Supermassive Black Hole Binaries:
Multi-Messenger Astrophysics and Long Baselines with the Next-Generation Very Large Array

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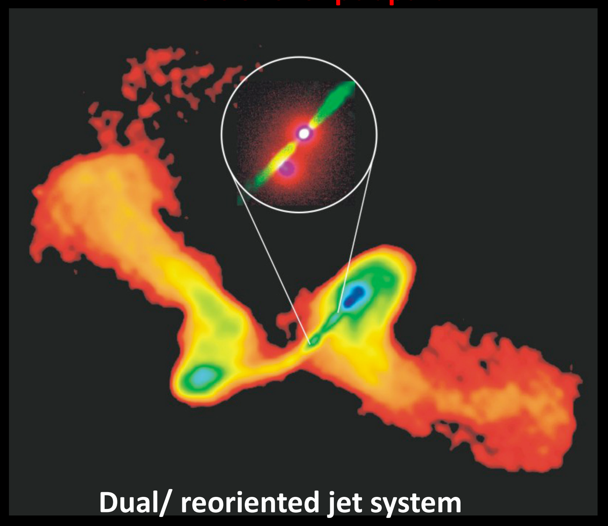
Binary Supermassive Black Holes in Radio Waves

Radio jets can be a literal smoking gun for binary supermassive black holes (SMBHs), exhibiting dual or X-shaped jets, flux variability, and morphological variability.

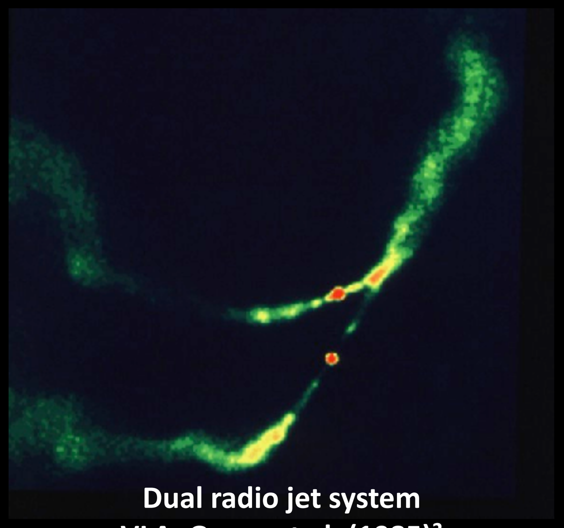
Radio interferometry allows for broad fields of view and exquisite resolution. With enough resolution, the sensitive ngVLA could directly image binary SMBH cores down to sub-parsec resolutions at moderate redshifts.

NGC 326: 9kpc apart



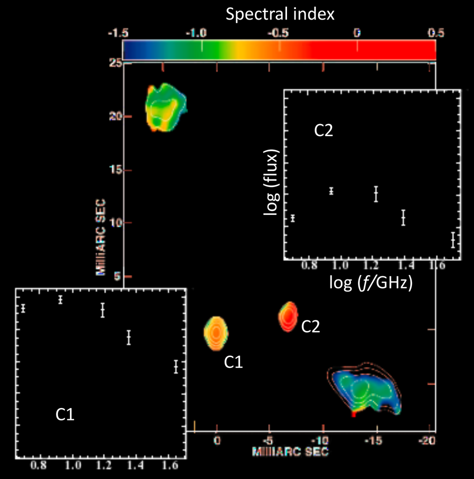
Dual/ reoriented jet system
VLA; Merritt & Ekers (2002)[1]

3C75: 7 kpc apart



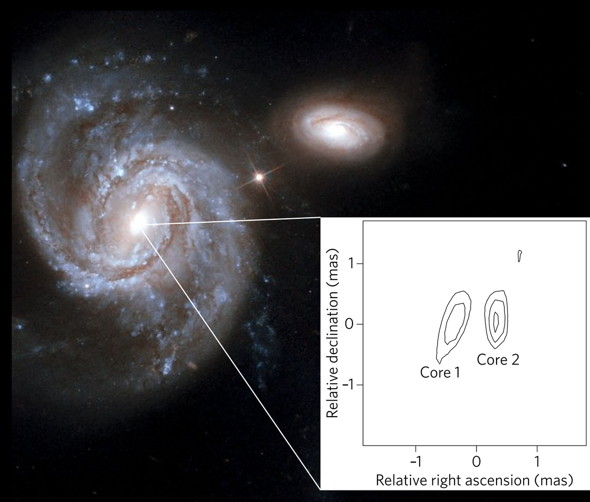
Dual radio jet system
VLA; Owen et al. (1985)[2]

