

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

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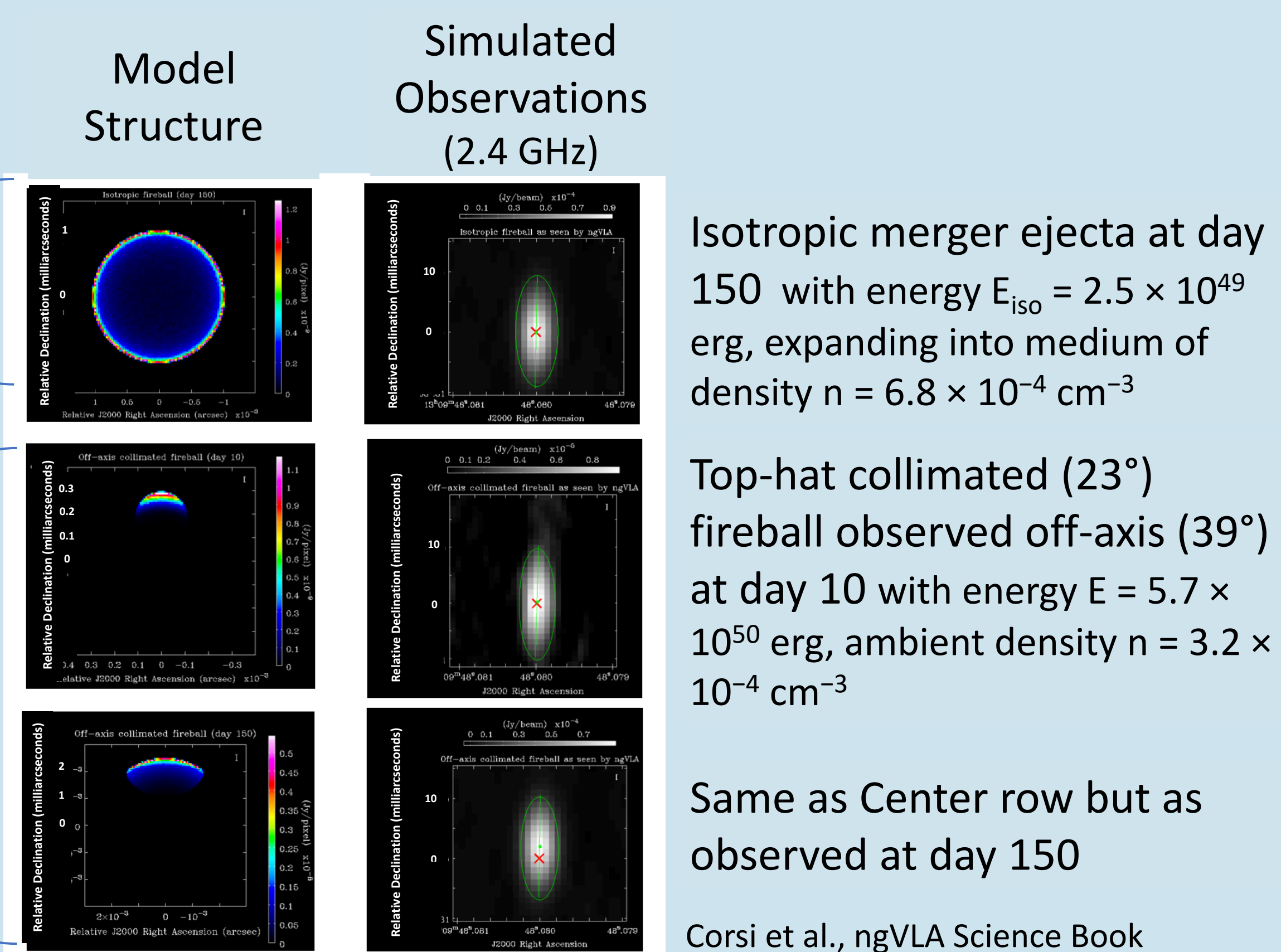
Merging Stellar Mass Black Holes, Gravitational Waves, and Electromagnetic Counterparts

A radio afterglow has been observed from the neutron star-neutron star (NS-NS) merger GW 170817. VLA observations have been instrumental in constraining the properties of the ejecta, and the ngVLA would be able to expand the accessible volume dramatically and resolve the afterglows from NS-NS and black hole-neutron star (BH-NS) mergers.

