Star and Planet Formation with the Next Generation VLA

“Technology Concepts for a ngVLA”, Pasadena, CA

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Areas of Interest

“Cradle of Life” Science Working Group @ ngVLA

Credit: A. Isella
What do these areas of interest have in common?

They are *dusty* environments!
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Amount of material needed to become optically thick
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Protoplanetary Disks

Optically thick

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Amount of material needed to become optically thick

Terrestrial Planet forming region inaccessible for short $\lambda$

Protoplanetary Disks

Optically thick

Optically thin

\[ T = 1 \text{ (g cm}^{-2}\text{)} \]

\[ \lambda \text{ (cm)} \]

ALMA

ngVLA
What do these areas of interest have in common?

They are compact in size!

(Hyper/Ultra) Compact HII regions .. < $10^3$ AU
Protoplanetary disks ..................< $10^2$ AU
Planet forming region .................< 10 AU

Krauss et al. (2014)

Synergy with Exoplanet Science

TMT, JWST, etc.
NextGen VLA will provide critical spatial resolution.
The Formation of Our Solar System
(Some) NextGen VLA Science Cases

- Unsolved problems in star formation:
  - Disks in early phases?
  - Origin of multiplicity?
  - Role of magnetic fields?

- Chemistry in precursors (volatiles, complex organic molecules)

- Imaging the planet-forming region in nearby protoplanetary disks

- Probing planet formation through the distribution of dust and pebbles
mapping atmospheres of giant planets in Solar System

- Unsolved problems in star formation:
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- Chemistry in precursors to our Solar System (volatiles, complex organic molecules)

High Mass Star Formation
- Resolving inner ionized regions of accreting massive stars
- Star formation near a black hole in the inner few pc in the Galactic Center

SETI:
- Search for artificial non-man-made radio signals

probing planet formation through the distribution of dust and pebbles

mapping atmospheres of giant planets in Solar System

chemistry of comets (ammonia/water)
White Paper on Cradle of Life Science

Next Generation VLA Science White Paper

Working Group 1: “The Cradle of Life”

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Abstract

This paper summarizes the contribution of more than twenty scientists spread across North America, Europe, and East Asia and is aimed at developing science cases for the Next Generation Vary Large Array (NGVLA). The Cradle of Life science working group focuses on the formation of low and high mass stars, on the formation and evolution of protoplanetary disks, on the study of the Solar System, and on the possible detection of radio signals from extraterrestrial civilizations. The proposed science cases have been tailored based on the current specifications of the NGVLA, with particular attention

For more info:

https://safe.nrao.edu/wiki/bin/view/NGVLA/CradleOfLifeSWG
Mapping atmospheres of giant planets in Solar System

NGVLA frequency coverage: \( \sim 5-100 \text{ GHz} \) → trace deep atmospheric dynamics with different molecules

NGVLA high resolution → storms and small scale features gas giants

NGVLA sensitivity → longitudinal resolution on fast-rotating planets

IR and radio (VLA-2cm) thermal maps of Jupiter (Sault et al., 2004)
Chemistry of COMs in Solar System Precursors

COMs = Complex Organic Molecules

Detectability of Glycine, Jimenez-Sierra et al. 2014

NGVLA frequency coverage: up to ~100 GHz → access to multiple COMs

NGVLA resolution → detection more important than resolution

NGVLA sensitivity → ~2mk RMS for ~10-σ detection of Glycine @ ~60GHz
Chemistry of COMs in Solar System Precursors

COMs = Complex Organic Molecules

Detectability of Glycine, Jimenez-Sierra et al. 2014

COMs in Protostellar Cores, Codella et al. 2014
Imaging planet-forming region in nearby disks

1. Pebbles and rocks throughout the disk
2. Low optical depth across disk radii
3. Access to terrestrial planet-forming regions

Refereed papers with keyword “Protoplanetary Disks”
At a given wavelength, large grains \((a>\lambda)\) are the most efficient emitters. Turnover at \(2\pi a\).

Net effect: Smallest grain that can emit efficiently will dominate flux at a given wavelength.

Grain size \(\approx\) Wavelength of observation.

Many more small grains than large!

Net effect: Smallest grain that can emit efficiently will dominate flux at a given wavelength.

Grain size \(\approx\) Wavelength of observation.

Credit: M. Hughes

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Log [Emission Efficiency (Q)]

Log \(\lambda\)

Log [Number of Grains (N)]

Log [Grain Size (a)]

\(\frac{dN}{da} \approx a^{-3.5}\)
Imaging planet-forming region in nearby disks

We can only trace underlying mass distribution of solids where $\tau < 1$
Want to know when, where, how much mass in pebbles exists

$\tau = 1$ at $\lambda = 3\text{cm} \quad \text{(NGVLA)}$

$\tau = 1$ at $\lambda = 1\text{mm} \quad \text{(ALMA)}$
* Note this is for “typical” and face-on disk

Credit: M. Hughes
Emission from pebbles declines steeply with frequency.

Requiring lots of sensitivity!!
Guidance in parameter space for ngVLA

- 5-10x surface area, with *increased efficiency* compared to VLA antennas
- Continuum science pushes for wide bandwidths (32GHz *nice!*)
- COMs detections (multiple lines) pushes for wide bandwidths
- Terrestrial-planet formation science pushes for long baselines

Caveat: think carefully about array configuration:
- Continuum science pushing to sensitivity in long baselines
- But spectral line science needs short baselines for Tb sensitivity
• The NGVLA could push down to 5–10AU separation at distances out to 1 kpc \(\rightarrow\) current ALMA science throughout the Galaxy!
Why low optical depths?

We can only trace underlying mass distribution of solids where $\tau < 1$
Want to know when, where, how much mass in pebbles exists

VLA @ 8mm  
CARMA @ 1.3 mm

Self-gravitating disk?  
Optically thick?
Seeing Pebbles and Rocks

One more piece of the puzzle: \( \kappa_v \propto \lambda^{-1} \)

Millimeter flux (optically thin): \( F_v \propto \Sigma \ast \kappa_v \ast B_v(T) \)

\( \propto \lambda^{-3} \)

(Surface density) (Planck function \( \propto \lambda^{-2} \))

The bottom line: Flux drops off like crazy with wavelength. Need LOTS of sensitivity to image pebbles.