Effective area at 40GHz ~ 10x JVLA

- Frequency range: 1 – 50, 70 – 115 GHz
- ~300 18m antennas w. 50% to few km + 40% to 200km + 10% to 3000km?
- Design goal: minimize mass production and operations costs
Thermal imaging on mas scales at $\lambda \sim 0.3\text{cm}$ to $3\text{cm}$

- Sensitivity $\sim 0.1\text{uJy} @ 1\text{cm}$, $10\text{hr}$, $\text{BW} = 20\text{GHz}$
- $T_B \sim 1\text{K} @ 1\text{cm}$, $10\text{mas}$
- Molecular lines become prevalent above $15\text{GHz}$
IAU @ 140pc
Terrestrial Zone Planet Formation
JVLA: Good 3mm site, elev. ~ 2200m

Residual phase rms after calibration

90% coherence
Ongoing Process

- Science working groups ~100 authors
  - Cradle of Life (chairs: Isella, Moullet, Hull)
  - Galaxy ecosystems (chairs: Murphy, Leroy)
  - Galaxy assembly (chairs: Lacy, Casey, Hodge)
  - Time domain, Cosmology, Physics (chairs: Bower, Demorest)
  - White papers are now online on ngVLA memo series and arXiv

- Jan 2015: AAS Jan community discussion
- April 2015: Pasadena technology meeting
  - Antennas, correlators, receivers
- Dec 8/9, 2015: 2nd technical meeting in Socorro
  - LO/IF, data transmission, operations, computing
- Jan 4, 2016: 2nd AAS Jan community meeting
Circle of Life: origin stars, planets, life

Accretion in dust-obscured early phases

OrIGIN OF STELLAR MULTIPLICITY

High Mass Star Formation

Low Mass Star Formation

Organic chemistry Protoplanetary Disks

Pre-biotic chemistry Debris

Pre-biotic molecules

Imagining chemistry, dynamics deep in planetary atmospheres

Magnetospheres and exo-space weather

Aircraft radar from nearby planetary systems in 10 min
Terrestrial zone planet formation = ‘ngVLA zone’

Typical ~ 1 Myr protoplanetary disk at $R \sim$ few AU

Optically thick at short ALMA wavelengths, but unresolved at long ALMA wavelengths

Areal density for $\tau > 1$

Isella ea.
ngVLA: Terrestrial zone planet formation imager

- See through dust to pebbles: inner few AU disk optically thick in mm/submm
- Grain size stratification at 0.3cm to 3cm
  - Poorly understood transition from dust to planetesimals
  - SI => combination of grain growth and optical depth

Optically thick at short ALMA wavelengths, but unresolved at long ALMA wavelengths.

Typical ~ 1 Myr protoplanetary disk at \( R \sim \text{few AU} \)

Inner 10AU = ngVLA zone @ 10mas res

ALMA 250GHz Brogan ea.

100AU 0.7" at 140pc
NGVLA: Protoplanetary disk at 130pc distance

- Jupiter at 13AU, Saturn at 6AU
- Inner gap optically thick at 100GHz
- Image both gaps + annual motions
- Circumplanetary disks: imaging accretion on to planets
Circle of life: pre-biochemistry

- Pre-biotic molecules: rich spectra in 0.3cm to 3cm regime
- Complex organics: ice chemistry in cold regions
- Ammonia and water: temperature, evolutionary state, PP disks, comets, atmospheres…

Glycine

Codella ea. 2014

SKA

Glycine

Codella ea. 2014

L1544

Jimenez-Sierra ea 2014

L1544

NGVLA

ALMA Band 2

ALMA Band 3

ALMA Band 4

ALMA Band 6

Band 4

ngVLA

FLux (mJy/beam)

Frequency (MHz)
ng-Synergy: Solar-system zone exoplanets

‘ALMA is to HST/Kepler as ngVLA is to HDST’

High Definition Space Telescope
Terrestrial planets: top science goal
• Direct detection of earth-like planets
• Search for atmospheric bio-signatures

ngVLA
• Imaging formation of terrestrial planets
• Pre-biotic chemistry
Cool Gas History of the Universe

- SFHU has been delineated in remarkable detail back to reionization
- SF laws => SFHU is reflection of CGHU: study of galaxy evolution is shifting to CGHU (source vs sink)
Low order CO: key total molecular gas mass tracer

\[ M_{\text{H}_2} = \alpha \times L_{\text{CO}1-0} \]

- Total molecular gas mass
- w. ALMA => gas excitation
- Dense gas tracers associated w. SF cores: HCN, HCO⁺

\[ \frac{S}{S_{1(1-0)}} \]

\[ \text{GHz} \]

\[ \text{Redshift} \]

\[ \text{ngVLA ‘sweet spot’} \]

\[ \text{VLA/GBT} \]

\[ \text{SKA 1} \]

\[ \text{ALMA} \]
New horizon in molecular cosmological surveys

CO emission from typical star forming, ‘main sequence’ galaxies at high $z$ in 1 hour

Number of CO galaxies/hour, 20 – 40 GHz:
• JVLA ~ 0.1 to 1, $M_{\text{gas}} > 10^{10} M_\odot$
• ngVLA: tens to hundreds, $M_{\text{gas}} > 2 \times 10^9 M_\odot$

Increased sensitivity and BW => dramatic increase molecular survey capabilities.
Galaxy assembly: Imaging on 1 kpc-scales

- Low order: large scale gas dynamics, not just dense cores
- w. ALMA dust imaging: resolved star formation laws at \( \sim \) 1 kpc

\[
\text{CO 1-0} \\
\text{\( n_{cr} \sim 10^3 \text{ cm}^{-3} \)}
\]

\[
\text{CO 3-2} \\
\text{\( n_{cr} > 10^4 \text{ cm}^{-3} \)}
\]
ngVLA: SMG at z=2, CO1-0

