THE OHIO STATE UNIVERSITY

JWST High Redshift Galaxies: Chemical Evolution of the Universe

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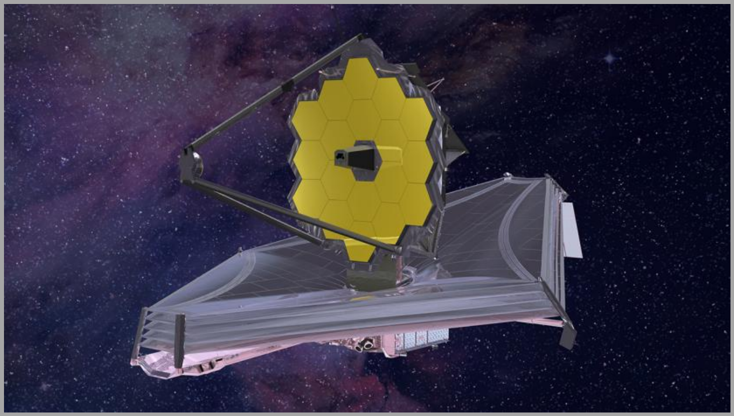
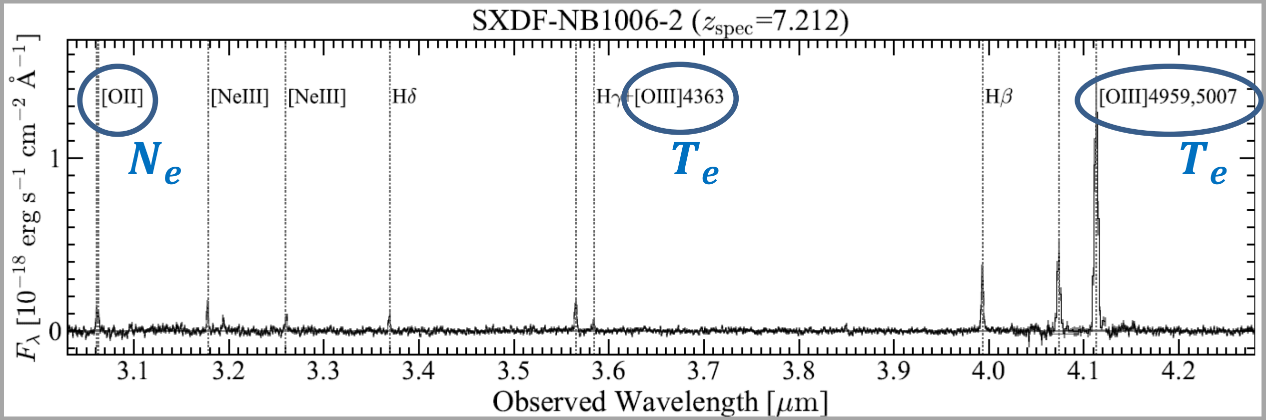
Introduction

- JWST observations reveal that the first stars and galaxies formed much earlier than believed, within about **500 million years** after Big Bang.
- Spectra of metals (elements other than H and He) have been prominently observed from high-z galaxies.
- Oxygen is a good tracer of chemical evolution for early universe. We aim to build an **Oxygen abundance versus redshift relation**.
- Using the nebular **emission line ratios**, we can diagnose **electron temperature T_e**, **electron density N_e**, and **abundance of Oxygen**.
- JWST enables researchers to measure line ratios from high-z galaxies, which were limited by earlier instruments.



JWST (James Webb Space Telescope)
Credit: NASA, ESA, CSA, Northrop Grumman



Spectra of a JWST high redshift galaxy SXDF-NB1006-2
Credit: Harikane et al. 2025

Method
SPECTRA code

- SPECTRA code is a tool that could generate the relation between **line emissivity ratios**, T_e, and N_e for **EIE**(electron impact excitation) in specific elements (OIII, OII, and SII in this research).
- SPECTRA code take the following parameters:
  - Level energies (**E**)
  - Maxwellian averaged EIE collisional strenghth (**Ups**) (Storey et al. 2015)
  - Einstein spontaneous radiative decay coefficient (**A**)

Inputs:

		E:	Ups(for 10^4K):	A:
OIII:	$^1S_0$	3.94E-1		
	Emit 4364Å photon		6.17E-1	1.78E0
	$^1D_2$	1.85E-1		
	Emit 5008Å photon		1.26E0	1.96E-2
	$^3P_2$	2.79E-3		

SPECTRA

Outputs:

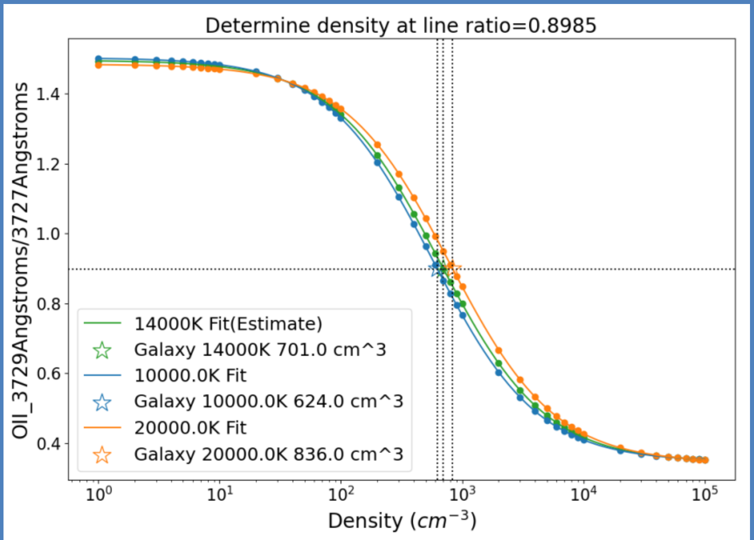
T_e(K)	$N_e(cm^{-3})$	Ratio
10000	10	4076
10000	20	4076
10000	30	4076
10000	40	4076
……		

Method

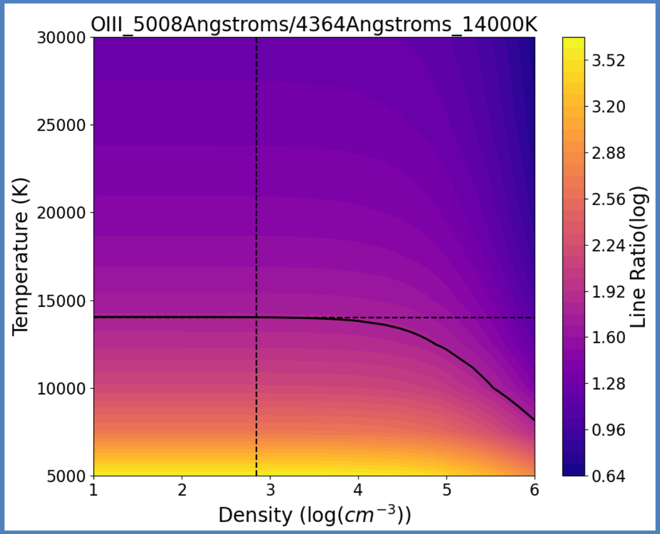
1. Extract line ratios from literatures.

Our example: SXDF-NB1006-2 at z=7.212(Line ratios from Harikane et. al 2025)

2. OII3729/OII3726 ratio and SII6718/SII6732 ratio are sensitive to N_e. We can get N_e by these OII or SII doublets ratio.



3. OIII4364 line is a good target for temperature diagnostic. We can get T_e by OIII5008/4364 ratio and N_e.



Method

4. By the empirical formula from Izotov et. al 2006,

- Using OII3727 doublet flux or OII7320,7330 doublet flux and T_e, N_e we can get OII abundance.
- Using OIII4959,5007 doublet flux and T_e we can get OIII abundance.

These two ionized states are dominant, we can just add them up to get total Oxygen abundance 12+log(O/H).

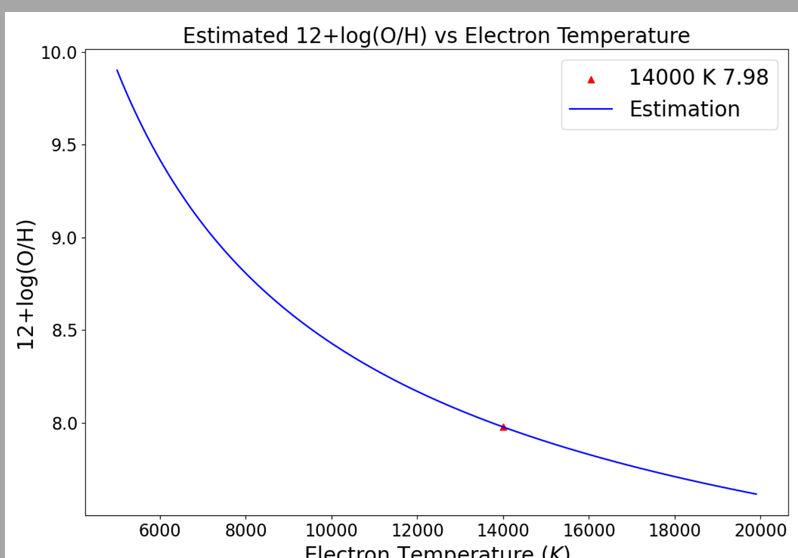
$t = 10^{-4} T_e(\mathrm{O\ III})$ $x = 10^{-4} N_e t^{-0.5}$

