# ngVLA Key Science Goal 3: Charting the Assembly, Structure and Evolution of Galaxies Over Cosmic Time

ngvla
Next Generation Very Large Array

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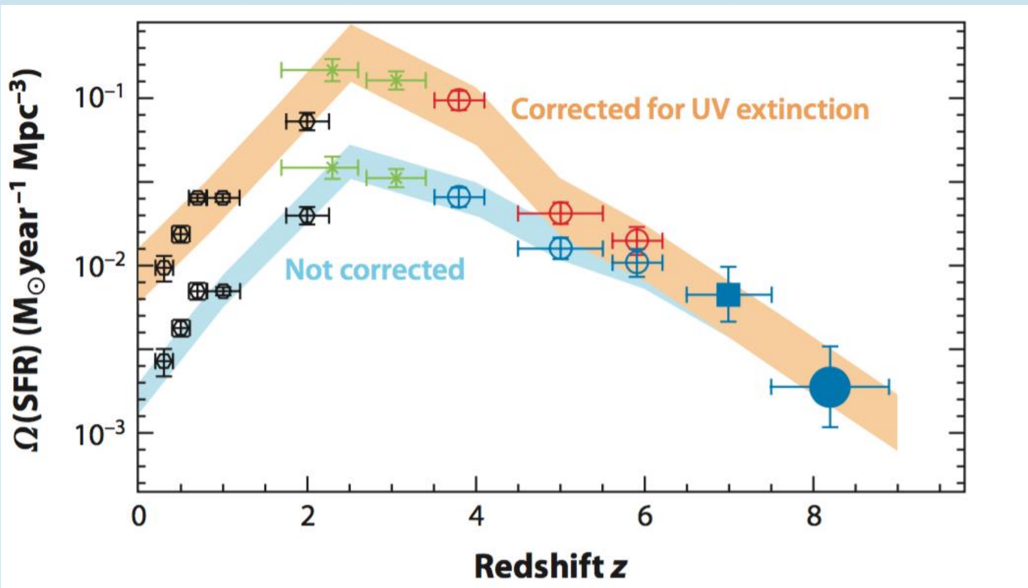
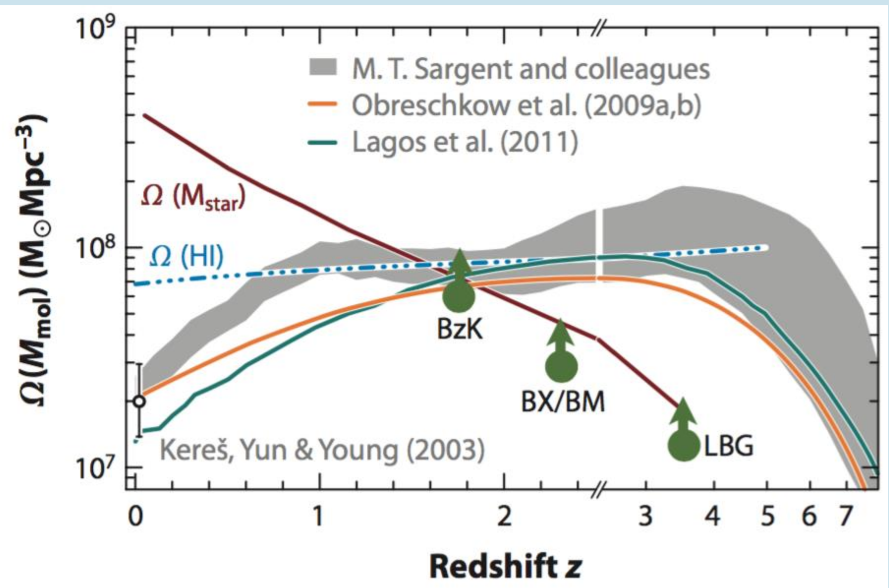
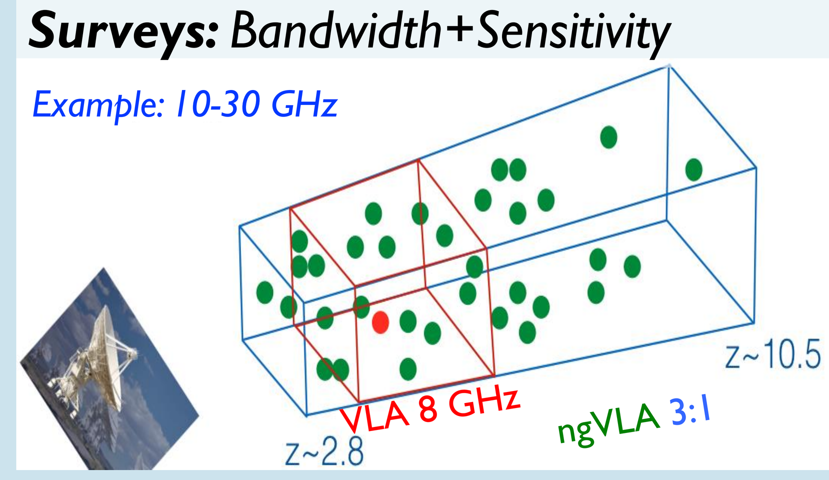
The Next Generation Very Large Array (ngVLA) will fundamentally advance our understanding of the formation processes that lead to the assembly of galaxies throughout cosmic history. The combination of large bandwidth with unprecedented sensitivity to the critical low-level CO lines over virtually the entire redshift range will open up the opportunity to conduct large-scale, deep cold molecular gas surveys from the present epoch back to the first billion years, mapping the fuel for star formation in galaxies over substantial cosmic volumes. Imaging of the sub-kiloparsec scale distribution and kinematic structure of molecular gas in both normal main-sequence galaxies and large starbursts back to early cosmic epochs will reveal the physical processes responsible for star formation and black hole growth in galaxies over a broad range in redshifts. In the nearby universe, the ngVLA has the capability to survey the structure of the cold, star-forming interstellar medium at parsec-resolution out to the Virgo cluster. A range of molecular tracers will be accessible to map the motion, distribution, and physical and chemical state of the gas as it flows in from the outer disk, assembles into clouds, and experiences feedback due to star formation or accretion into central super-massive black holes. This will crucially complement studies of the neutral gas, star formation and stellar mass histories with large low-frequency arrays, the Large UV/Optical/Infrared Surveyor, and the Origins Space Telescope, providing the means to obtain a comprehensive picture of galaxy evolution through cosmic times.

