*ngVLA Science Use Case # 1:*

**Mapping High-z CO Gas**

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**I. Science Goal(s)***: Briefly (in a sentence or two) summarize the key science goal(s) for this science case.*

The goal of this science case is to map CO(1-0) and the nearby HCN(1-0) and HCO+ (1-0) lines in two galaxies at z=2.5 on ~kpc scales to map the distribution and dynamics of the total cold molecular gas as well as the dense, UV-shielded gas. Line-free channels will be used to measure the radio continuum to look at the distribution of star formation relative to the gas. The line-to-continuum will provide maps of the star formation efficiencies throughout the galaxy disks.

**II. Scientific Rationale**

**(A) Scientific Importance** *: Provide a brief discussion on the scientific importance for this science case.*

To understand the distribution of molecular gas in typical galaxies when star formation activity was an order of magnitude more rapid than today. Galaxy evolution models currently lack.. ***ETC…***

**(B) Measurements Required***: Provide a description of the necessary measurements to be carried out by the ngVLA to adequately address this science case. Please coordinate these measurements with the Science Requirements table in Section III.*

Deep, high-resolution imaging at the observed frequency for CO (1-0; 115.2712 GHz), HCO+ (1-0; 89.1885 GHz), and HCN (1-0; 88.6318GHz) at z~2.5 for two galaxies. We require a spectral resolution of ~30km/s to resolve the lines, and a total instantaneous bandwidth of 1000km/s to conservatively cover the full velocity range (in case of outflows). We require a sensitivity of ~10uJy/bm per 30 km/s channel for a 0.1” beam to detect and resolve molecular gas structures having mases of a ~10^8 Msun on ~kpc scales. We will use the line-free channels to measure the rest-frame continuum emission near ~80-90GHz, to provide a map of unobscurred star formation. We additionally require sensitivity on ~5” scales to ensure that we are not resolving out a significant amount of extended emission. ***ETC….***

**(C) Uniqueness to ngVLA Capabilities (e.g., frequency coverage, resolution, etc.)***: Is this science case uniquely addressed by the ngVLA? Can other facilities address this science and reach the same conclusion?*

The ngVLA is the only observatory in the world that both has the necessary frequency coverage, angular resolution, and sentitivity to make the proposed measurement. While it is possible to use high-resolution, long-wavelength dust continuum observations with ALMA to infer the total molecular gas contend of high-z systems, the ngVLA is able to both map the total molecular gas reservoir (CO 1-0) and dense, UV-shielded components independently to***… ETC….***

**(D) Longevity/Durability: with respect to existing and planned (>2025) facilities***: Describe potential synergies/complementarities between this ngVLA science case and those from future facilities at all wavelengths (e.g., JWST, ALMA, WFIRST, SKA, TMT/E-ELT, LUVOIR, OST, HABEX, etc. ).*

Such observations will critically complement those made by upcoming OIR surveys made by JWST, WFIRST and ELTs, which are sensitivities to the stellar continuum (mass) of high-z galaxies, and will have enough resolution to map out the distribution of stars to compare with the distribution of molecular gas (the fuel for star formation). Moving forward, there are no planned facilities that will be able to supersede the observations carried out with the ngVLA***. ETC …***

**III. Science Requirements Tables**

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| **(A) ‘TARGETS’ OF OBSERVATIONS** |
| Type of observation(what defines a ‘target’) | X | Individual pointings per object |
|  | Individual fields-of-view with multiple objects |
|  | Mosaics of multiple fields of view |
|  | Non-imaging pointings |
| Number of targets | 2 |
| Position range of targets (RA/Dec.) | RA: All ; Dec: >-25deg.  |
| Field of view (arcmin2) | 1 |
| Rapidly changing sky position?(e.g., comet, planet) |  | YES [details: ] |
|  | NO |
| Time Critical? |  | YES [details: ] |
|  | NO |
| Required rms (μJy/bm) [per km/s for lines]  | 54 uJy/bm/km/s |
| Peak brightness (μJy/bm) | ~540 uJy/bm/km/s |
| Expected polarized flux density(expressed as % of total) | N/A |

