



NATIONAL RADIO ASTRONOMY OBSERVATORY



# The Cold Side of Galaxy Formation: Dense Gas Through Cosmic Time

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*AAS Special Session: The Very Large Array Today and Tomorrow:  
First Molecules to Life on Exoplanets*

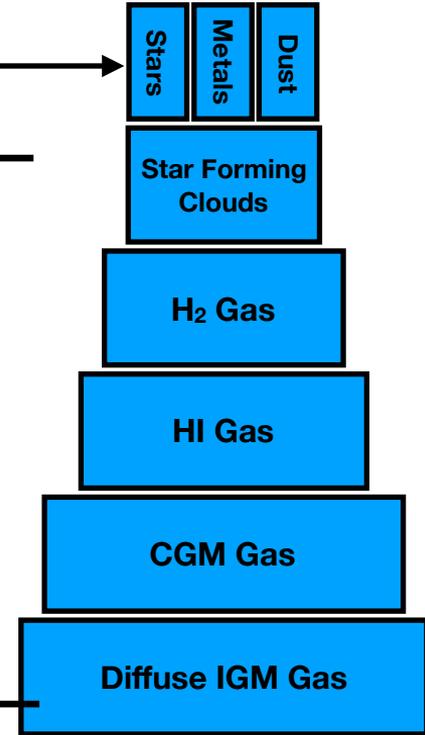
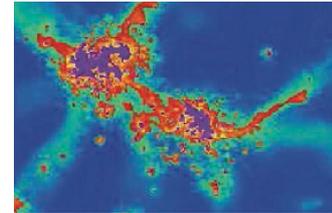
January 11, 2018





# Importance of Cold Gas for Galaxy Evolution

- Cold gas is the “fuel” for star formation and black hole growth at all cosmic epochs
- Gas abundance and distribution controls galaxy growth through star formation
- The ngVLA will probe different phases of the cold and dense gas and their physical properties throughout cosmic history