$$12 + \log \mathrm{O}^+/\mathrm{H}^+ = \log \frac{\lambda 3727}{\mathrm{H}\beta} + 5.961 + \frac{1.676}{t} - 0.40 \log t - 0.034t + \log(1 + 1.35x), \quad (3)$$

$$12 + \log \mathrm{O}^+/\mathrm{H}^+ = \log \frac{\lambda 7320 + \lambda 7330}{\mathrm{H}\beta} + 6.901 + \frac{2.487}{t} - 0.483 \log t - 0.013t + \log(1 - 3.48x), \quad (4)$$

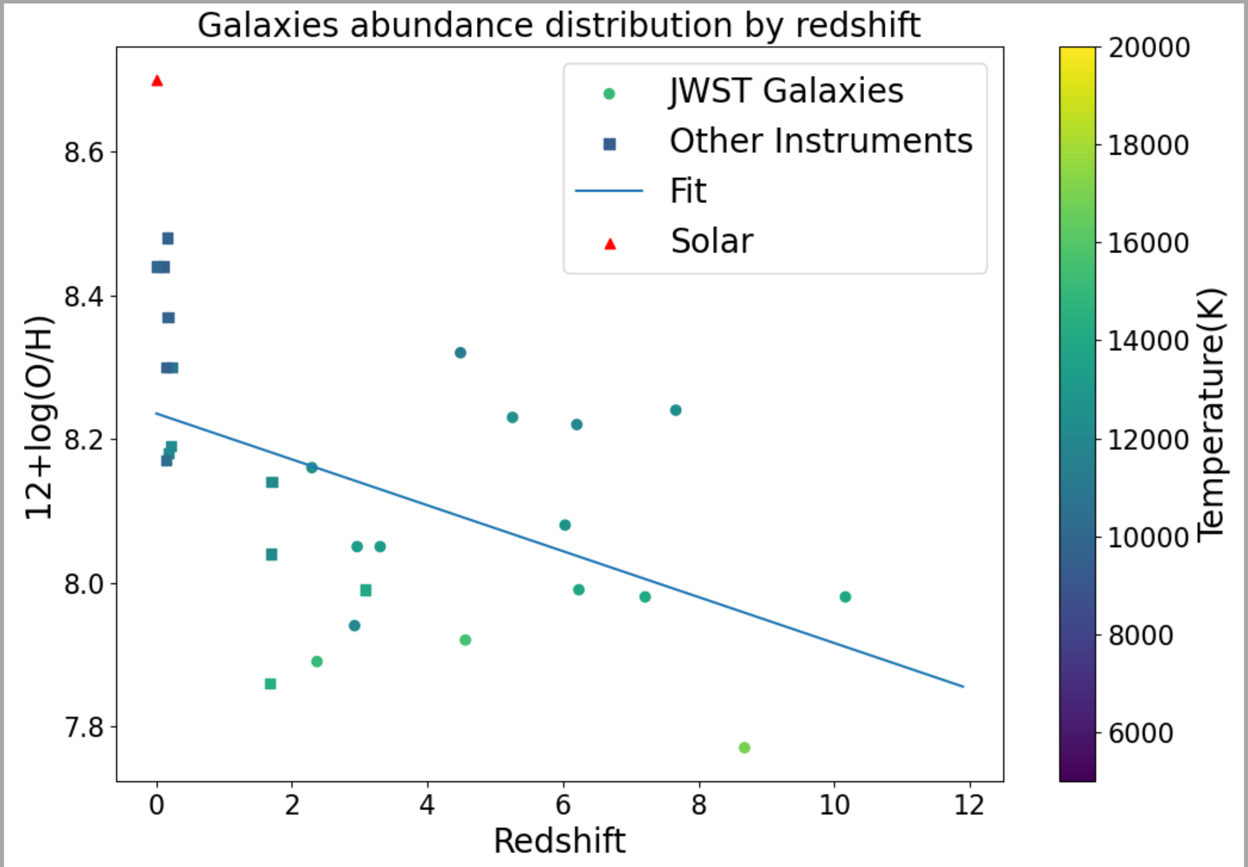
$$12 + \log \mathrm{O}^{2+}/\mathrm{H}^+ = \log \frac{\lambda 4959 + \lambda 5007}{\mathrm{H}\beta} + 6.200 + \frac{1.251}{t} - 0.55 \log t - 0.014t, \quad (5)$$

$$\frac{\mathrm{O}}{\mathrm{H}} = \frac{\mathrm{O}^+}{\mathrm{H}^+} + \frac{\mathrm{O}^{2+}}{\mathrm{H}^+}. \quad (16)$$