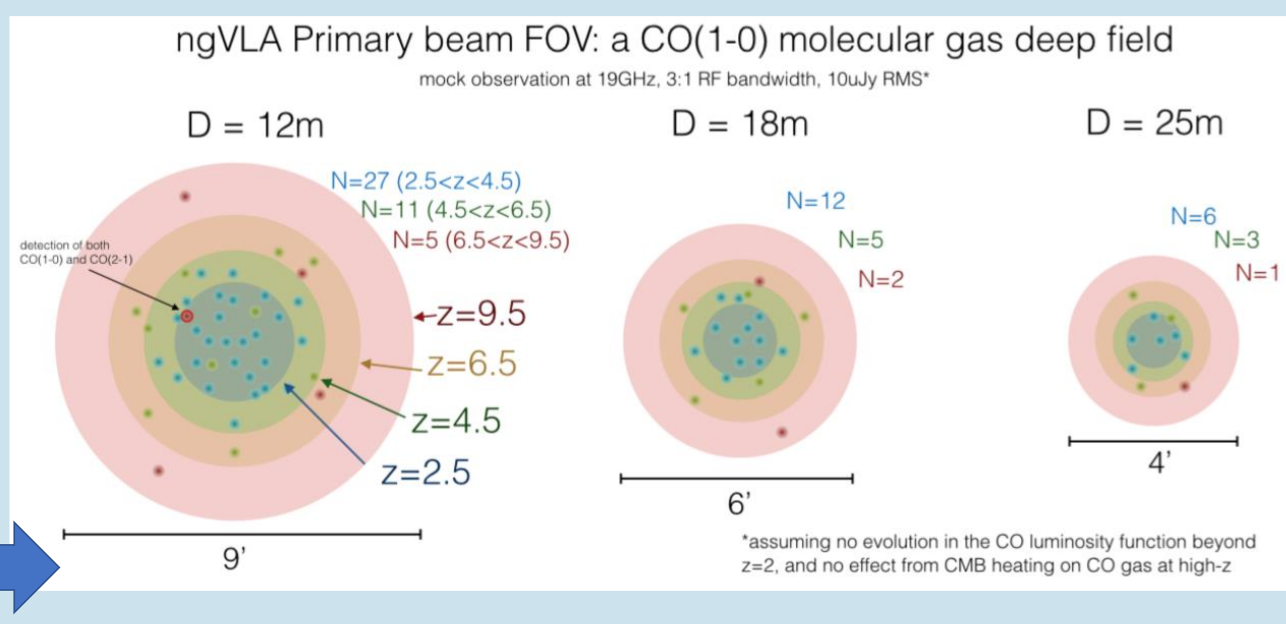


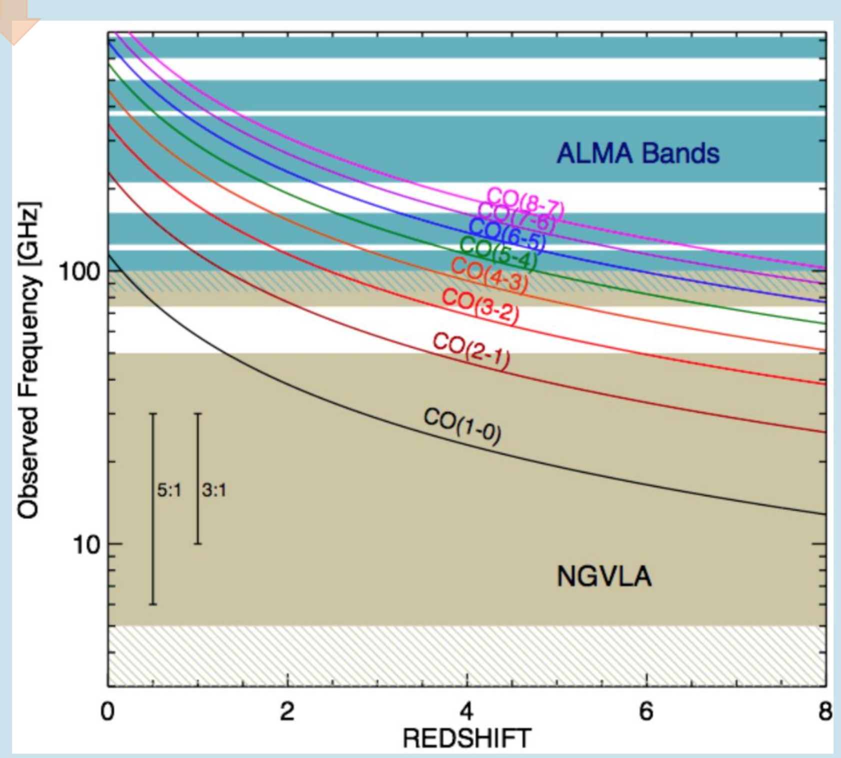

**Star Formation History of the Universe** (SFHU; *left*) and **Cold Gas History of the Universe** (CGHU; *right;* Carilli & Walter 2013). The SFHU has been quantified very well over the past two decades, but the origin of its shape remains subject to debate. The CGHU will be the most critical measurement to address this question in the coming decades, because the cold molecular interstellar gas in galaxies drives their star formation.

