ngVLA Key Science Goal 2
Probing the Initial Conditions for Planetary Systems and Life with Astrochemistry

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One of the most challenging aspects in understanding the origin and evolution of planets and planetary systems is tracing the influence of chemistry on the physical evolution of a system from a molecular cloud to a solar system. Existing facilities have already shown the stunning degree of molecular complexity present in these systems. The unique combination of sensitivity and spatial resolution offered by the ngVLA will permit the observation of both highly complex and very low-abundance chemical species that are exquisitely sensitive to the physical conditions and evolutionary history of their sources, which are out of reach of current observatories. In turn, by understanding the chemical evolution of these complex molecules, unprecedentedly detailed astrophysical insight can be gleaned from these astrochemical observations.

Physical History of Protoplanetary Disks

Understanding not just the present state of a forming planetary system, but the evolutionary history of its physical conditions, is critical. For example, the thermal history of the densest regions of disks, which the ngVLA will be uniquely capable of imaging, can be studied by observing the D/H ratio of various molecular species.

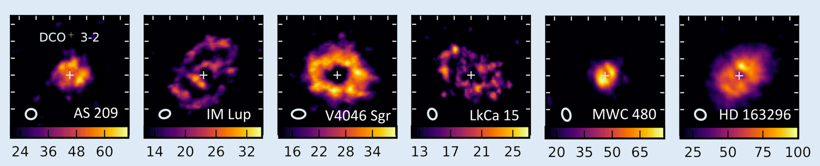

Figure 1. ALMA observation of DCO^+ emission across six different protoplanetary disk sources. Adapted from Fig. 1 of [3].

The relation of the D/H ratio to the temperature at which those molecules formed is well-constrained (e.g. [1]), and the ratio is preserved as the gas heats up [2], providing a permanent indicator of the thermal history of the region.

While deuterated species are already routinely detected in disks with ALMA [3], abundances in the planet-forming midplane are obscured by high dust opacities. The ngVLA will be the first facility to have a high enough sensitivity to detect these molecules at low frequencies where the dust becomes optically thin.

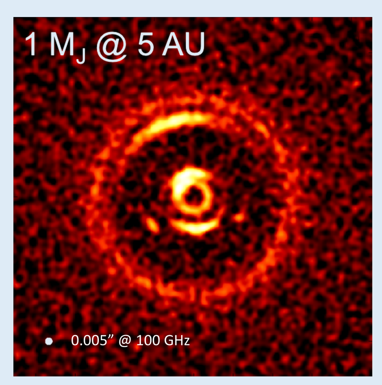

Figure 2. Simulation of ngVLA continuum observations of a disk with a 1 M_J planet, this region is dust obscured in ALMA bands.

1. [ADS] Taquet et al. 2012 *ApJL* 748, L3

2. [ADS] Cazaux et al. 2011 *ApJL* 741, L34

3. [ADS] Huang et al. 2017 *ApJ* 835, 231

Image Ammonia Snow Line in Disks

Snow lines in protoplanetary disks, where molecules freeze out onto grains, offer invaluable insight not just into the physical conditions at various locations within the disk (temperature, density, radiation), but also into the volatile composition of planets forming in that location.

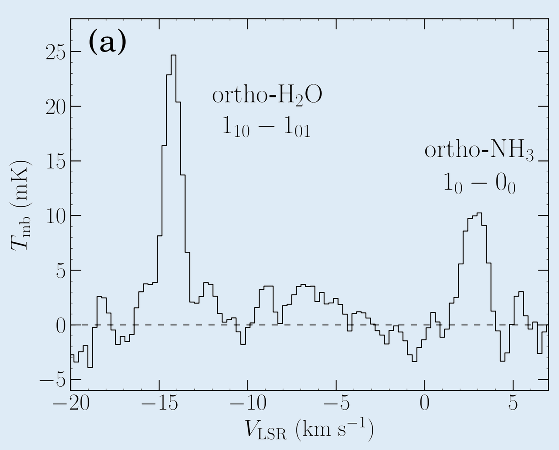

Figure 4. *Herschel* HIFI detection of NH3 and H2O in the TW Hya protoplanetary disk. Adapted from Fig. 1 of [5].