Imaging with the ngVLA would determine the speed distribution and distinguish between collimated relativistic fireballs observed off-axis and quasi-spherical relativistic ejecta. The magnetic field structure can be further constrained via full polarimetric imaging. Consider two extreme cases likely to "bracket" the possible outcomes:

Isotropic relativistic ejecta would appear in ngVLA images as ring-like: brighter near edges and dimmer near center

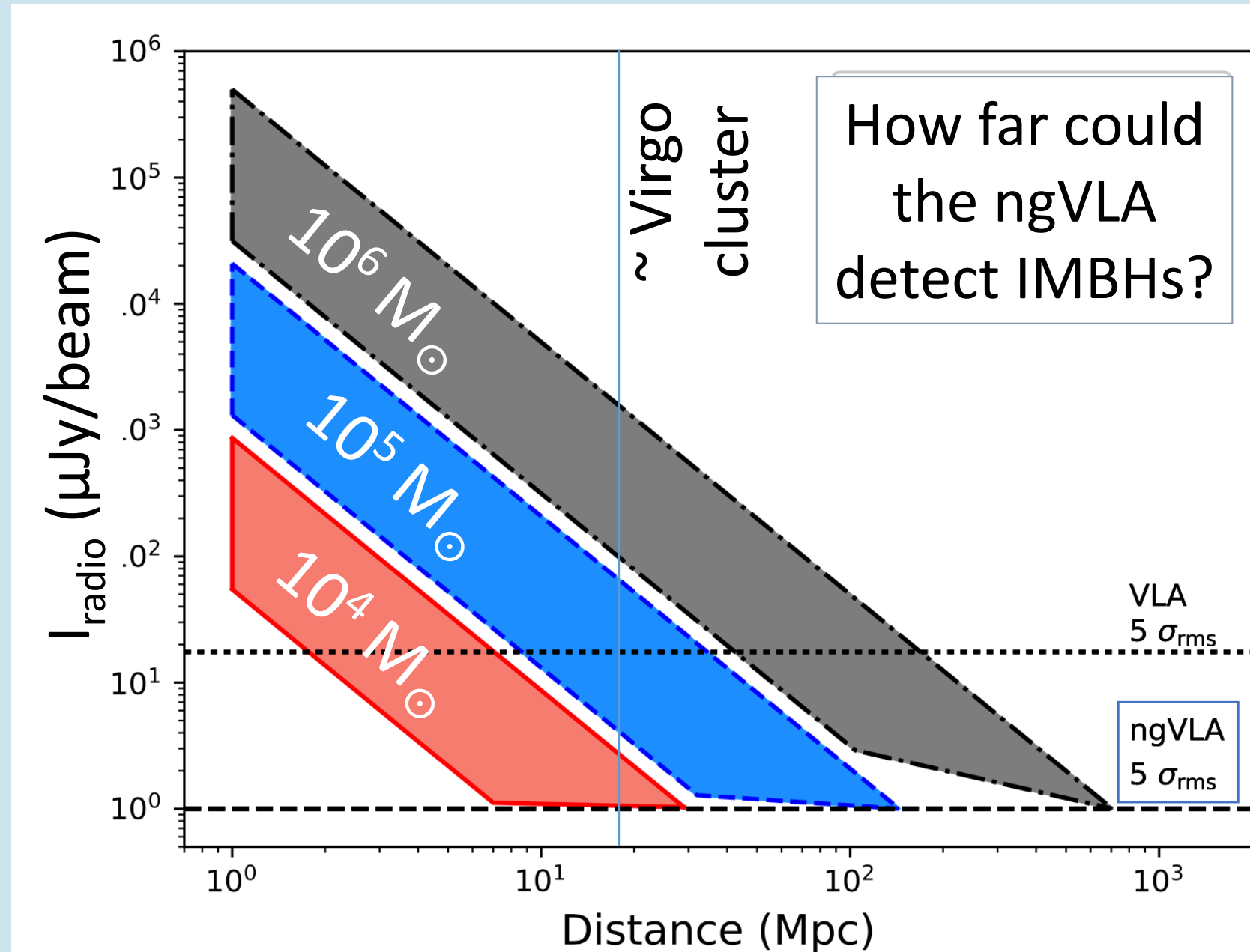