## *ngVLA "Molecular Deep Field" Surveys: Bandwidth+Sensitivity*

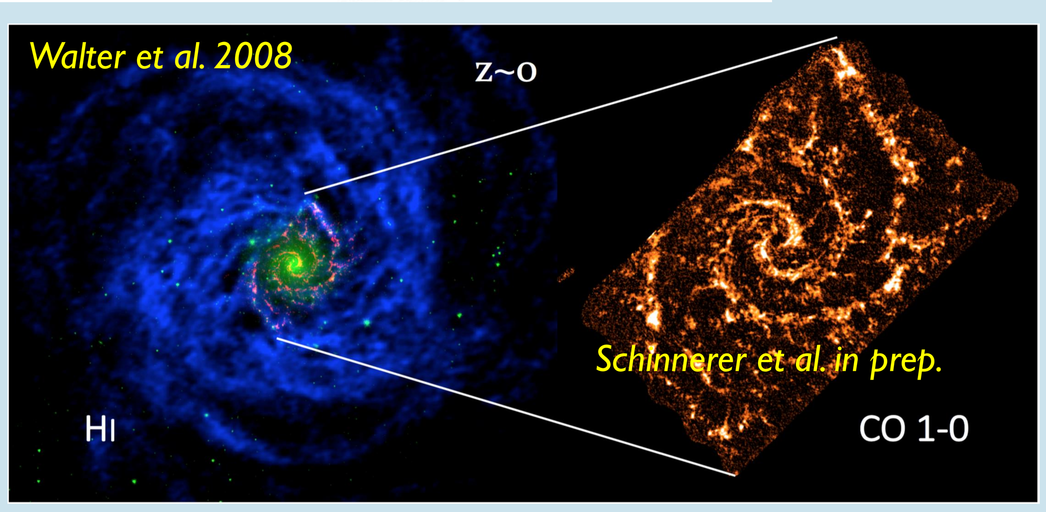


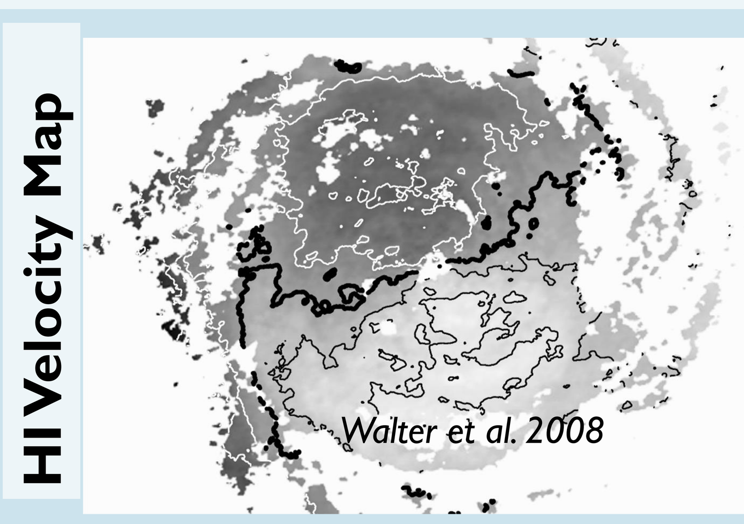




Due to its large bandwidth and collecting area, the **ngVLA** will carry out "molecular deep field" surveys to measure the CGHU at vastly increased efficiency, probing larger cosmic volumes (i.e., redshift ranges; *left*) down to an order of magnitude lower galaxy CO luminosities. The "field-of-view" (FoV; primary beam size) of an antenna scales with frequency (i.e., redshift) and antenna diameter *D*. As such, at a fixed total array collecting area, smaller antennas yield *higher survey efficiencies*, and thus, higher numbers of detections *N* per FoV due to greater volumes probed. Its large bandwidth will give access to several CO lines at the same time, constraining the *gas excitation*.

