ngVLA Key Science Goal 5: Understanding the Formation and Evolution of Stellar and Supermassive Black Holes in the Era of Multi-Messenger Astronomy

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Overview

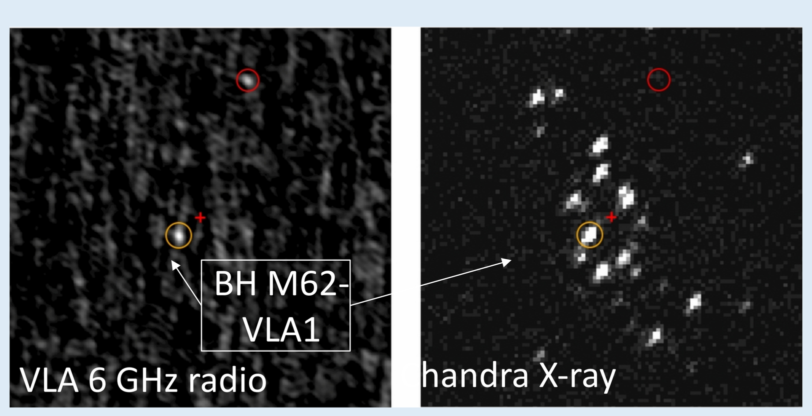
The ngVLA would be a powerful telescope for finding and studying black holes, surveying everything from the remnants of massive stars to the supermassive black holes in the centers of galaxies.

Combined with facilities across the spectrum and gravitational wave observatories, the ngVLA would provide crucial constraints on the interaction of supermassive black holes with their environments, with implications for the evolution of galaxies and the emission of gravitational waves from in-spiraling supermassive black holes. The ngVLA would identify the radio counterparts to transient sources discovered by other multi-messenger observatories, and its high-resolution, fast-mapping capabilities would make it the preferred instrument to pinpoint counterparts to events such as supermassive black hole mergers. High-resolution imaging abilities would allow the separation of low-luminosity black holes in the local Universe from background sources, thereby providing critical constraints on the formation and growth of black holes of all sizes. Its combination of sensitivity and angular resolution would provide new constraints on the physics of black hole accretion and jet formation.

Low Luminosity Black Holes in the Nearby Universe

Black holes accreting well below Eddington luminosity could be widespread, but how to find them?

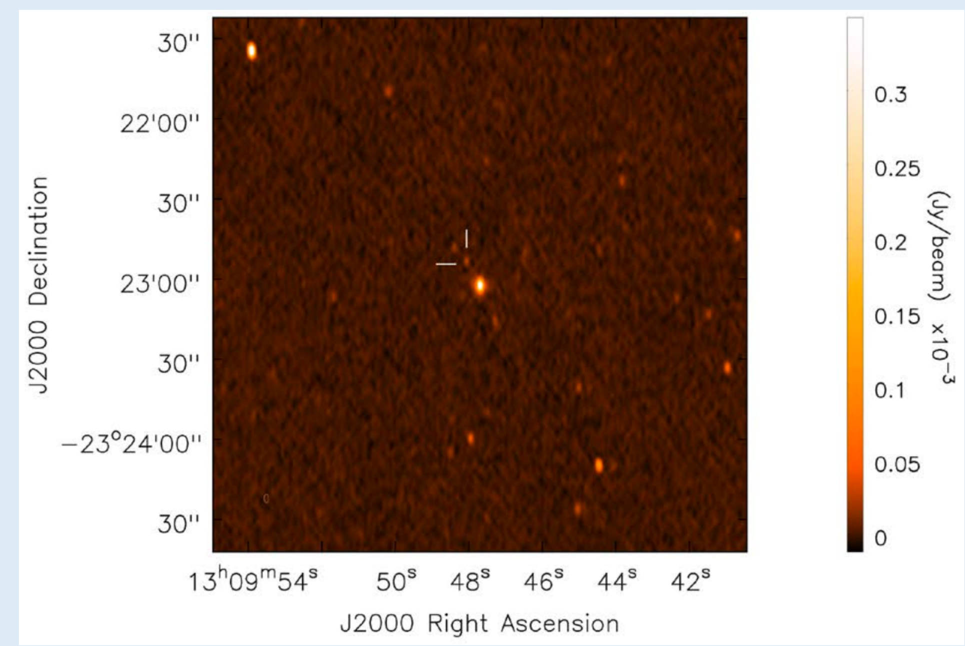
E.g., Sgr A* at Galactic center has $L_{Edd} \sim 10^{-9}$