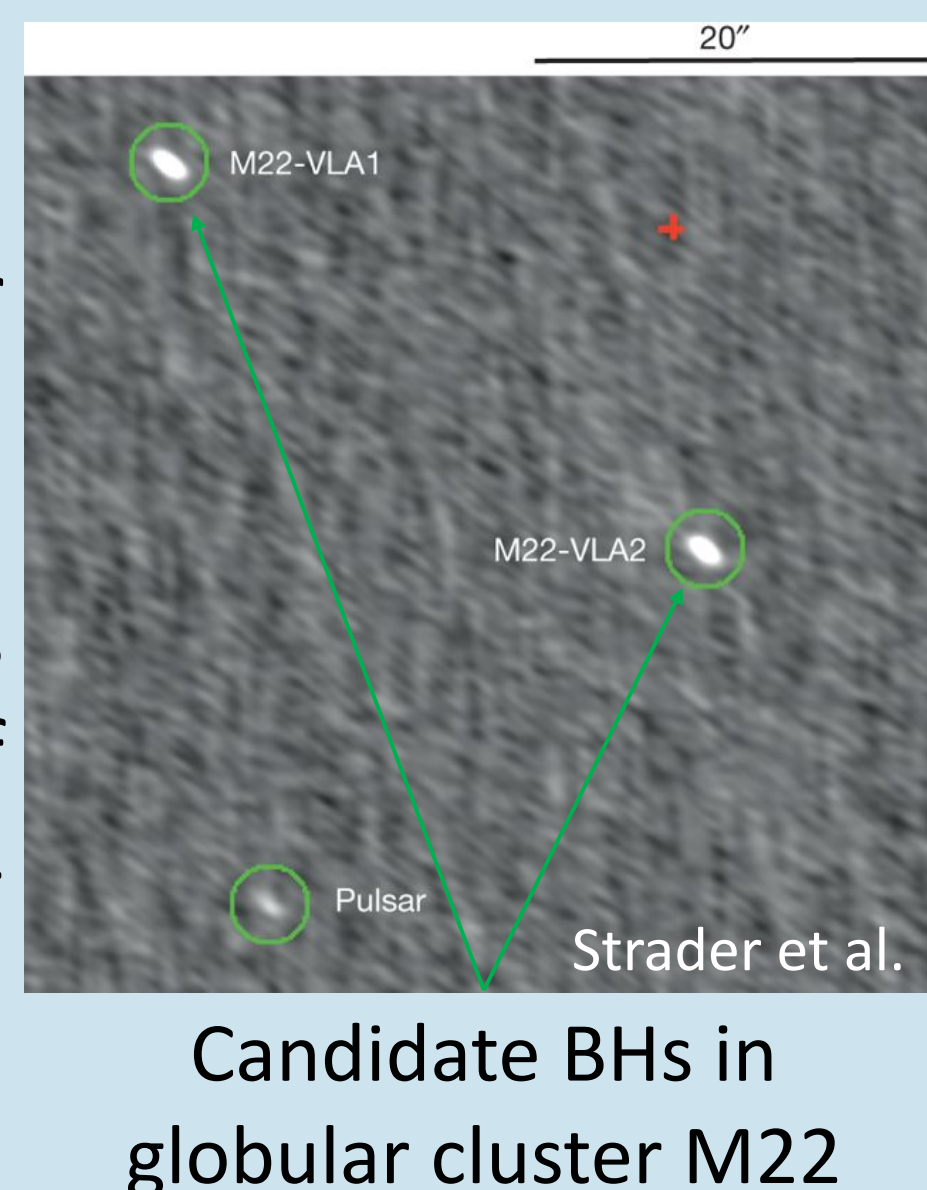
Collimated relativistic jets, having top-hat ejecta distributions, and with jet axes misaligned to observer would evolve in ngVLA images, with centroids of emission moving as jets propagate



Large populations of stellar- and intermediate-mass black holes (IMBHs) could exist in the local Universe:

- Identification of BHs in globular clusters could help resolve the origin of field vs. cluster for BH-BH merger events detected by LIGO-Virgo
- Do IMBHs exist?