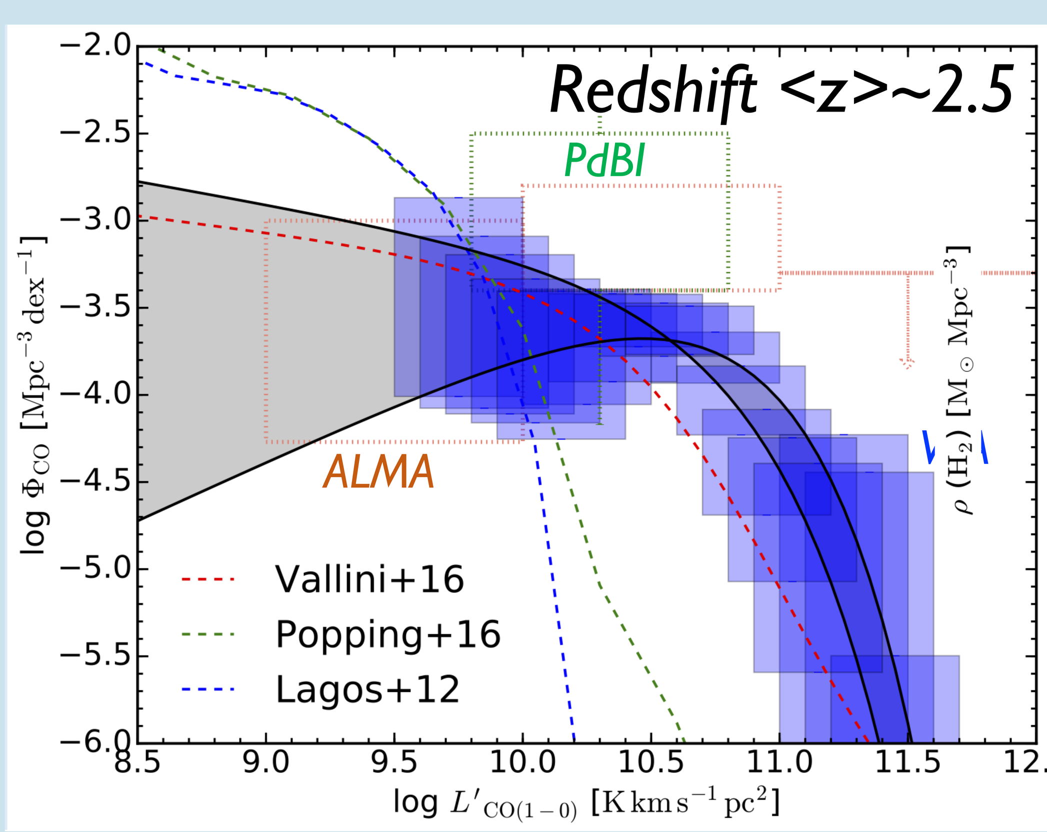


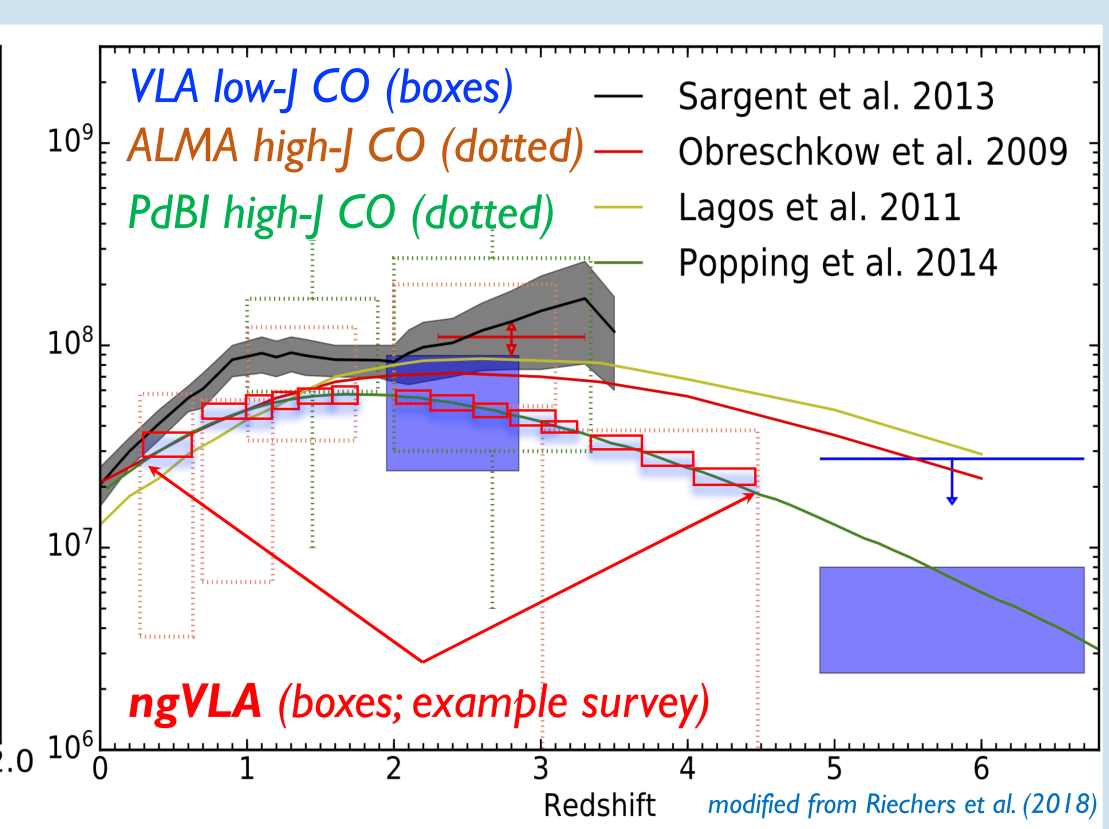

Multiple CO lines will be accessible to the **ngVLA** over virtually the entire redshift range, and its large bandwidth will instantaneously cover substantial cosmic volumes. Access to the fundamental CO(*J*=1-0) rotational transition at most *z* will be critical to convert CO luminosities to **molecular gas masses**, free of the uncertainties inherent to measurements in higher-*J* CO lines due to gas excitation.




State-of-the-art VLA+ALMA ISM maps of a nearby galaxy. The **ngVLA** will provide large galaxy samples with an order of magnitude more sensitive high-resolution imaging of the physical and chemical state, structure and dynamics of the cold ISM in HI, CO, dense gas tracers, and isotopologues.




To-date best observational constraints on the CO luminosity function at high redshift (*left*) and the integrated CGHU from the implied molecular gas masses (*right*) from the PdBI Hubble Deep Field (Decarli et al. 2014), ALMA **ASPECS**-Pilot Hubble Ultra Deep Field (Walter et al. 2016), and VLA **COLDz** COSMOS+GOODS-N (Riechers et al. 2018) surveys (*boxes and black curves*), alongside model predictions (*lines*). The **ngVLA** will enable an accurate measurement at all epochs, paralleling precise studies of the SFHU, stellar mass buildup and black hole growth in galaxies across cosmic history with the best future facilities across complementary wavelength regimes.

***References:*** *Carilli & Walter 2013, ARA&A, 51, 105; Decarli et al. 2014, ApJ, 782, 78; Riechers et al. 2018, ApJ (arXiv:1808.04371); Walter et al. 2008, AJ, 136, 2563; Walter et al. 2016, ApJ, 833, 67*

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