**(A) ‘Targets’ of Observations Discussion**

*Provide a brief discussion describing any trade-offs, interrelationships between specifications, or other nuance that is not captured in the above table.*

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| **(B) OBSERVATIONAL SETUP** |
|  | Tuning 1 | Tuning 2 | Tuning 3 | Tuning 4 |
| Central Sky Frequency(ies) (GHz)  | 32.93 | 25.48 | 25.32 | Continuum |
| Instantaneous Bandwidth for each Sky Frequency (GHz/pol; max 40GHz) | 1 | 1 | 1 | Max |
| Spectral resolution(s) [km/s or kHz] | 30 km/s | 30 km/s | 30 km/s |  |
| Temporal resolution (in seconds)  |  | YES [details: ]  |
| X | NO [*set by time/bandwidth smearing considerations*] |
| Subarrays  | (y/n; number): No |
| VLBI |  | YES [detail, including phased field of view: ] |
| X | NO |

**(B) Observational Setup Discussion**

*Provide a brief discussion describing any trade-offs, interrelationships between specifications, or other nuance that is not captured in the above table.*

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| **(C) POLARIZATION DATA PRODUCTS REQUIRED** |
| Y | Stokes I |
| N | Stokes Q |
| N | Stokes U |
| N | Stokes V |

**(C) Polarization Product Discussion**

*Provide a brief discussion describing any trade-offs, interrelationships between specifications, or other nuance that is not captured in the above table.*

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| **(D) IMAGING CONSIDERATIONS (Continuum & Line, Including VLBI Observations)** |
| Required angular resolution (mas)(single value or range) | 100 |
| Largest angular scale required (arcsec) | 5 |
| Mapped image size (arcmin2) | 1 |
| Required pixel resolution (mas) | 20 |
| Number of output/image channels |  |
| Output bandwidth (minimum and maximum frequency - GHz) [Continuum] | 25 – 45GHz |
| Channel width (km/s or kHz) [Spectral line] | 30 km/s |
| Required rms (μJy/bm) [per channel for spectral line] (if polarization products required define for each) | 10 uJy/bm (per 30 km/s channel) |
| Dynamic range within image(if polarization products required define for each) | 10^3 |
| Polarization accuracy (%) | N/A |
| Required polarization angle accuracy (deg) | N/A |
| Zero spacing/total power required?  | (y/n) |
| Required flux density scale calibration accuracy |  | 1-3% |
| X | 5% |
|  | 10% |
|  | 20-50% |
|  | n/a |

**(D) Imaging Considerations Discussion**

*Provide a brief discussion describing any trade-offs, interrelationships between specifications, or other nuance that is not captured in the above table.*

**(E) Other Functional Requirements**

*If the observation has additional functional needs, such as a phased array mode, VLBI recording capability, etc., please describe those needs here.*

**(F) Other Performance Requirements**

*If the observation has additional performance requirements not captured above, please describe those needs here.*

**IV. Appendix: Additional material, relevant sensitivity calculations, etc.**

*Please provide any other relevant material necessary to understand and substantiate this Science Use Case.*

DERIVATION OF SENSITIVTY CALCULATION:

[USING EQUATIONS – just adlibbing here]: We assume galaxies of this size with total molecular gas masses of 10^10. If uniformly distributed in clouds having velocity dispersions of ~100 km/s spread over ~30 beams across the galaxy, we expect the typical H2 mass per square kpc to be 3.5x10^8 per cloud (1-sigma). We assume a CO(1-0) conversion factor of 3.4 Msun/(K km/s) to convert the H2 mass into a CO line brightness. For a minimum of 2.5 sigma detections over the disk, we therefore require an rms of 10uJy/bm per 30km/s channel to ensure that we resolve the lines.

We assume both HCO+ and HCN to be a factor ~10 fainter than CO and located near the most recent star formation activity. Consequently, we will only be sensitive to regions located around the brightest CO peaks. To determine the amount of flux that we might be missing, we will use the core of the array to obtain measurements for the total integrated line brightnesses at the cost of a factor of 2 in point source sensitivity