The VLA has found BH candidates in globular clusters; the ngVLA would find fainter BHs in Galactic globular clusters and probe nearby dwarf galaxies. With long baselines, the ngVLA could measure proper motions.



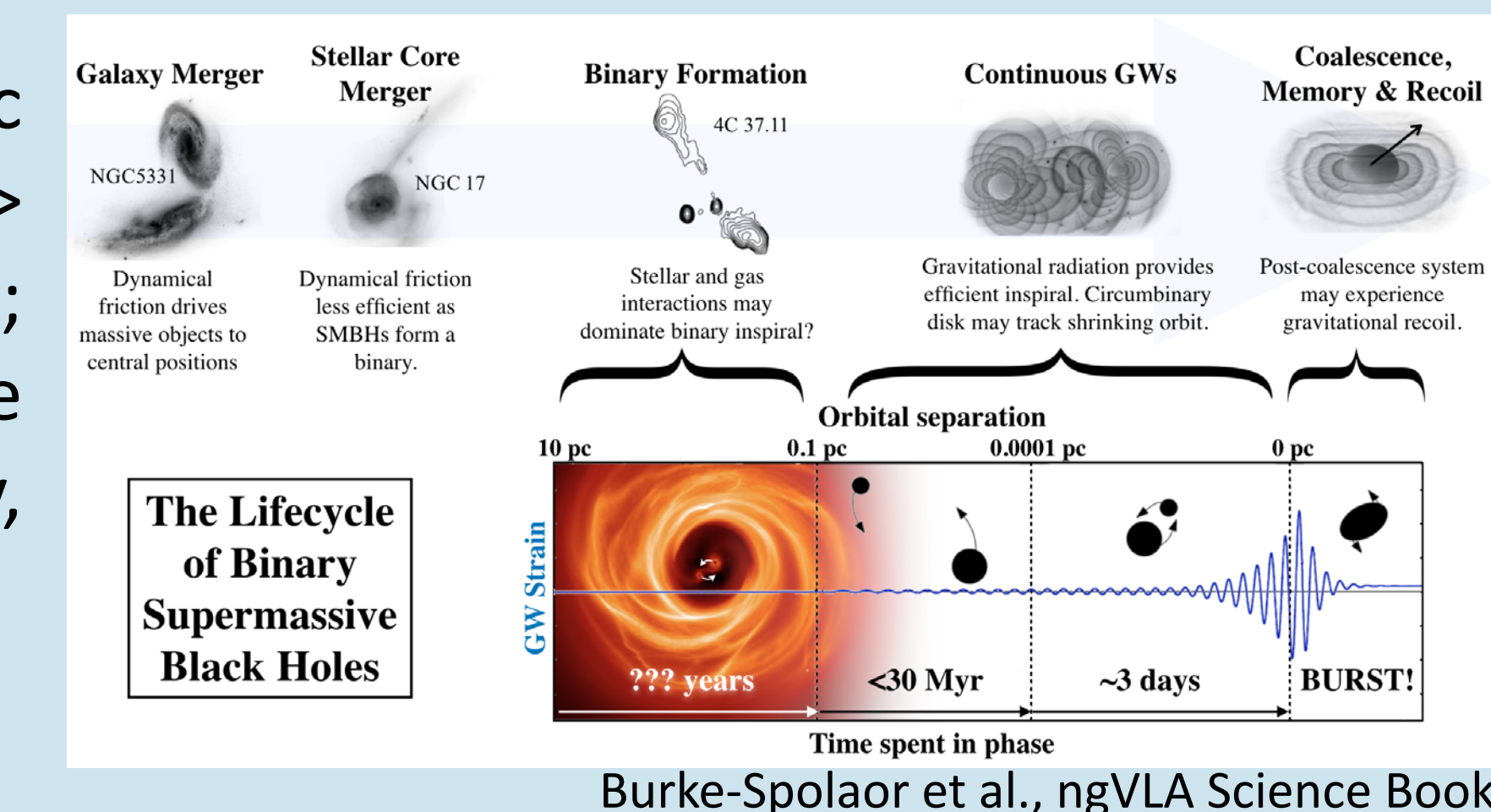
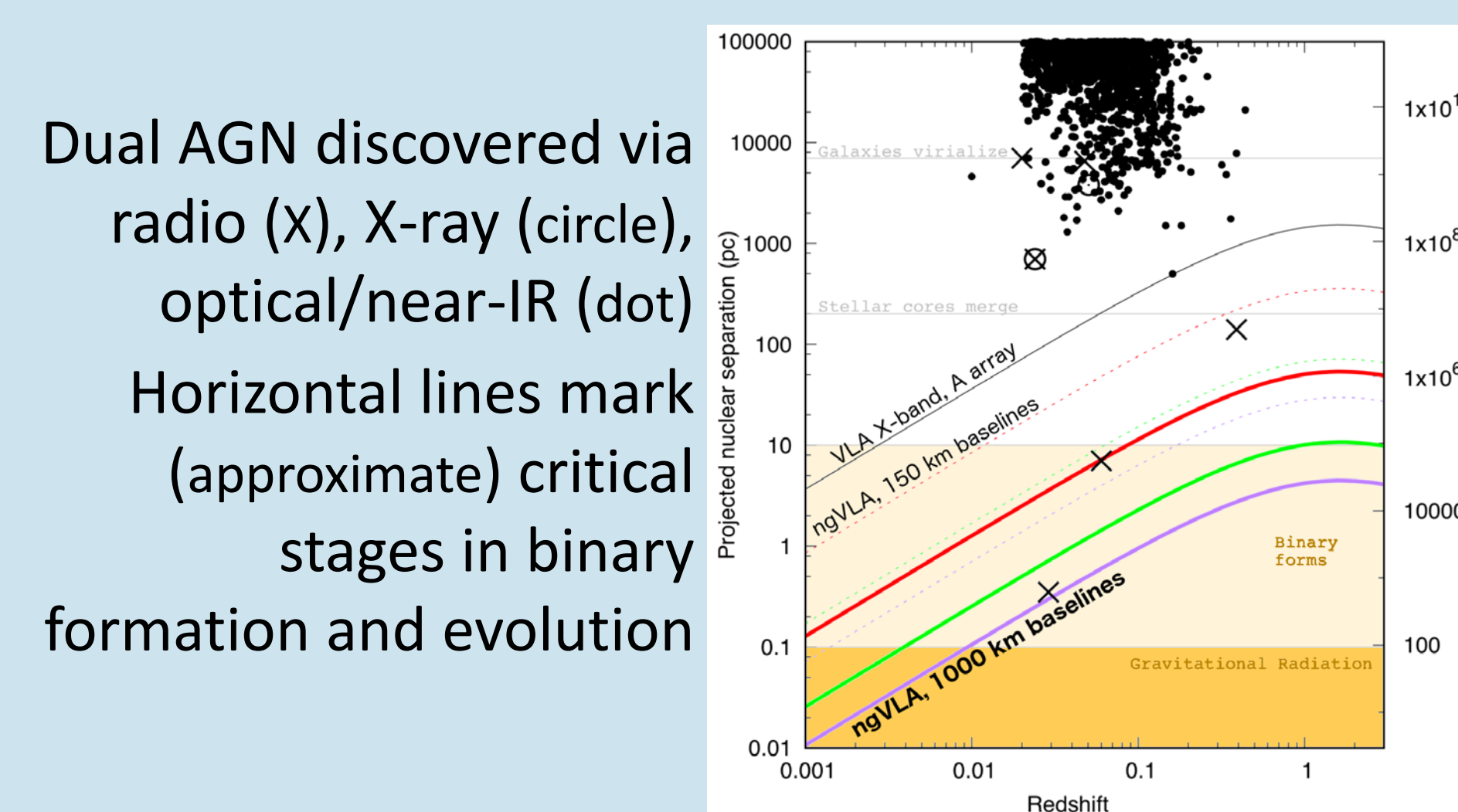
The ngVLA could detect IMBHs out to Virgo cluster for $10^4 M_\odot$ IMBHs, out to 1 Gpc for $10^6 M_\odot$ IMBHs. Assumes 1 hr observation at 8 GHz, IMBH with 2 keV-10 keV X-ray flux $> 10^{-15} \text{ erg s}^{-1} \text{ cm}^{-2}$ and $10^{-5} L_{\text{edd}} < L_x < 10^{-3} L_{\text{edd}}$ (Plotkin & Reines, ngVLA Science Book)

Supermassive Black Hole Mergers

Dual ($\lesssim 10 \text{ kpc}$ separation) and binary ($\lesssim 10 \text{ pc}$ separation) supermassive black holes (SMBHs, $M > 10^8 M_\odot$) should form during major galaxy mergers; in late stages of evolution, they should produce nHz and μHz gravitational waves, and, potentially, electromagnetic bursts as they merge.



