The Dense Gas History of the Universe

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One of the great legacies of cosmological deep fields, as exemplified by those with the Hubble Space Telescope, is a detailed delineation of the rise and fall of the cosmic star formation rate density, starting with the first galaxies within a few hundred Myr of the Big Bang ($z \sim 10$), through the peak epoch of star formation at $z \sim 2$, to the present [1]. However, these observations reveal only half of the process: the stars. Radio telescopes operating in the 0.1cm to 1cm regime, have opened a new window on the 'missing-half' of galaxy formation: the cold molecular gas. Such gas represents the immediate fuel for star formation in galaxies. Deep observations in this wavelength range with ALMA, the JVLA, and NOEMA, have made the first measurements of the cold gas content of the galaxies to large look-back times, principally through observation of rotational transitions of CO [eg. 2, 3].

I will focus on results from the ASPECS survey with ALMA. ASPECS is a deep, wide band, volumetric search for molecular gas out to $z \sim 4$. The results indicate a rise and fall of the cosmic molecular gas density that parallels the star formation history. The data confirms a fundamental change in the gas-to-stellar mass ratio with look-back time. In nearby star forming galaxies, this ratio is ~ 0.1. The ratio increases by an order of magnitude, to roughly unity, for galaxies during the peak epoch of cosmic star formation ($z \geq 2$) [4]. We are now in a position to consider the complete history of the baryon content of galaxies back to the first galaxies, which I will summarize [5].

Unfortunately, these observations make extreme demands on existing facilities, requiring tens to hundreds of hours per galaxy to determine detailed physical properties, such as the gas distribution and dynamics. We are approaching the limit of what is possible with existing facilities. I will close with a brief summary of the capabilities of the Next Generation VLA to explore, at ten times the sensitivity and resolution, the detailed physics of the interstellar medium during the peak epoch of cosmic star formation, and beyond [6].

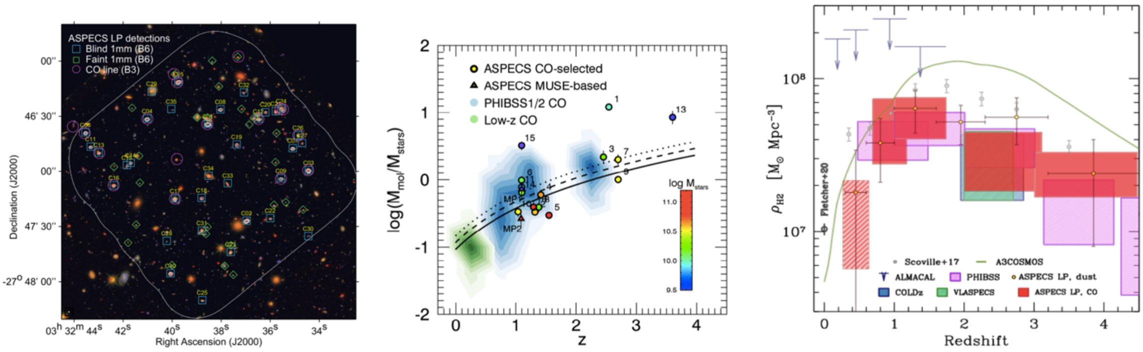

Figure 1. Left: HST image of the ASPECS deep field, with CO detected sources (22 galaxies), and dust continuum detected sources (34 galaxies), identified [7, 8]. Center: evolution of the ratio of molecular gas to stellar mass ratio in star forming galaxies. Right: the evolution of the cosmic density of molecular gas [4].

References

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