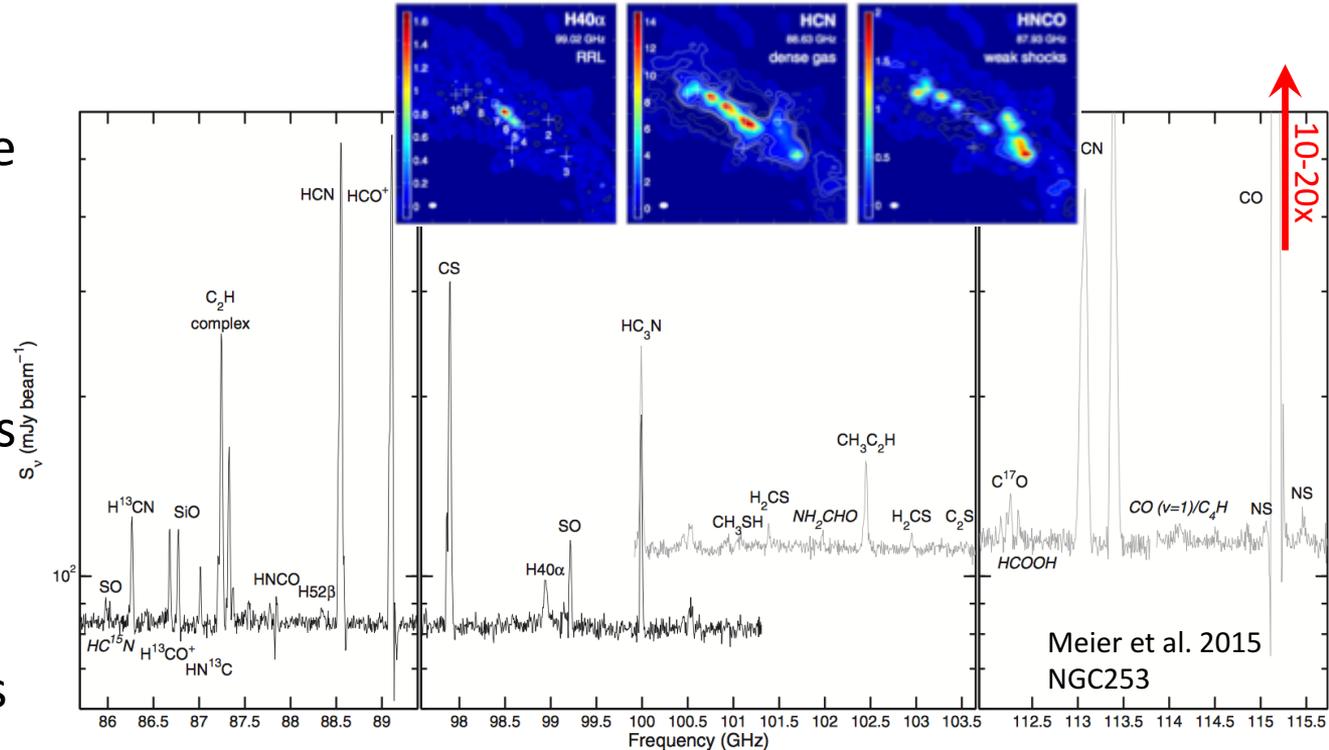


# Galaxy Ecosystems: Thermal Emission on all Scales

- CO by far the brightest, but other species required to probe dense cores, energetic processes, chemistry,...

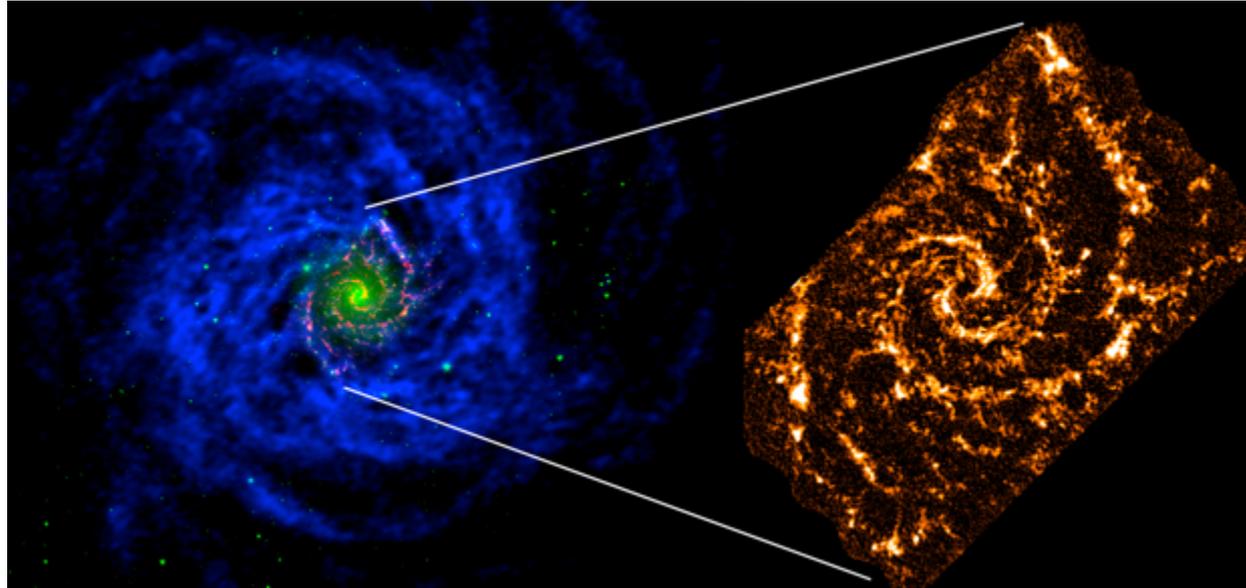
- *Thermal* emission over large range in size scales

→ ngVLA sensitivity *and* interferometer baseline coverage key for progress



# How do Galaxies Produce New Generations of Stars?

- ngVLA will study extended atomic reservoirs *and* large samples of GMC populations across galaxy types to large distances
- Unique windows into the physical and chemical properties of accretion, transport, phase change, and excretion processes



NGC 628: THINGS HI (12", blue), PHANGS ALMA CO (1", red), IRAC 4.5 um (green)

