The [NII]205 micron and [CII]158 micron line emissions of four star forming Submillimeter Galaxies at z~3-5.7

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Introduction

Studies of galaxies and the warm, neutral gas of the interstellar medium (ISM) in the early universe can be done through submillimeter investigations of far-infrared (FIR) fine structure lines. Fine structure lines of carbon, oxygen, and nitrogen reveal characteristics of the ISM that help us learn about the properties of stars and the gas that forms these stars. [NII]205μm is used as a tracer of C+ gas due to the very similar critical densities to the [CII]158μm, therefore the line ratio of [CII]158/[NII]205 in the ionized gas is constant[3]. As C+ gas is found in both neutral gas in the Photodissociation Region (PDR) and the ionized HII region, the percentage of ionized and neutral gas was computed. We present data for the [NII]205μm and [CII]158μm line emissions, acquired with the Atacama Large Millimeter/Submillimeter Array (ALMA) telescope, to investigate the star forming properties of lensed, submillimeter galaxies at high redshifts between z~3-5.7.

High z Submillimeter Galaxies (SMG's)

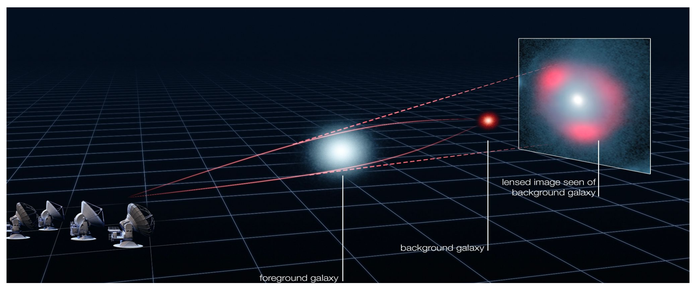


Figure 1: An image on how gravitational lensing distorts the emission areas of galaxies due to any objects that are in the line of sight from the observer to target. Credits: ALMA (ESO/NRAO/NAOJ), L. Calçada (ESO), Y. Hezaveh et al.

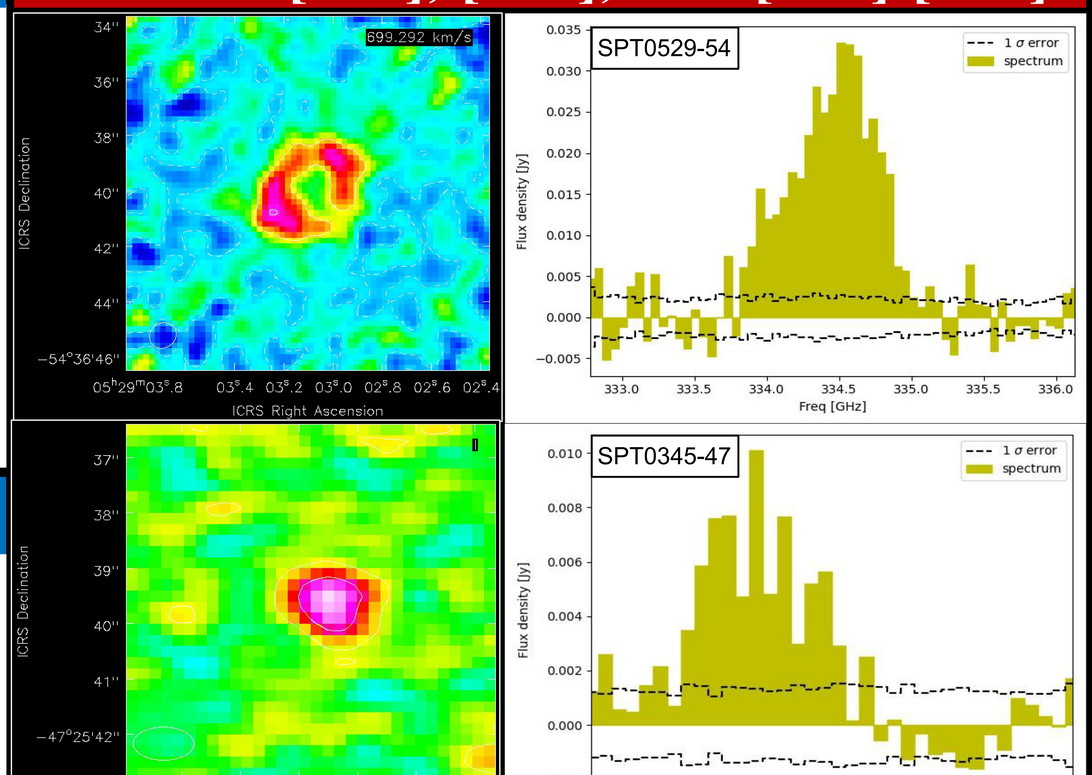
- Very luminous, high redshift galaxies that represent star forming galaxies during the early stages of the Universe of peak star formation.
- Contain very active star forming regions of ionized and neutral gas (C, N, and O) that are most luminous in the submillimeter wavelength.
  - [CII]158 micron is <u>most luminous</u> in these galaxies.
  - [NII]205 micron <u>complements</u> [CII] as both have similar critical densities[1].
- SMG's are often **lensed galaxies**.
  - Lensing magnifies the galaxy and makes it easier to observe.
  - Lensing models created to recreate the galaxy structure.

Submillimeter Interferometry

Figure 2: The Atacama Large Millimeter/Submillimeter Array (ALMA) telescope, (located in Chile) has 50 antennas and can be arranged in many configurations. The telescope operates in the wavelength range between 0.32mm to 3.6mm. Credits: ALMA (ESO/NAOJ/NRAO).

