AGN life cycles, SMBH Masses, and Galactic Winds: Advancing our Understanding of SMBH-Galaxy Co-evolution with the ngVLA

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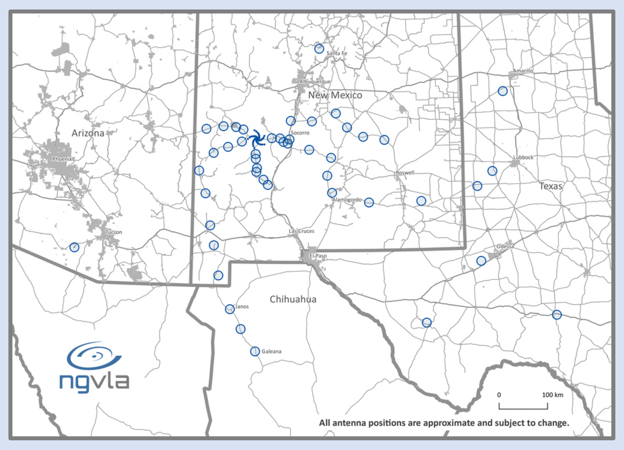
The Next-generation Very Large Array

The ngVLA is a concept for a new radio telescope under development for Astro2020 review with 10X the sensitivity of the JVLA and ALMA and 30X longer baselines than the JVLA.



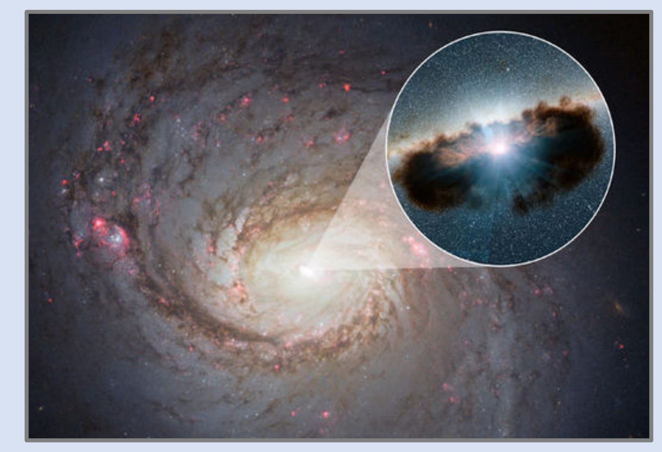
Coverage from 1 to 116 GHz	214 x 18m dishes
ngVLA	
$B_{max} \approx 1000$ km	80% $B < 36$ km

See poster 361.02

SMBHs and Galaxy Evolution in the ngVLA Era

Deep continuum surveys will constrain the evolution of the radio source population

Detections of winds and outflows at high *z* will probe stellar and SMBH feedback



Precision SMBH masses from CO dynamics will test models of SMBH formation/evolution

Broadband radio SED analyses will provide key insights on AGN triggering and life cycles

Deep Continuum Surveys

★ The resolution of the ngVLA will greatly enhance our ability to identify AGN emission from jets, and to spatially isolate AGN cores from lower surface brightness emission from star formation, which is critical for identifying low-power radio AGN and for calculating radio SFRs as a function of redshift.

