changing the pollution fraction ($f_{\mathrm{SMS}} = \frac{M_{\mathrm{ej}}}{M_{\mathrm{ej}}+M_{\mathrm{gas}}}$) (Fig. 5). ($M_{\mathrm{ej}}$: Mass of ejecta, M_{gas}: Mass of galactic gas)

To determine the realistic pollution fraction, we assumed the size ionized bubble. We assumed gas number density $10^3, 10^4$ and $10^5\ \mathrm{cm}^{-3}$ and calculated enclosed gas mass and pollution fraction (f_{SMS}) of SMS (Table 1).

Table 1	n_{H} [cm^{-3}]	Strömgren radius [pc]	Enclosed gas mass [$\mathrm{M}_\odot$]	Pollution fraction[%]
Low density model	10^3	16.4	4.59×10^5	0.99
Middle density model	10^4	3.54	4.59×10^4	9.09
High density model	10^5	7.63×10^{-1}	4.59×10^3	50

From Fig. 5, the pollution fraction ~ 30 % is most suitable.
⇨ $10^{4-5}\ \mathrm{cm}^{-3}$ gas density is most desirable.

Summary

- GN-z11 is nitrogen-rich and supermassive stars (SMS) are possible polluters.
- By using galactic simulation, we added SMS pollution to galactic chemical evolution.
- We assumed SMS was formed at the galaxy center, formed the ionized bubble, polluted inside, and emitted emission lines.
- From star formation history, we assumed the central SMS weighed $10^{3-5}\ \mathrm{M}_\odot$. Mixing SMS ejecta with galactic gas by changing a pollution fraction,
- We found that 10—30 % pollution can reproduce GN-z11-like galaxy. This pollution fraction can be realized when SMS formed Strömgren sphere under $10^{4-5}\ \mathrm{cm}^{-3}$ gas density.