- Multiple antennas can be combined as an interferometer to collect waves of light from sources at large distances away from Earth.
- **Submillimeter interferometry** collects data in the submillimeter wavelength ~ 0.2mm - 1.0mm.
  - Observations done to learn about the chemical abundances that result from star formation which occured in the early universe.
- **ALMA telescope** used to understand the galaxy formation and evolution by observing high redshift galaxies and collecting spectral data from molecular gas and dust.

Results - [NII], [CII], and [CII]/[NII]



- Using CASA, **Moment 0** maps were created.
  - Depict the integrated flux at each pixel.
  - Found the flux density of [NII]205.
- **Spectra** depict the the variations of intensity from a luminous object as the frequency changes.
  - Emission of [NII]205 can be seen in the spectra for each galaxy.
- From the flux values of [NII] and total [CII], the contribution of [CII] in the ionized HII region and [CII] in PDR's was calculated.
- <u>More [CII] neutral gas than ionized gas in each galaxy.</u>
- Between 65% - 80% of [CII] comes from PDR's.
- Values shown in Table 1.

Name	z	SdV_NII [Jy km/s]	SdV_NII_lit [Jy km/s]	SdV_CII [Jy km/s]	SdV_CII_lit [Jy km/s]	SdV_CII_C20 [Jy km/s] [1]	SdV_CII_PDR [Jy km/s]	% of neutral CII in PDR
SPT0529-54	3.369	19.8 ± 0.96	13.6 ± 1.7	----------	217 ± 18	64.6 ± 7.7	163.7 ± 19.2	75%
SPT0113-46	4.232	9.9 ± 0.7	9.1 ± 0.5	89.9 ± 4.4	91 ± 19	49.7 ± 12.8	63.4 ± 5.6	70.5%
SPT0345-47	4.296	3.4 ± 0.6	4.4 ± 0.7	53.2 ± 1.2	63.7 ± 8.3	15.4 ± 4.3	43.9 ± 2.2	82.6%
SPT2146-55	4.567	5.2 ± 0.3	9.3 ± 0.7	----------	39 ± 9	11.3 ± 5.8	25.1 ± 9.2	64.5%

Table 1: The literature values for [NII] were found from Cunningham+20. The values for [CII] were found from Gullberg+15 and Rizzo+21. For the flux of the total amount of [CII], the values for SPT0113-46 and SPT0345-47 were found through reduction of ALMA data. For SPT0529-54 and SPT2146-55, the values from the literature sources were used in calculations. It can be seen that the flux values of [CII] from Cunningham+20 are different compared to the Gullberg+15 and Rizzo+21 values, along with the values found through data reduction. It was also found that neutral [CII] gas is more abundant in high redshift SMG's than ionized [CII] gas.

Discussion and Conclusion

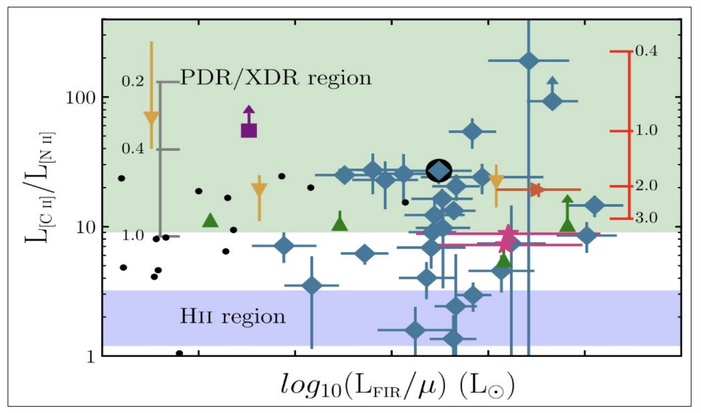


Figure 3: From the Cunningham+20 paper[2]. The line ratios of [CII]/[NII] are plotted. Any line ratios that are above 10 mean that the ISM condition is consistent with the PDR region. For these galaxies, the line ratio values found in the Cunningham+20 paper are lower than values that we found and from other literature.

- From flux values of [CII] and [NII] in Table 2, the line ratios were computed.
  - <u>Line ratios ~ 10 or above</u> were found and compared to literature values.
    - Both values, along with the literature references are found in Table 2.
  - Cunningham+20 found line ratios less than 10 for these four galaxies (seen in Table 2).
    - We do not know why these values vary compared to the ones we found and from others literature sources.
- A higher line ratio means that there is more neutral [CII] gas from PDR's than ionized [CII] from the HII regions.
  - The line ratios found in this research are higher than 10, proving the above statement is true.
  - Values we found fall in the PDR region part of Figure 3, which agree with the results from Table 1.
- In conclusion, <u>there is a higher percentage of [CII] in the PDR than in the HII regions</u> of these submillimeter galaxies.

Name	[CII]/[NII]205	[CII]/[NII]_lit	CII_reference	[CII]/[NII]_C20 [2]
SPT0529-54	14.2	20.7	Gullberg+15	4.8
SPT0113-46	11.8	12.9	Rizzo+21	5.5
SPT0345-47	20.1	18.7	Rizzo+21	3.5
SPT2146-55	9.8	5.4	Gullberg+15 Rizzo+21	1.2

Table 2: The line ratio of total [CII]/[NII] are shown above, along with the literature values from the references stated in the fourth column. Both values are very similar. Cunningham+20 values in the fifth column.

References

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