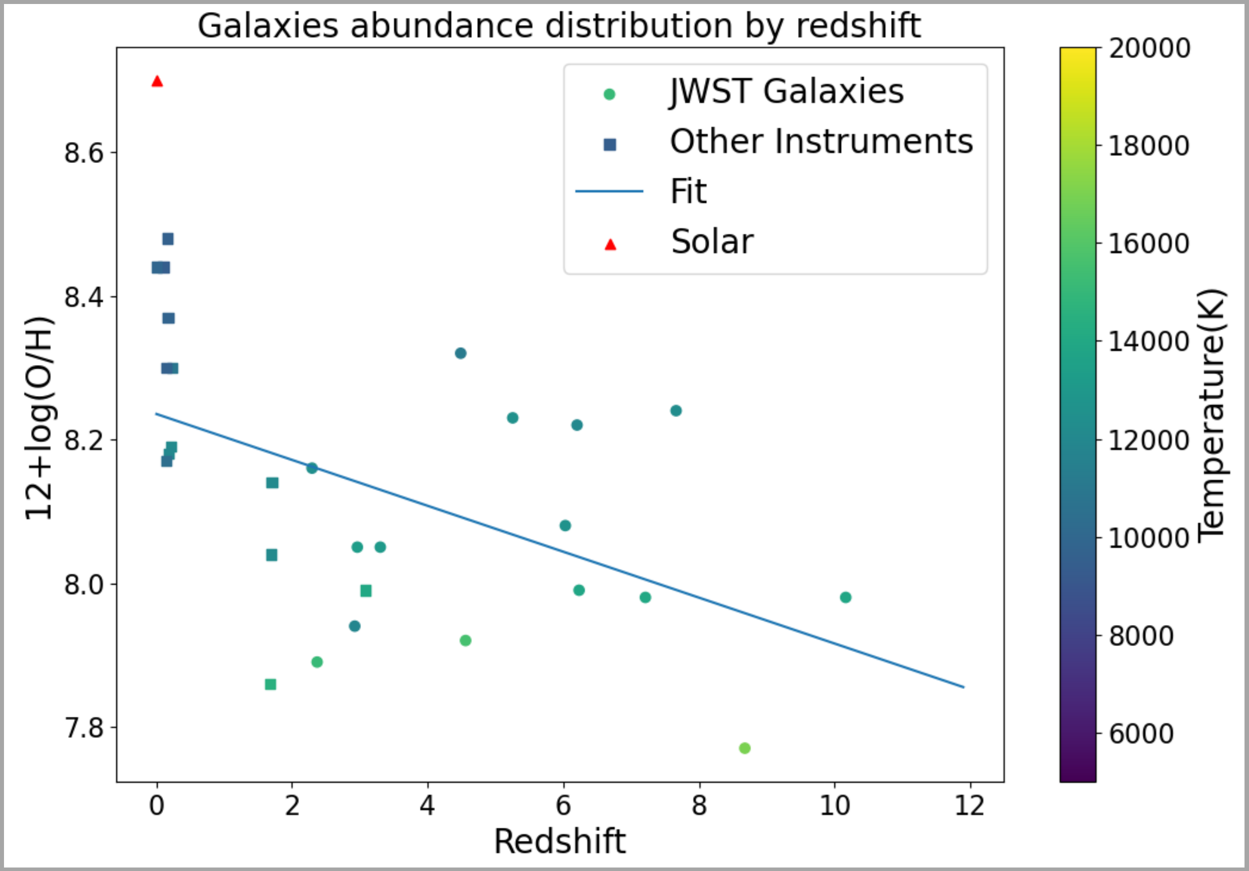
- For SXDF-NB1006-2 at z=7.212, with T_e = 14000K, we get an oxygen abundance 12+log(O/H) = 7.98 (Normalized by taking Hydrogen abundance as 12 in log scale).
- This is close to literature (13900K and 7.99).
- Solar value is 12+log(O/H) = 8.70.
- This means, at ~720 Myr after the Big Bang(12.7 Gyr ago), Oxygen in SXDF-NB1006-2 is just 19% of current universe.

Result – Oxygen Abundance vs Redshift



- If we just adopt a linear fitting, an downward trend of oxygen abundance with increasing redshift is prominent.
- Some outliers might be dominant by AGN.

Conclusion



- **Oxygen abundance evolves from a much lower value in the early universe to solar value as the universe ages.**
- Future Works:
  - Confirm on the line ratio extracted from papers.
  - Analyze on more galaxies.
  - A more precise curve-fitting.

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