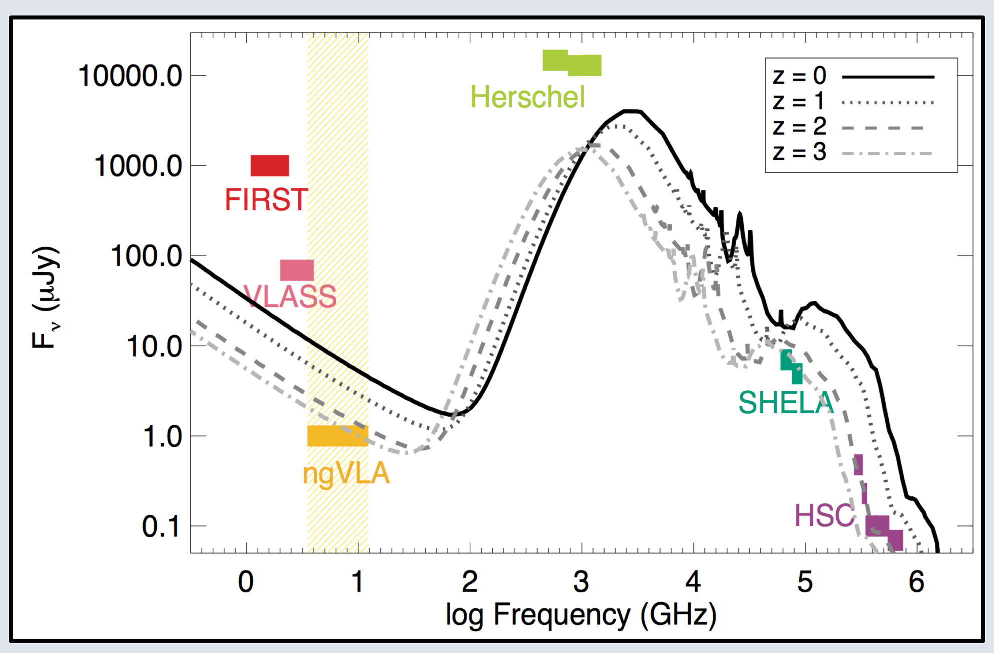


Figure 1: An L_* SFG SED over a range of redshifts (Kirkpatrick et al. 2018). The ngVLA 8 GHz band is shaded in orange. The rms noise level of 1 μJy/beam (orange bar) of a deep ngVLA survey of Stripe 82 corresponds to an L_* galaxy at $z = 3$. Flux limits of other Stripe 82 surveys are shown for comparison.

★ For a 10 deg^2 ngVLA survey over the Stripe 82 field at 8 GHz tapered to θ_{FWHM} = 0. 1" with a 1σ depth of 1 μJy/beam (given the current ngVLA reference design; Selina et al. 2018), we estimate an integration time of ~200 hr, not including overheads. Such a survey is expected to detect 112,000 SFGs and 18,000 AGN.

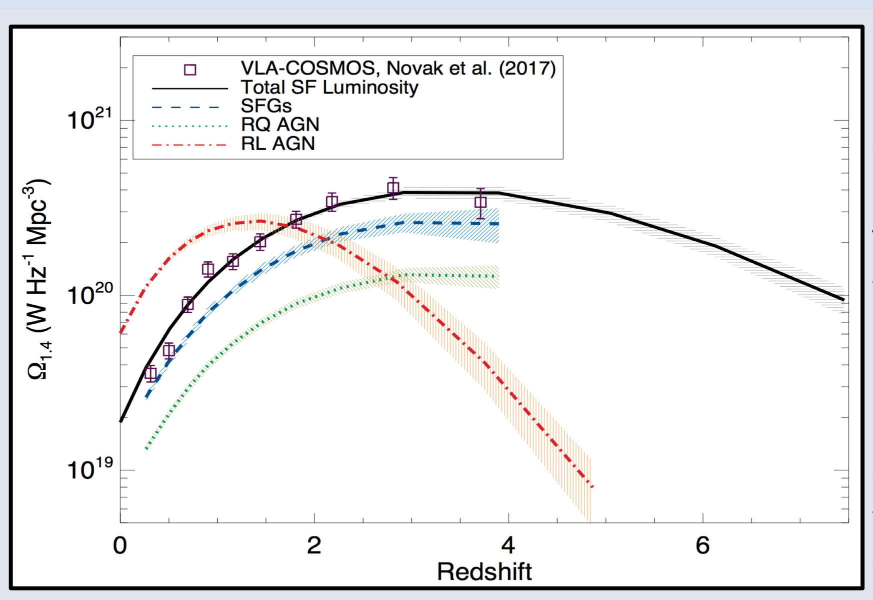


Figure 2: Predicted radio luminosity functions from an 8 GHz ngVLA survey converted to 1.4 GHz (Kirkpatrick et al. 2018). The black curve predicts $\Omega_{1.4}$ from SF, and is divided into components from SFGs (blue) & RQ AGN (green). Purple squares show the best known SFG $\Omega_{1.4}$ constraint. The red curve shows the RL AGN constraint from COSMOS (Smolčić et al. 2017).

★ With a deep Stripe 82 ngVLA survey, it will be possible to test whether the RL AGN luminosity density shown in Figure 2 really declines so strongly beyond $z \sim 3$ as suggested by recent studies.

Precision SMBH Masses

★ Through observations of CO(1-0) kinematics, the ngVLA will expand on ALMA's revolutionary capability to probe circumnuclear molecular gas rotation within the SMBH sphere of influence ($r_g \sim G\, M_{SMBH}/\sigma^2$).

