X39a JWST & ALMA Joint Analysis to Understand the ISM Properties of Early Galaxies

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We present a JWST and ALMA detailed study of the ISM properties of high-redshift galaxies. Our JWST/NIRSpec IFU spectroscopy targeting three galaxies at $z = 6 - 7$ detects key rest-frame optical emission lines, allowing us to derive [OII]$\lambda\lambda$3726,3729-based electron densities of $n_{\rm e,optical} \sim 1000$ cm^{-3} on average. New ALMA Band 9/10 observations detect the [OIII]52μm line in one galaxy but do not in the others, resulting in FIR-based densities of $n_{\rm e,FIR} \lesssim 500$ cm^{-3} from the [OIII]52μm/[OIII]88μm ratios, systematically lower than the optical [OII]-based measurements. These low FIR-based densities are comparable to those at both $z \sim 0$ and $z > 6$ in the literature, suggesting little evolution up to $z \sim 14$, in contrast to the increasing trend of optical-based densities with redshift. By conducting a JWST and ALMA joint analysis, we demonstrate that the direct-$T_{\rm e}$ method can sometimes significantly underestimate metallicities up to 0.8 dex due to the presence of the low-density gas not fully traced by optical lines alone, highlighting the importance of combining optical and FIR lines to accurately determine gas-phase metallicities in the early universe.