0402+379: 7pc apart



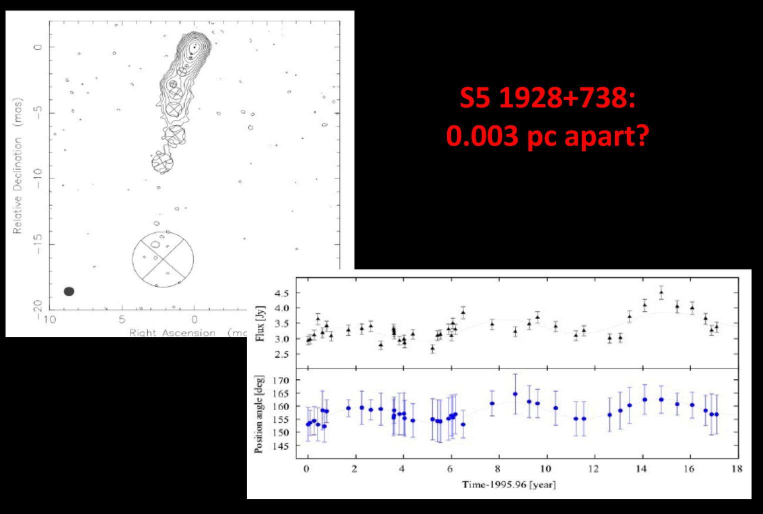
Resolved dual flat-spectrum core
VLBA; Rodriguez et al. (2007)[3]

NGC7674: 0.3 pc apart



Resolved dual flat-spectrum core
VLBA; Kharb et al. (2017)[4]

S5 1928+738: 0.003 pc apart?



Helical jets and flux variations
VLBA; Roos et al (1993)[5], Kun et al. (2014)[6]