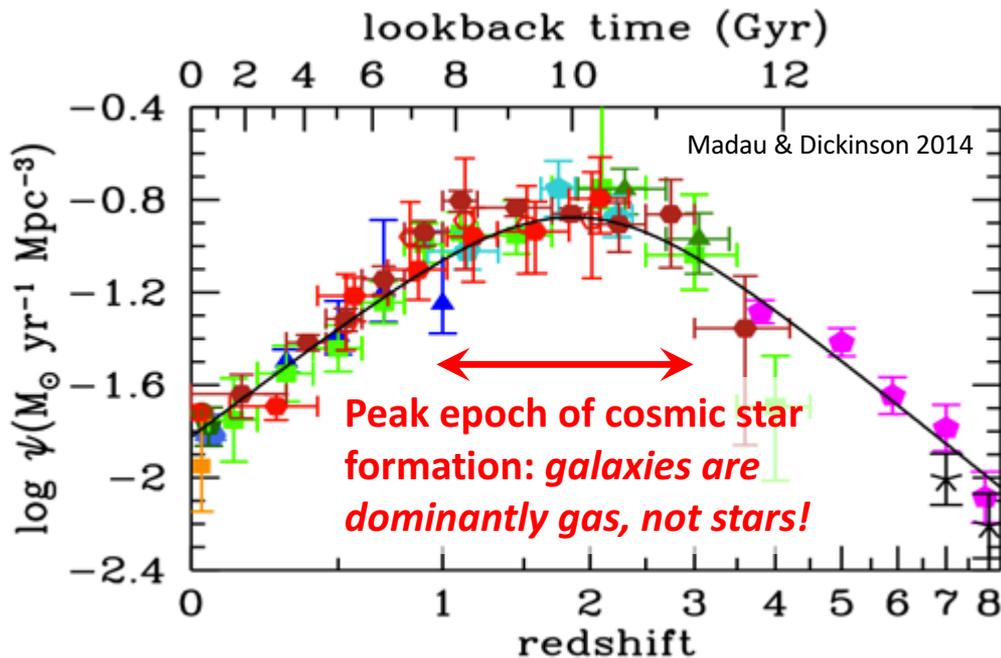


# Gas in Galaxy Assembly Through Cosmic Time

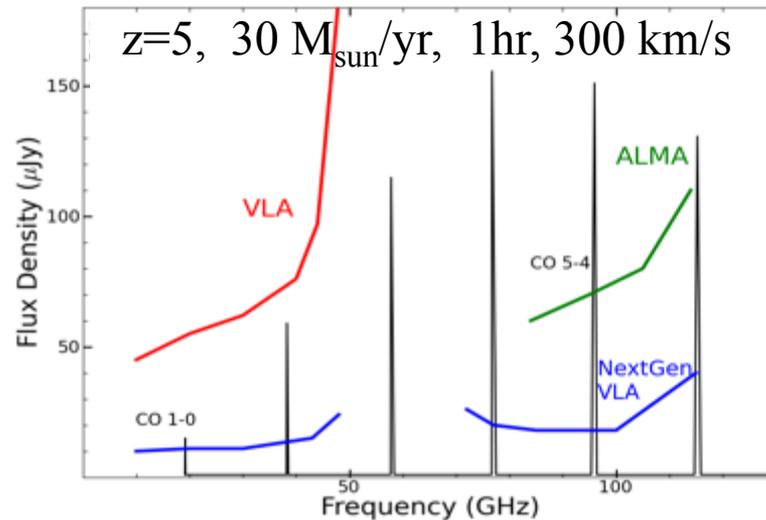
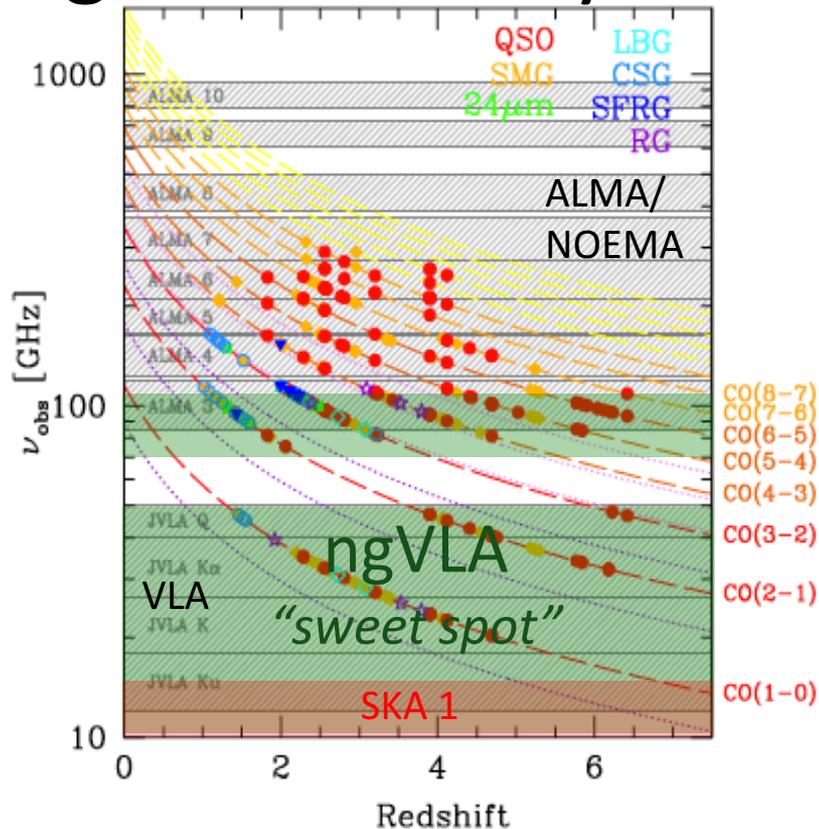