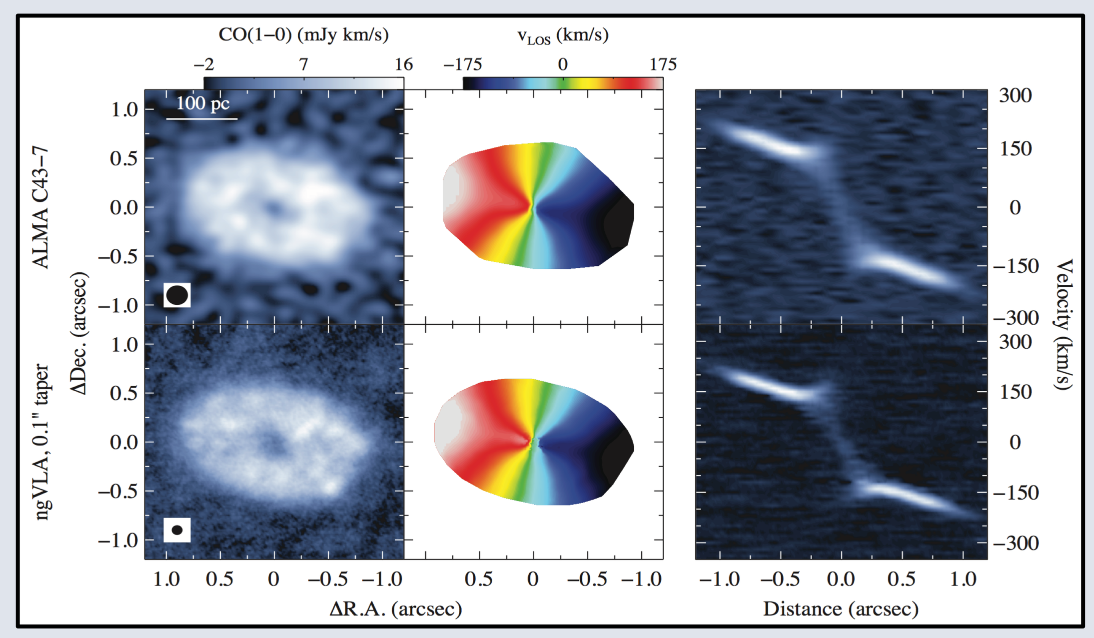


Figure 3: Moment maps and PV diagrams from ALMA 0.2" (top) and ngVLA 0.1" (bottom) simulations of CO(1−0) disk rotation (Boizelle et al. 2018). The circumnuclear disk at D = 30 Mpc has a central hole (radius ~0.2" ≈ 30 pc) in CO-bright gas and resides in a galactic gravitational potential with $M_{SMBH} = 2 \times 10^8$ M$_\odot$ ($r_g \sim 0.3$"). Two hr of integration yields σ_{rms} of 0.46 and 0.14 mJy/beam per 10 km/s channel for ALMA and ngVLA, respectively.

★ With tapering to θ_{FWHM} = 50 mas and integration times of a few hr, the ngVLA will probe $M_{SMBH} \sim 10^9$ M$_\odot$ at D < 300 Mpc and D < 75 Mpc with ~20% and ~10% accuracy, respectively (Figure 4).