Binary Supermassive Black Holes

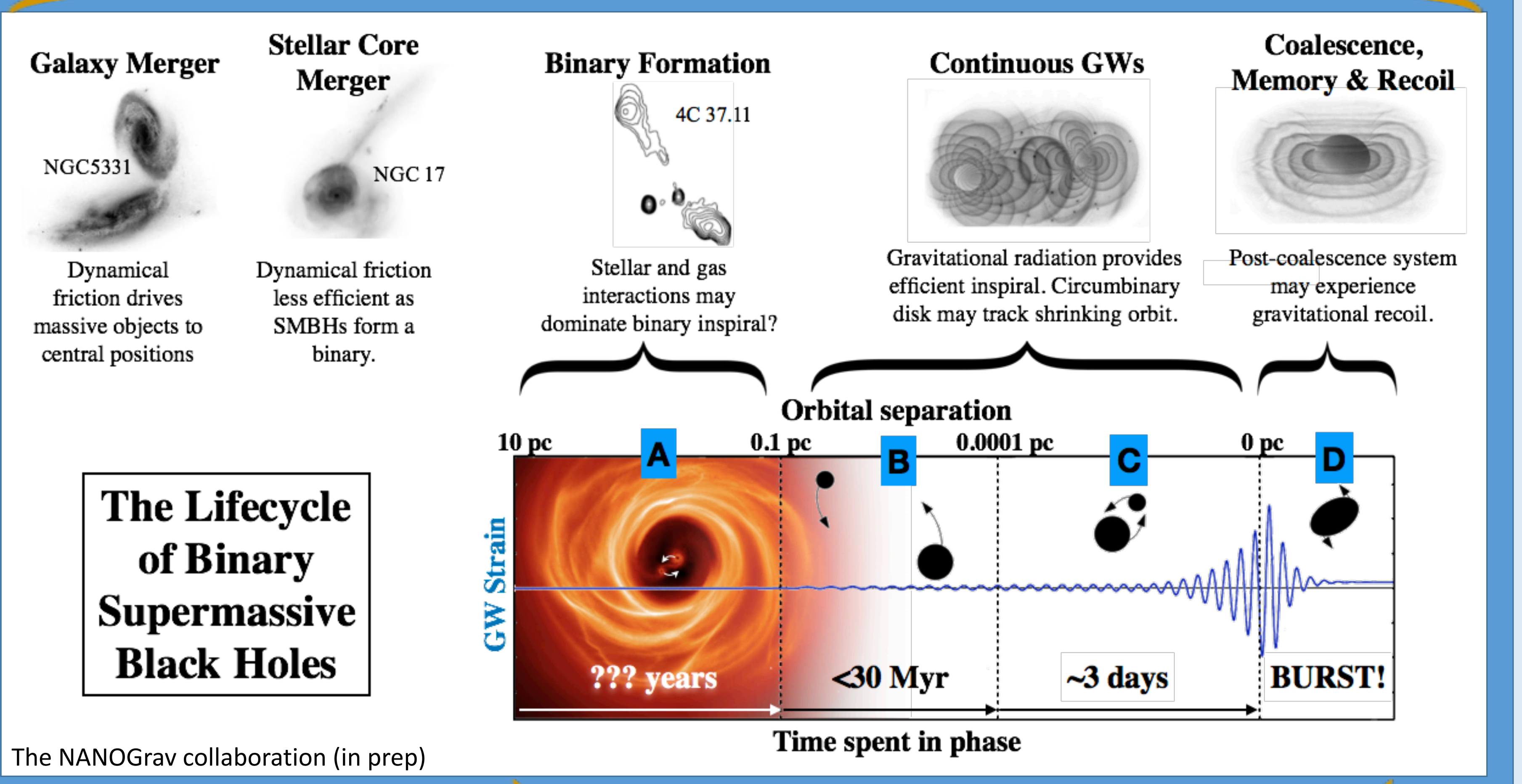
The ngVLA could be a powerful tool to identify dual and binary SMBHs, performing detailed studies of the population and evolution of these systems, as well as enabling powerful multi-messenger science when combined with gravitational-wave detection.

The figure to the right details SMBH binary evolution, from formation in a galaxy merger to their emission of gravitational waves. In the lower panel, gravitational waves can be detected by Pulsar Timing Arrays (PTAs) in stages B and D, and by space-based laser interferometers in stages C and D. However, there are still major uncertainties in early binary evolution (stage A). Here, and throughout the gravitational-wave regime, radio emission may be identifiable for one or both black holes.

ngVLA detections of dual/binary SMBH populations can directly measure:

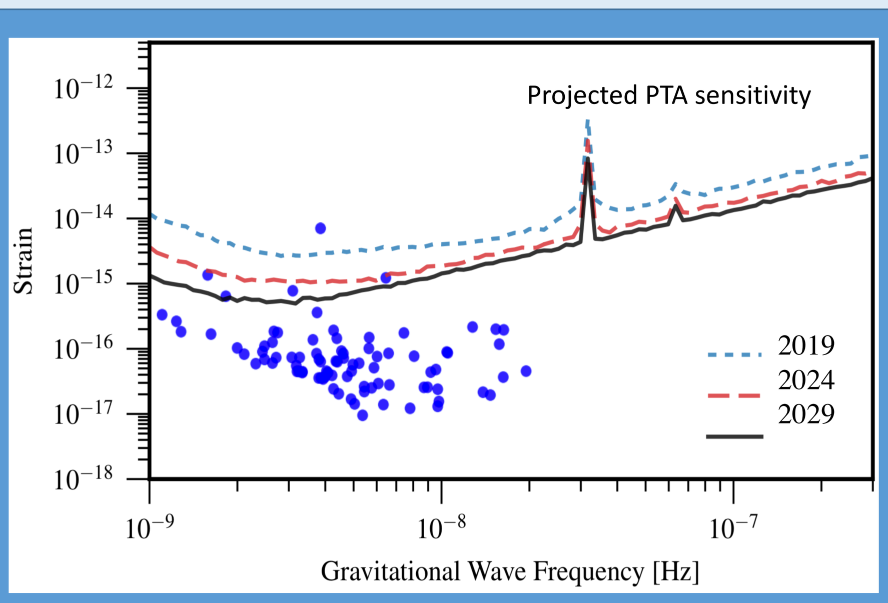
- Merger-induced active nucleus activity.
- Supermassive black hole growth.
- Processes driving the remnant's dynamics and the binary inspiral.

ngVLA discovery possible!