- 38GHz, 10hrs
- rms(100 km/s) = 12uJy \Rightarrow 2e8 \ (\alpha/0.8) \ M_\odot$
- Resolution = 0.15$
- Low mass satellite galaxies, streamers, accretion?
JVLA state of art
Beyond blob-ology

GN20 z=4.0

- CO2-1 at 0.25”
- Resolved gas dynamics
  - 14kpc rotating disk
  - $M_{\text{dyn}} = 5.4 \times 10^{11} M_\odot$
- Resolve SF law

- 120 hours on JVLA
- Few hours on ngVLA
Galaxy eco-systems
Wide field, high res. mapping of Milky Way and nearby Galaxies

Broad-Band Continuum Imaging
- Cover multiple radio emission mechanisms: synchrotron, free-free, cold (spinning?) dust, SZ effect
- Independent, obscuration free estimates of SFR
- Physics of cosmic rays, ionized gas, dust, and hot gas around galaxies
NGVLA: Free Free emission from peculiar spiral in Virgo

- NGC 5713: distance \( \sim 30 \text{Mpc} \), total SFR \( \sim 5 \, M_\odot \, \text{yr}^{-1} \)
- Free-Free ideal estimator of ionizing photon rate
- Full array point source sensitivity at 1cm, 10hrs is 0.1 uJy \( \Rightarrow \) HII region associated single O7.5 main sequence star
- BW+resolution \( \Rightarrow \) spatially/spectrally separate thermal/non-thermal
- Local-group-type studies out to Virgo!
Spectral Line Mapping: Map cool ISM 10x faster than ALMA (‘gold mine’ A. Leroy)

- Rich frequency range: 1\textsuperscript{st} order transitions of major astrochemical, dense gas tracers
- Current CO mapping: tens hours
- Other tracers: 10x fainter => need ngVLA

\begin{figure}
\centering
\includegraphics[width=\textwidth]{spectrum.png}
\caption{NGC 253 \textit{Snell et al.}}
\end{figure}
VLBI μas astrometry

- Spiral structure of MW: masers in SF regions to far side of Galaxy
- Local group cosmology: proper motions + parallax w. masers + AGN: 0.1 uas/yr => dark matter, fate MW, real-time cosmology (local Hubble expansion)
- Not DNR limited imaging => include few big antennas ~ 10% area?

Local group proper motions 0.1 uas/year = 0.4 km/s!
(Darling)
Physics, cosmology, time domain
(Bower et al. SWG4)

Time domain: bursts brighter and peak earlier at high frequency (0.3cm to 3cm)
- GRB, TDE, FRB
- Novae: ‘peeling onion’
- Radio counterparts to GW event:
- Galactic Center Pulsars
Star – Planet interactions: exo-space weather
NGVLA most sensitive telescope to study broad-band stellar radio phenomena

• Thermal stellar winds
  - M dwarfs most likely hosts habitable planets, but very active, flares up to $10^4 \times$ Sun
  - Wind – planet interactions => early evaporation of planetary atmospheres?

• Brown dwarf Auroras! Star-planet magnetospheric interactions

• Key drivers of exo-space weather: dictate exo-planet environments (and the development of life)
• Magnetic reconnection vs. shock acceleration: broad band phenomena
• S-Z for individual galaxies
  ➢ ngVLA-short (1 cm, 3", 10hrs) ∼ 1 μK
  ➢ nT ∼ 10^6 over 10 kpc => 20 μK
• Evolution of fundamental constants using radio absorption lines: most promising ∼ 1 cm
Antennas (Padin, Napier, Woody, Lamb…)
- 12m to 25m? 75% eff at 30GHz
- Offaxis (high/low), symmetric?
- Hydroform, panel?
- Reconfigurable?

Feeds, Receivers (Weinreb, Pospiezalski, Morgan…)
- 1 – 115GHz: 3 bands? 4 bands? more?

Correlator: FPGA (Casper), GPU (nVidia), ASIC (JPL), Hybrid (DRAO)

Illustration of Wide Band Noise Matching

Morgan mmic: Rack full of warm electronics in your hand
• Antennas (Padin, Napier, Woody, Lamb…)
  ➢ 12m to 25m? 75% eff at 30GHz
  ➢ Offaxis (high/low), symmetric?
  ➢ Hydroform, panel?
  ➢ Reconfigurable?

• Feeds, Receivers (Weinreb, Pospiezalski, Morgan…)
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Conclusions
• No major single-point failures
• Could build today for not-unreasonable cost
• Development geared to optimize performance and minimize mass production and operational cost
• Data processing for KSP also not likely bottle neck

Morgan mmic: Rack full of warm electronics in your hand
ngVLA: Next Steps

• Broad, open community participation beyond the Working Groups
• Setup of a Science Advisory Board/Project Scientist
• Studies of weather impact, array configs, short spacing needs, Rx recommendations, VLBI, calibration strategies, simulations, …
• 2nd technical meeting Dec 8/9 2015 Socorro
  (operations, clock transfer, data transmission, algorithmic work, computing reqs ..)
• AAS meeting full day 4 January 2015 (2/3 science, 1/3 technical implications, with call for abstracts deadline Nov 22)
• Large ngVLA science meeting in 2016
• Goal to submit a solid project for the upcoming decadal plan in 2019
ngVLA home page:

https://science.nrao.edu/futures/ngvla

Links to

ngVLA forum

WG wikis

ngVLA memo series:

Project overview and working group white papers