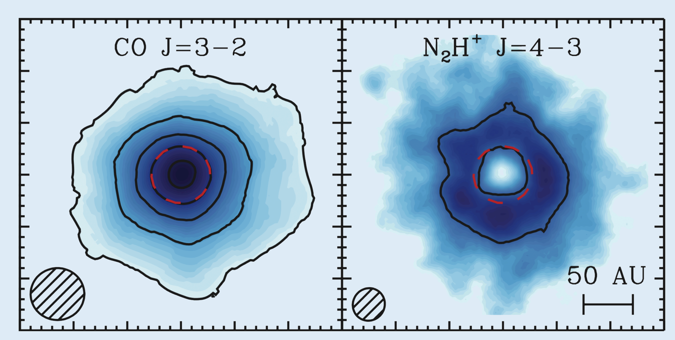

Figure 3. ALMA observation of the CO snowline in TW Hya. Adapted from Fig. 1 of [6].

Perhaps the most crucial, the water snow line, is nearly impossible to observe from the ground. Ammonia, which has been Seen before in disks [5], and lifts from grains at nearly the same temperature as water [4], is an excellent proxy. The ngVLA will have the necessary frequency coverage and angular resolution to image the ammonia snow line directly in protoplanetary disks.

4. [ADS] Collings et al. 2004 *MNRAS* 354, 1133

5. [ADS] Salinas et al. 2016 *A&A* 591, A122

6. [ADS] Qiet al. 2013 *Science* 341, 630

Molecules in Giant Planet Atmospheres

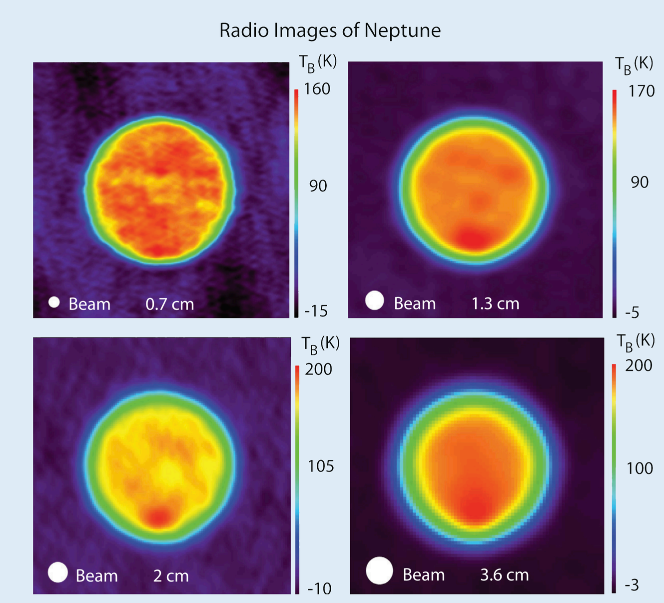

Figure 5. VLA observations of Neptune in its most extended configurations showing the bright southern polar region. Adapted from Fig. 6 of [7].

The growing ability of observatories to characterize the atmospheres of giant exoplanets heightens the need to have a detailed understanding of the giant planets in our own system. At the highest frequencies, the VLA can only resolve large-scale structures on planets like Jupiter and Neptune. The ngVLA will provide ~100 km resolution at 40 GHz for observations of Neptune. The high sensitivity of the ngVLA makes it possible to observe planets rapidly, with good UV coverage, to mitigate difficulties introduced by the planetary rotation.

The ngVLA will access large atmospheric depths, study cloud structures, and enable comparisons to chemical models.

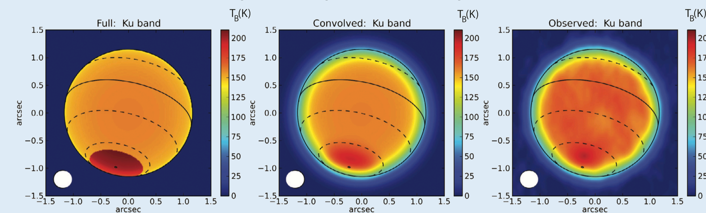

Figure 6. Chemical atmospheric models of Neptune compared to VLA observations. Adapted from Fig. 19 of [7].