Stellar-mass black hole in M62. Shown is central 50" (1.6 pc) of the globular cluster. The **red cross** marks the cluster's photometric center; the **red circle** is a known pulsar (Chomiuk et al. 2013)

- Are there IMBHs in globular clusters or dwarf galaxies?
- What fraction of dwarf galaxies host low-luminosity AGN?
- Frequency range + wide field of view would make ngVLA well suited to survey nearby Universe

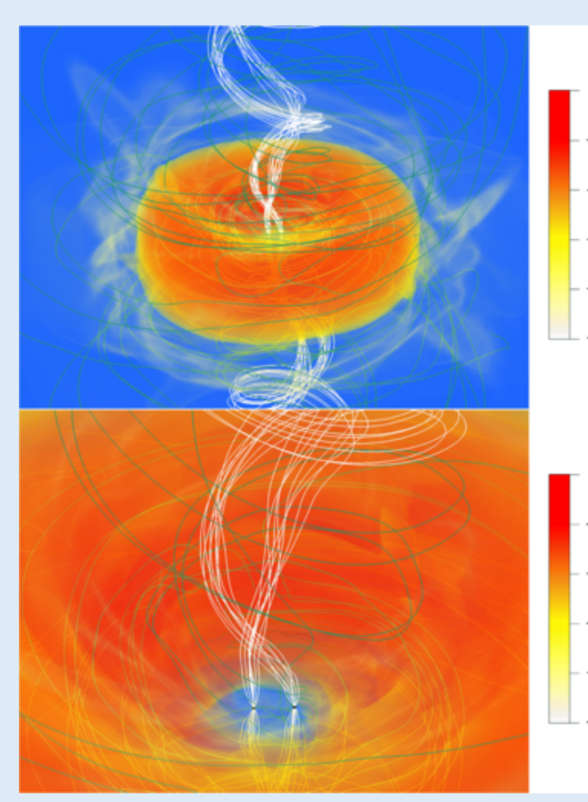
Black Hole Mergers – Stellar and Supermassive



LIGO-Virgo confirms that black holes merge and produce gravitational waves(!).

Deep VLA (3 GHz) radio image of NGC 4993 (3' × 3'), from 2017 September 8 and 10. The galaxy's AGN is at the center of the image. The radio counterpart to EM170817 is highlighted. While EM170817 was a neutron star-neutron star merger, the ngVLA would be valuable for NS-BH mergers also, and potentially SMBH-SMBH mergers (Hallinan et al. 2017)

- Radio imaging plays critical role in localizing electromagnetic counterparts to gravitational wave events and characterizing environments.
- Ground-based interferometers (LIGO, Virgo, …) will find many more gravitational wave events (BH-BH, BH-NS, NS-NS), requiring continued localization and characterization.
  - ➢ Frequency agility of ngVLA well suited for finding counterparts that brighten first at higher frequencies (NS-NS mergers; NS-BH mergers).
  - ➢ ngVLA survey speed well suited for covering ~ 10 deg^2 (typical gravitational wave event localization uncertainty)