The NANOGrav collaboration (in prep)

>=1000 km baselines required!



Gravitational waves from binary SMBHs simulated to inhabit nearby 2MASS galaxies, based on a standard prescription for galaxy merger rates, as compared with the projected sensitivity of the International Pulsar Timing Array.[8]

Multi-messenger Astronomy on a Supermassive Scale

By 2030, PTAs will have detected the ensemble background of binary SMBHs,[13] and are expected to have detected several resolved binary SMBH systems[8,14]. LISA is expected to be directly constraining SMBH binary coalescence rates soon after its launch. The combined abilities of PTAs, LISA, and ngVLA have the potential to unravel the full evolutionary puzzle of binary SMBH evolution and their influence on galaxy core formation.

Gravitational-wave astronomy with SMBHs will thus be a leading pursuit of the ngVLA era. Particularly with long baselines, ngVLA will have the potential to identify the hosts of emitting gravitational-wave systems, enabling critical future science, including:

- Precise orbital tracking of binary SMBHs.[8]
- Use of SMBHs as a standard ruler.[9]
- Measurement of merger-induced accretion rates and imaging of small-scale AGN feedback.
- Detailed multi-wavelength and multi-messenger studies of circumbinary disk evolution.[10,11]
- Calibration of M_{BH}-host relations up to moderate/high redshifts via direct SMBHB mass measurements.[12]

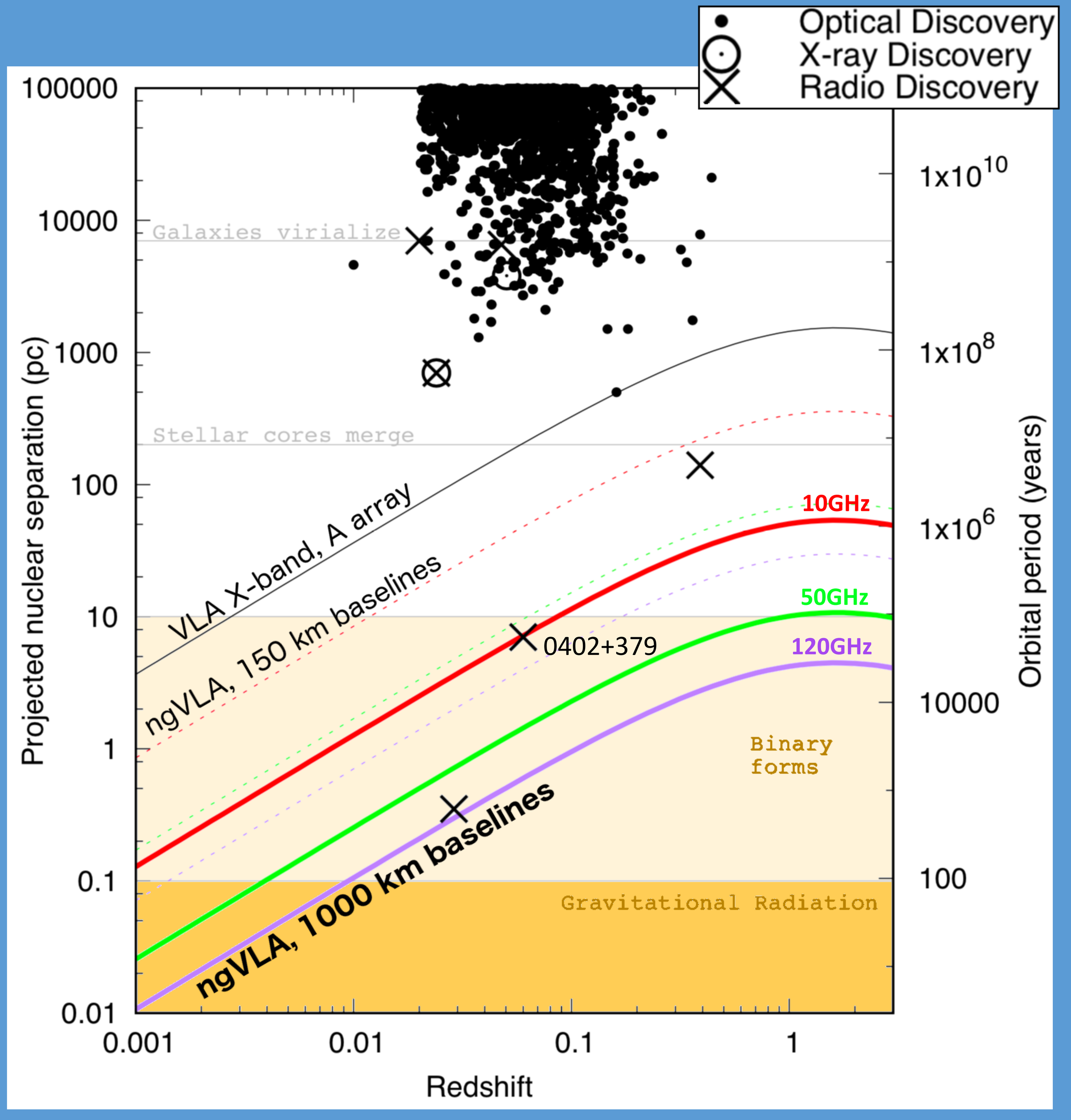
References:

1 Merritt & Ekers (2002), Science, 297, 1310
2 Owen, O'Dea, Inoue, & Eilek (1985), 294, 85
3 Rodriguez , Taylor, Zavala et al. (2006), ApJ, 646, 49
4 Kharb, Lal, Merritt (2017), Nature Astronomy, 1, 727
5 Roos, Kaastra, & Hummel (1993), ApJ, 409, 130
6 Kun, Gabanyi, Karouzos et al. (2014), MNRAS, 445, 1370
7 Bansal, Taylor, Peck, et al. (2017), ApJ, 843, 14
8 Mingarelli, Lazio, Sesana, et al. (2017), Nature Astronomy, 1, 886.
9 D'Orazio & Loeb, submitted
10 Mayer, Kazantzidis, Madau, et al. (2007), Science, 429, 3114
11 Kelley, Blecha, Hernquist (2017), MNRAS, 464, 3131
12 The NANOGrav Astrophysics Working Group, in prep.
13 Kelley, Blecha, Hernquist, et al. (2017), MNRAS, 471, 4508
14 Kelley, Blecha, Hernquist, et al. (2017), submitted

What Will it Take?

Particularly at low GHz frequencies where diffuse synchrotron regions are brightest, ngVLA can easily see evidence for *dual* SMBH systems via large-scale jet morphology (e.g. sources NGC326 and 3C75, shown at top of poster).

However, confident discovery of *small-orbit binaries* requires long baselines to directly image compact dual cores, or to identify morphological and/or flux periodicities. At low to a few 10's of GHz frequencies, cores can have flat, self-absorbed spectra, as in 0402+379 at the top of this poster.[3] While the high ngVLA frequencies will give better resolution, self-absorbed cores typically have declining flux (spectral index a<-0.5) by around 10 GHz, making them increasingly difficult to detect at these higher frequencies.



Resolved dual active nuclei, plotted here, have been observed in various wave-bands. Radio discoveries dominate the known systems at small separations. With extended baselines, ngVLA will have sufficient sensitivity and resolution to perform comprehensive searches for such systems. The curves on this plot demonstrate the optimal resolution reachable by various combinations of baseline and observing frequency for the ngVLA, as compared to the current VLA. Binary tracking via astrometry is possible for shorter orbits: an orbital period of ~10^4 years has already been inferred for 0402+379, at 7pc projected separation, based on data spanning 2003-2015.[7]

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