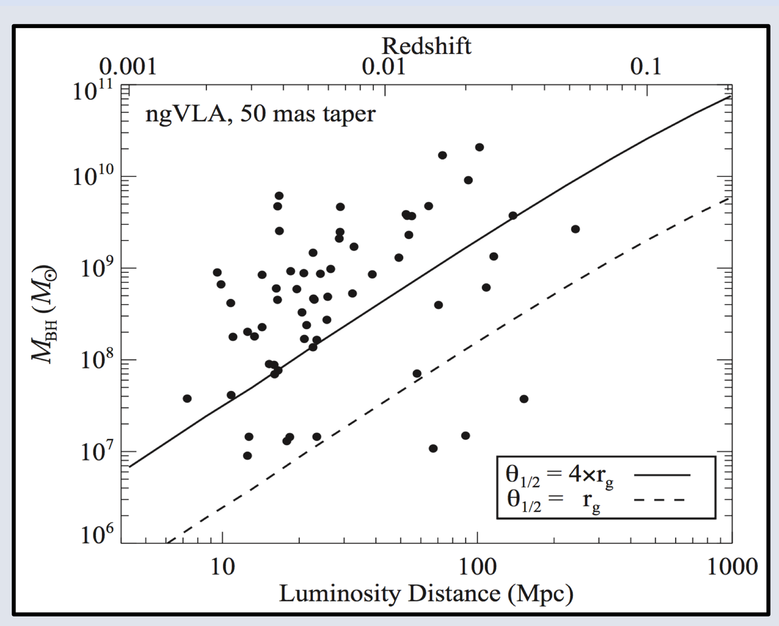


Figure 4: Minimum SMBH mass detectable with the ngVLA (Boizelle et al. 2018). Black points show the data on which the current M_{SMBH}–σ_* relation is based (Kormendy & Ho 2013). The curves show the mass limits from ngVLA observations that marginally (dashed) and highly (solid) resolve the BH sphere of influence.

Galactic Winds at High Redshift

★ The ngVLA will provide insights into the feedback processes that shape galaxies throughout the epoch of galaxy assembly when the bulk of the stars in the Universe were formed.

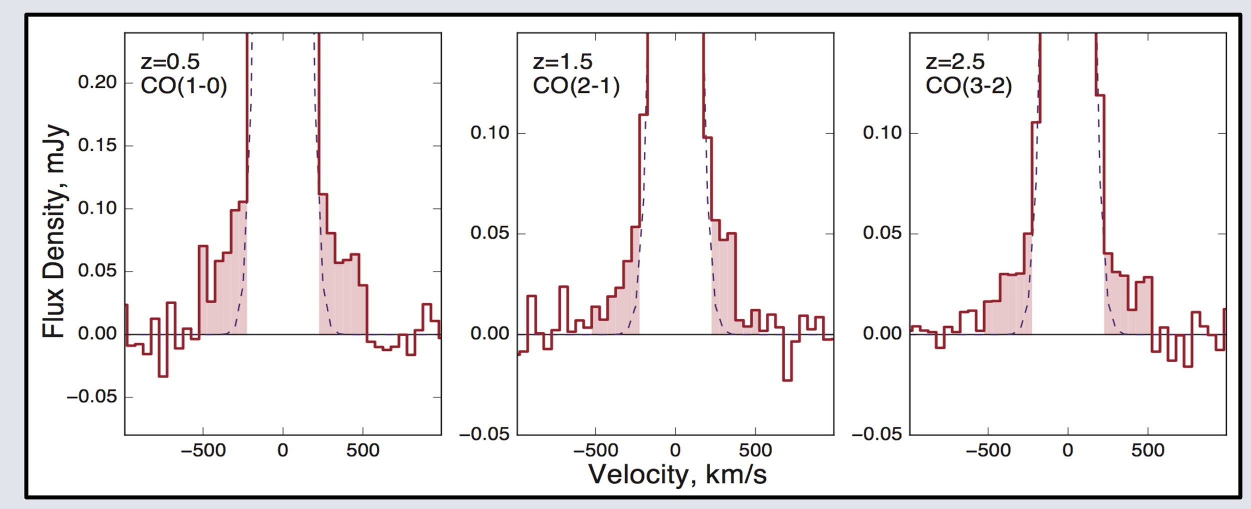
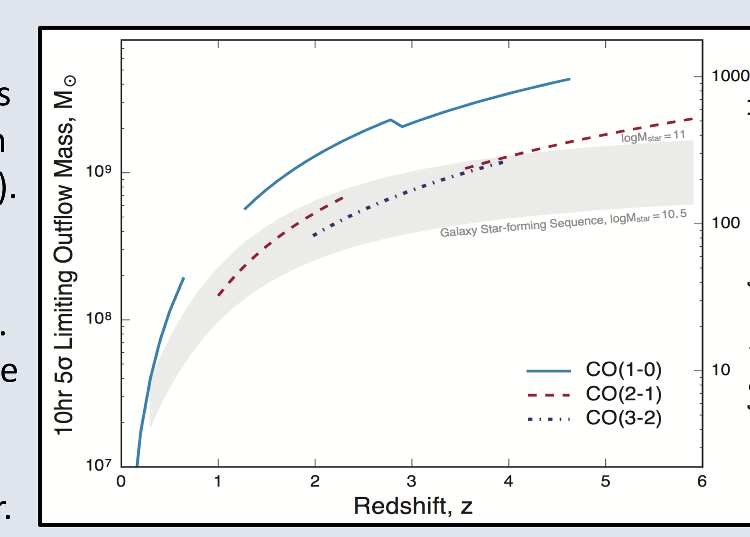


Figure 5: Example CO spectra of high-*z* galaxies illustrating the ability of the ngVLA to detect molecular outflows via the presence of high-velocity spectral wings (Spilker & Nyland 2018). The templates are based on known outflows in low-*z* U/LIRGs (SFR ≈ 100 M$_\odot$/yr, $M_{outflow}$ ~ few × 10^8 M$_\odot$; Cicone et al. 2014), assume a 10 hr on-source integration, and use the ngVLA sensitivity for 1" imaging.