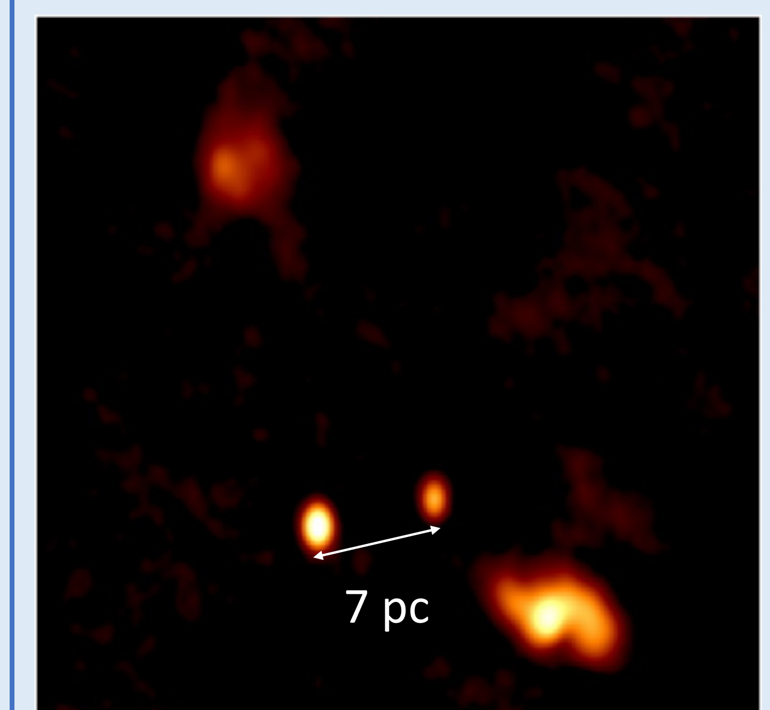


GRMHD simulations of a supermassive black hole binary with a circumbinary disk showing the launching of potential radio jet (From Gold et al. 2014)

Looking toward space-based interferometer (LISA)

- General conclusion of GRMHD simulations of a supermassive BH binary with circumbinary disk is the launching of a jet that could be radio bright
- ➢ ngVLA extremely well suited to searching for counterparts to LISA events

Supermassive Black Hole Binaries and Pairs



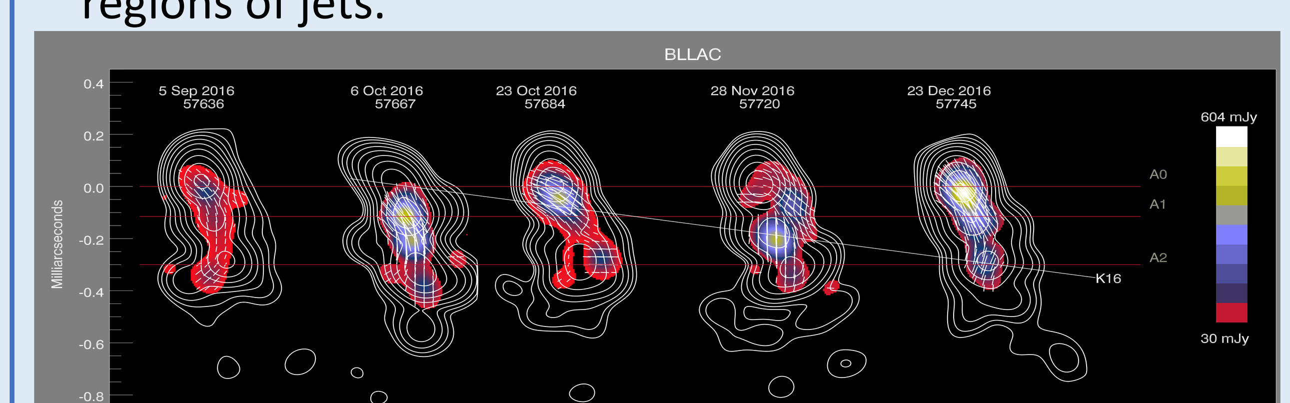
B0402+379, the closest known SMBH pair (7 pc [projected]); ngVLA would be able to find many more such pairs, particularly with a long baseline capability (Rodriguez et al. 2006)

➢ See also S. Burke-Spolaor et al. Poster #250.26

- SMBH pairs should be natural result of hierarchical structure formation
- Only *one* confirmed system on <~ 10 pc scales
- Radio observations able to probe pc-scale separations, with no dust obscuration
  - ➢ ngVLA would be able to search for SMBH pairs (and recoiling SMBHs!) on range of separation scales
  - ➢ With longest baselines, ngVLA would be able to observe sub-pc SMBH pairs

Jet Physics and Evolution

- Where is γ-ray emission generated relative to supermassive black hole?
  - Near jet base, in broad line region, in clouds intercepted by the radio jet, …?
- ➢ High-resolution radio observations in concert with γ-ray observations offer unique tracer of physics in inner regions of jets.



Comparison between radio and VERITAS very high energy (VHE) γ-ray emission of the blazar BL Lac is being used to trace the relationship between a superluminal radio jet knot and the generation of the VHE γ-rays. With long baselines, the ngVLA would provide higher dynamic range images and innovative opportunities for monitoring. (Credit: S. Jorstad & A. Marscher; see also Abeysekara et al. 2018, ApJ)

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ngvla

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