7. [ADS] de Pater et al. 2014 *Icarus* 237, 211

Detection of New Complex Molecules

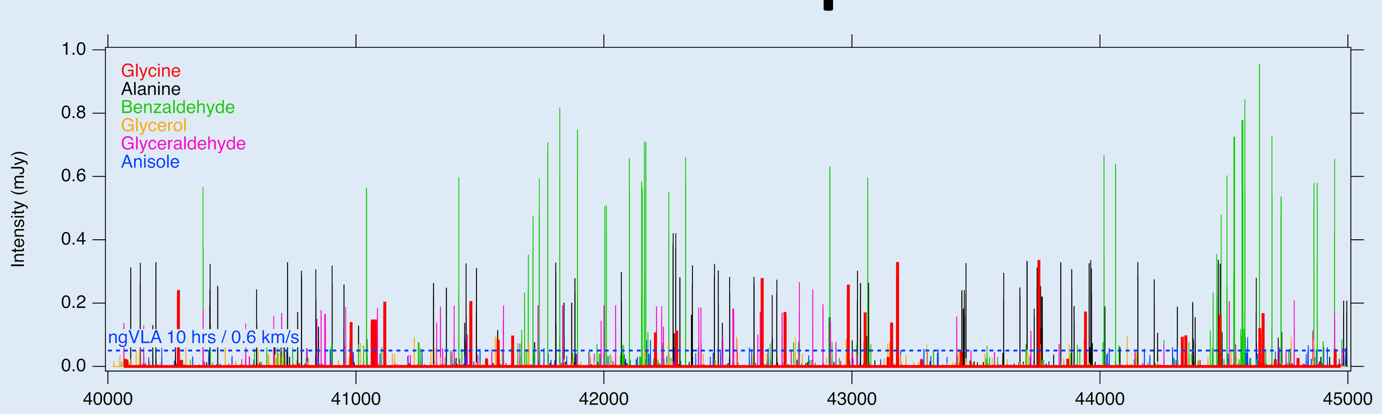

Figure 7. Simulation of the kinds of complex molecules that will be detectable with the ngVLA, but which are not observable with modern facilities in a practical integration time.

Single-dish facilities have driven the detection of new complex molecules largely because of their raw sensitivity [8, 9, 10] relative to interferometers, but have begun to approach a regime where additional detections will require the ability to spatially filter emission and/or observe with significantly increased sensitivity. With its well-matched beam sizes to compact emission features, greater sensitivity, and ability to push beyond the current line-confusion limit, the ngVLA will open a new era for the detections of complex molecules, outcompeting modern single-dish instruments.

8. [ADS] Remijan et al. 2007 *ApJL 664, 47*

8. [ADS] Belloche et al. 2013 *A&A* 559, A47

10. [MNRAS] Burkhardt et al. 2017 *MNRAS,* in press

Tracing Origin of Chiral Excess

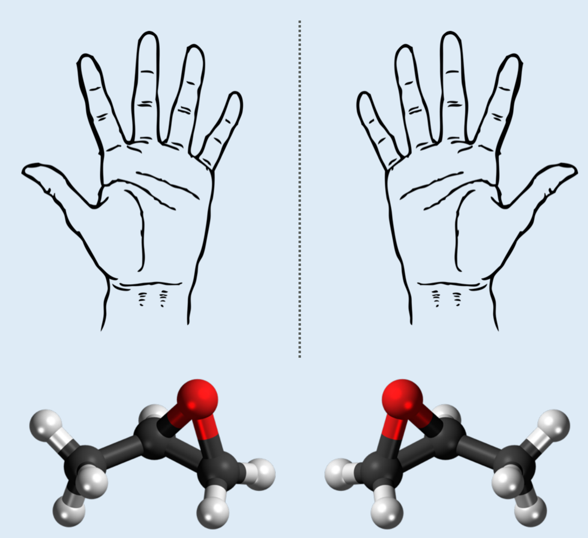

Figure 8. Many molecules, such as propylene oxide shown above, are like your hands: non-identical mirror images of one another. This is a property called *chirality*.

11. [PDF] McGuire & Carroll et al. 2016 *Science* 352, 1449.

12. [ADS] Modica et al. 2014 *ApJ* 788, 79.

All life on Earth uses a single handedness of most biological molecules, such as the amino acids that make up our proteins, which are all left-handed. There is no physical or energetic reason to use one handedness of these molecules over the other; a leading theory is that the molecules inherited by early Earth may have simply had an excess of one handedness.

Single-dish facilities have now detected chiral molecules in the ISM at cm-wavelengths [11], but interferometric observations are needed to determine the distribution of these species relative to the circularly-polarized UV light which may be responsible for generating an excess of one handedness over the other [12]. The ngVLA will be the first facility with the sensitivity to map these rare molecules at the cm-wavelengths where they are detected.

Further Reading

Scan the QR codes for more information

[PDF] Key Science Goals for the ngVLA: Report from the ngVLA Science Advisory Council. *(ngVLA Memo #19)*

[PDF] Science Working Group 1: Cradle of Life *(ngVLA Memo #6)*

[PDF] ngVLA Reference Design Development & Performance Estimates *(ngVLA Memo #17)*

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