★ Detections of outflows like those in Figure 5 using existing facilities would be virtually impossible: the JVLA lacks receivers that can access the 3 – 4 mm regime where the CO emission from outflows is brightest, and reaching equivalent depths with ALMA would require ~300 – 500 hr of observation.

Figure 6: Outflow mass detection limit assuming α_{CO} = 0.8 M$_\odot$ (K km/s pc^2)$^{-1}$ and an outflow velocity width of 500 km/s (Spilker & Nyland 2018). SFRs from the star-forming main sequence for log(M_*/M$_\odot$) = 10.5 to 11 are shaded in gray (Speagle et al. 2014). The right-hand axis shows the estimated galaxy SFR assuming an outflow mass of 3% of the total gas mass with t_{dep} = M_{gas}/SFR = 150 Myr.

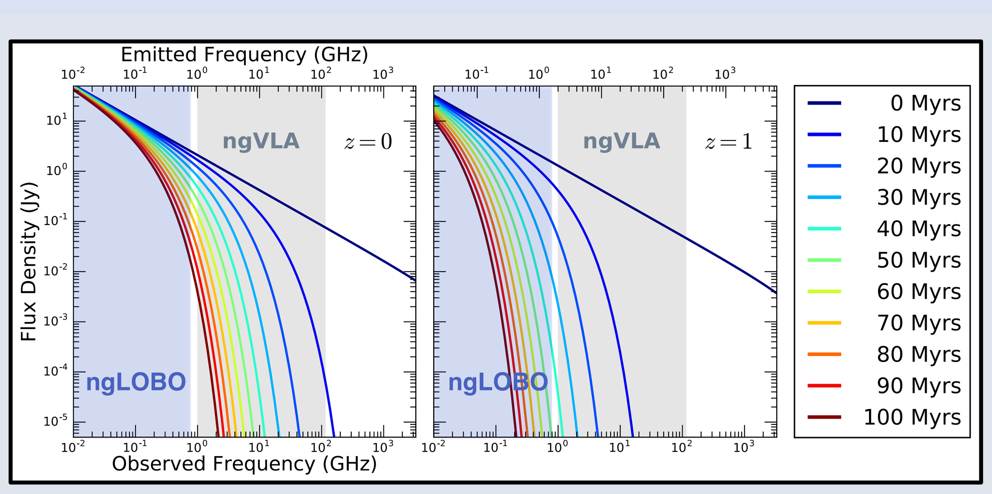


★ The ngVLA will be capable of detecting molecular outflows from typical galaxies on the star-forming main sequence with stellar masses of log(M_*/M$_\odot$) ≳ 10.5 out to $z \sim 3$, and galaxies with higher star formation rates beyond $z \sim 4$.

AGN Life Cycles and the Importance of ngLOBO

★ At 1 GHz, the ngVLA will be able to model the ages of sources as old as 30–40 Myrs at $z \sim 1$, but lower-frequency observations would be needed to study older and more distant sources (Figure 7).

Figure 7: Example of JP model (Jaffe & Parola 1973) spectral ages of a typical radio AGN calculated using the BRATS software (Harwood et al. 2013). The left and center panels correspond to $z = 0$ and $z = 1$, respectively. Fluxes have been arbitrarily scaled. See Nyland et al. (2018) and Patil et al. (2018).



The Next Generation LOw Band Observatory (ngLOBO) is a proposed enhancement to the main ngVLA design that would extend its frequency coverage to the sub-GHz regime.

See poster 361.15

★ The addition of ngLOBO would enable robust, high-resolution radio SED and spectral aging model studies with the ngVLA of compact, young radio AGN at $z > 1$. This would provide strong constraints on radio AGN triggering and duty cycles during the peak epoch of galaxy assembly.

References

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See ngVLA Science Book papers by Boizelle, Kirkpatrick, Nyland, Patil, and Spilker

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