*What "causes" the Star Formation History of the Universe?*

*ngVLA large-scale surveys and routine 100-pc resolution mapping of cold gas in galaxies at high redshift will be critical complement to LUVOIR, JWST, OST, ELTs, ALMA*



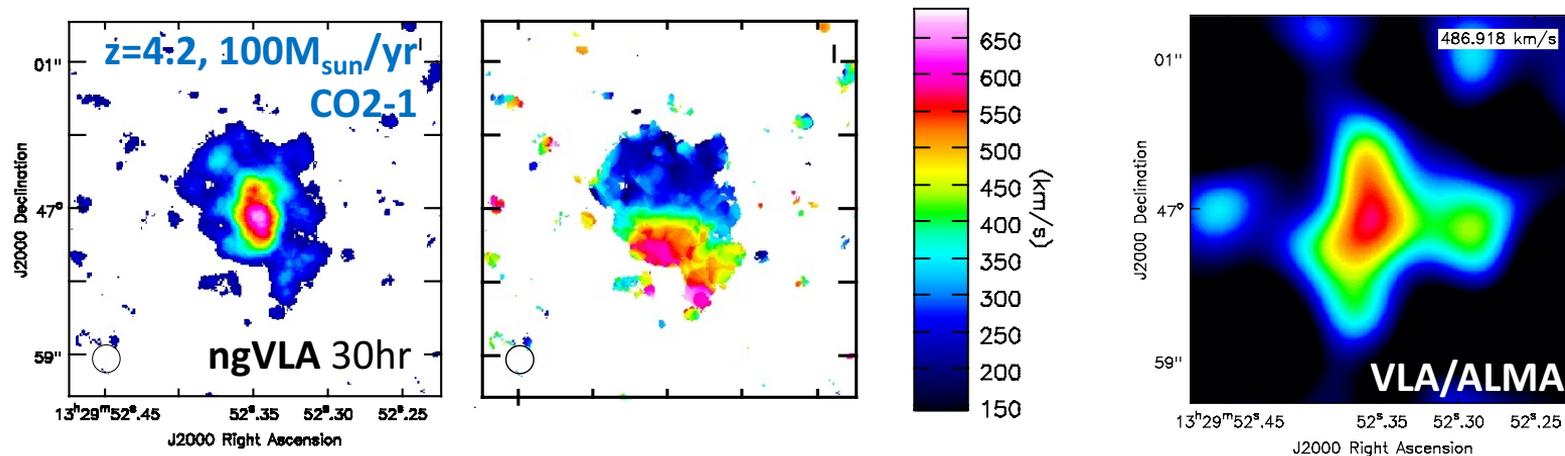
# ngVLA + Galaxy Evolution: Parameter Space



- **Frequency range:** ideal to study dominant molecular gas tracers
- **10x Sensitivity:** detect star forming disk (“main sequence”) galaxies in ~1hr



# Imaging the Fuel for Star Formation During the Epoch of Galaxy Assembly



- *1.0 kpc (0.15" @z=4.2) resolution ngVLA simulation*
- *Sensitivity: few 10<sup>8</sup> M<sub>sun</sub> of cold gas in 30hr (z=2-4)*
- *Detailed imaging of gas dynamics in "normal" disk galaxies*

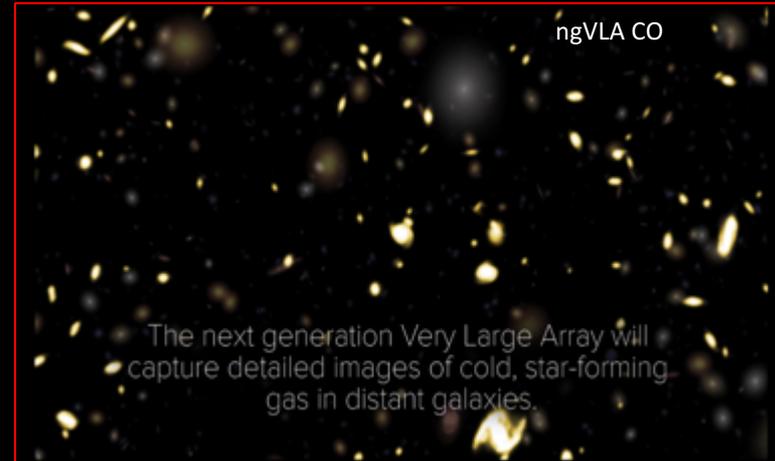


# ngVLA revolution!

10x sensitivity + large bandwidth=> 50 to 100-fold increase in CO-discovered galaxies per hour:

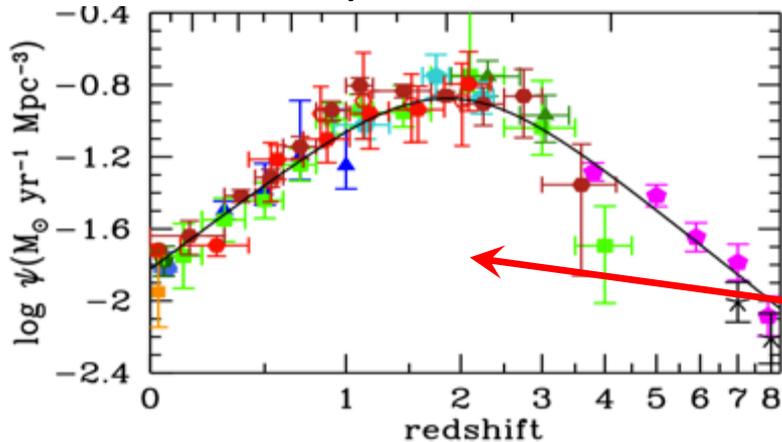
- JVLA ~ 1/hr,  $M_{\text{gas}} > 10^{10} M_{\text{sun}}$
- ngVLA ~ 100/hr,  $M_{\text{gas}} > 2 \times 10^9 M_{\text{sun}}$

*Galaxy counts in CO ~ deepest optical fields, with redshifts (3D)!*

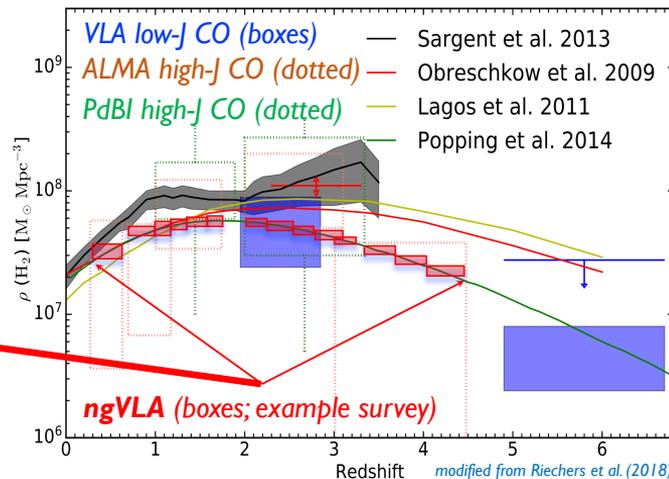
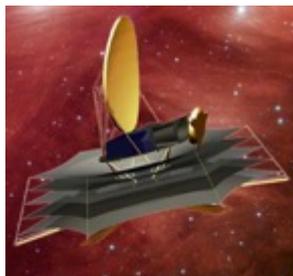
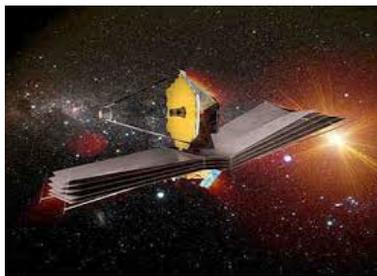


# Next-Gen Synergy: Cosmic Conversion of Gas to Stars

“A Precision Era in Galaxy Formation”



JWST/ELT/OST: stars, star formation, dust



ngVLA: cold gas fueling cosmic star formation



# Summary

The **ngVLA** will:

- reveal how gas is accreted onto galaxies, and the *processes that regulate galaxy growth* through cosmic history
- carry out *large cosmic volume surveys in cold gas* at virtually an order of magnitude lower gas masses, in the critical low-*J* CO lines, measuring the *cold gas history of the universe*
- Routinely *image the star formation reservoirs and gas dynamics down to sub-kpc scales* in galaxies back to the first billion years of cosmic time