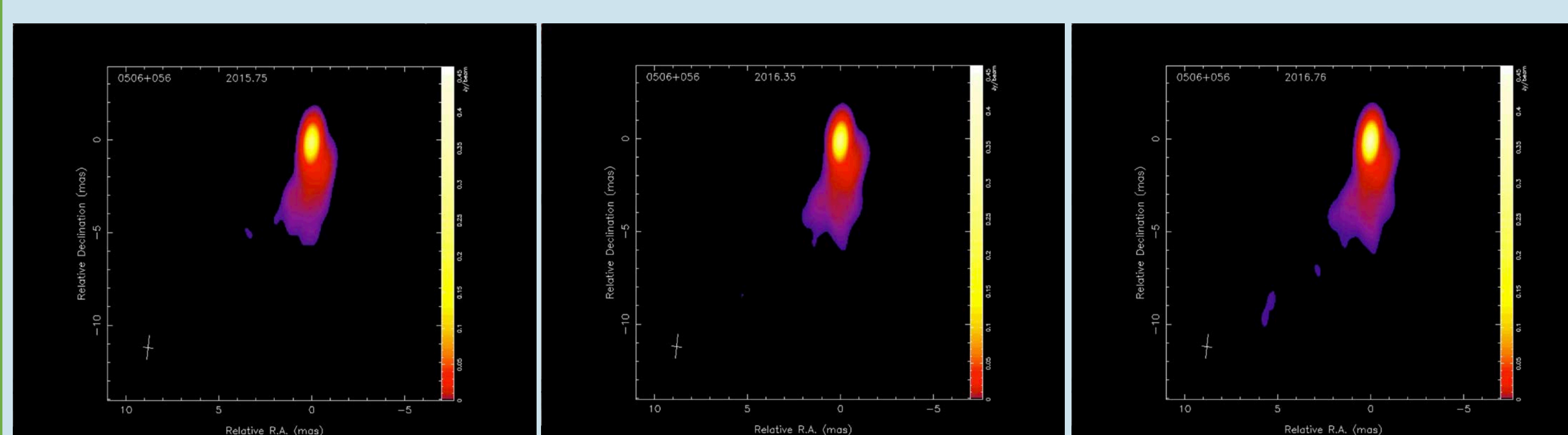
7 pc (projected) separation SMBH pair found with VLBA. How many more can be found? The ngVLA would be prime search machine.



SMBH pairs mark on-going galaxy mergers and imminent SMBH coalescences and are strong probes of redshift-dependent merger rates, occupation fractions of dual SMBHs in galaxies, and post-merger evolution.

Curves indicate ngVLA resolution at 10 GHz (red), 50 GHz (green), and 120 GHz (purple); dashed curves show resolution of 150 km baselines, solid curves show 1000 km extended baselines. The ngVLA has potential to resolve multi-messenger SMBH binaries in nearby Universe (curves that cross dark yellow region) at flux densities inaccessible to the VLBA.

Black Holes, Neutrinos, Cosmic Rays, Photons



(Left) Sequence of VLBA images of blazar TXS 0506+056 associated with the TeV neutrino event IceCube 170922A, at 6 mon. intervals, prior to the neutrino event. (Lister et al.; MOJAVE Program) (Right) ngVLA resolution as a function of redshift, illustrating that the ngVLA could be used to probe the inner jet structures and monitor jet structure changes potentially indicative of astroparticle events.

The ngVLA would be used to identify counterparts to future high-energy astroparticle events---neutrinos or cosmic rays---distinguishing between potential candidate sources; investigating their inner jet structures and assessing whether jets directed toward the Earth (as in the case of TXS 0506+056) are required for detection of high-energy neutrinos or cosmic rays; or tracking flux density changes indicative of potential future particle bursts from a candidate source.

