TOWARD ASTROMETRIC CONSTRAINTS ON A SUPERMASSIVE BLACK HOLE BINARY IN THE EARLY-TYPE GALAXY NGC4472

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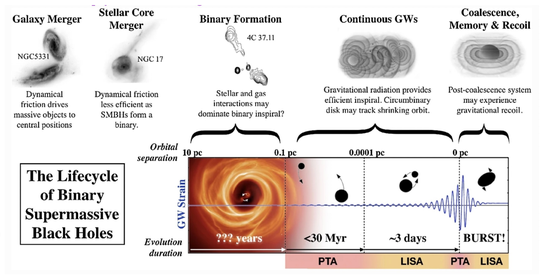
MOTIVATION

Subparsec Frontier

Study Indirectly
Photometric periods
Spectroscopic periods
Continuous GWs
Reviews
Burke-Spolaor+2019
De Rosa+2019

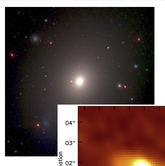


Study Directly via Astrometric Periods
Accretion at low Eddington rates: D'Orazio+2018, Safarzadeh+2019 ✓
Accretion at high Eddington rates: Dexter+2020

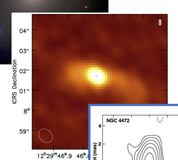
TARGET

Early-Type Galaxy NGC4472

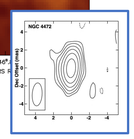
Blakeslee+2009
Distance 16.7 Mpc
Rusli+2013
Stellar dynamics
SMBH mass 2.4 x 10^9 $M_\odot$
Thomas+2014 eg
Stellar core suggests scouring by SMBH binary



FOV 99 kpc
SDSS gri
Baillard+2011



FOV 540 pc
ALMA 98 GHz
Active Galactic Nucleus



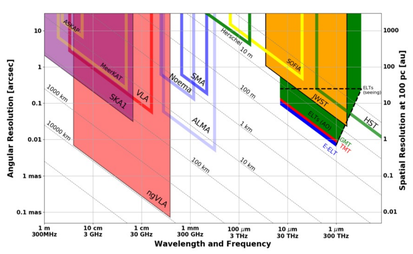
FOV 0.81 pc
VLBA 8.4 GHz
AGN size < 0.059 pc
Anderson+2005

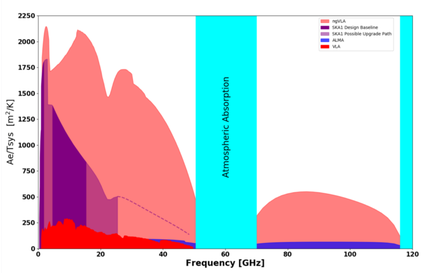
Goal: Use the AGN to seek information about the presence or absence of an SMBH binary on subparsec scales

TOOL ngvla.nrao.edu

The ngVLA is a versatile interferometric array at radio frequencies, envisaged to operate as a flagship NSF facility starting in the 2030s. It will provide dramatic new scientific capabilities to the world's astronomers.

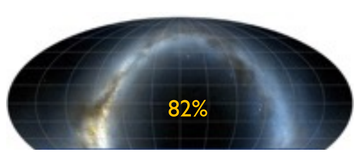
ngVLA science will be synergistic with other facilities on similar timescales.





The ngVLA will complementarily bridge frequencies observable with ALMA and the Square Kilometer Array.

Science Use Cases
Science Book
Community authored
↓
Science Driven Design
Short Array
Main Array
Long Array



ABSTRACT

The merger of two galaxies, each hosting a supermassive black hole (SMBH) of mass 10^6 $M_\odot$ or more, could yield a bound SMBH binary. For the early-type galaxy NGC4472, we study how astrometry with a next-generation Very Large Array (ngVLA) could be used to monitor the reflex motion of the primary SMBH of mass M_{pri}, as it is tugged on by the secondary SMBH of mass M_{sec}. Casting the orbit of the putative SMBH binary in terms of its period P, semimajor axis a_{bin}, and mass ratio $q = M_{sec} / M_{pri} \leq 1$, we find the following: (i) Orbits with fiducial periods of P = 4 yr and 40 yr could be spatially resolved and monitored. (ii) For a 95% accuracy of 2 μas per monitoring epoch, subparsec values of a_{bin} could be accessed over a range of mass ratios notionally encompassing major ($q > 1/4$) and minor ($q < 1/4$) galaxy mergers. (iii) If no reflex motion is detected for M_{pri} after 1 (10) yr of monitoring, an SMBH binary with period P = 4 (40) yr and mass ratio q > 0.01 (0.003) could be excluded. This would suggest no present-day evidence for a past major merger like that recently simulated, where scouring by a q ~ 1 SMBH binary formed a stellar core with kinematic traits like those of NGC 4472. (iv) Astrometric monitoring could independently check the upper limits on q from searches for continuous gravitational waves from NGC4472.

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OBSERVATIONS

ngVLA Long Array

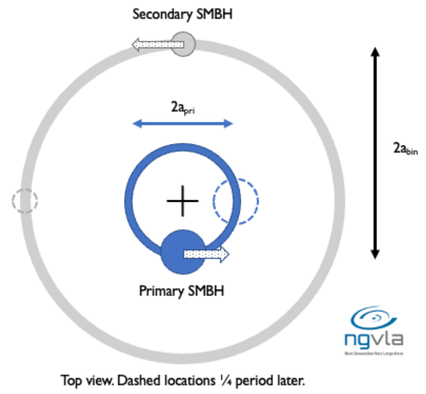
Ten continent spanning sites
Hlx2 WA BC CA IA WV NH PR VI

Enabling Capabilities

High angular resolution
High observation frequency 80 GHz
PSF = 100 μas at full width half maximum
High astrometric accuracy
Phase reference relative to background sources
Challenge: ±2 μas at 95% confidence level
High sensitivity
Paired antenna calibration
Frontier astrometric methods eg Rioja+2020

Monitor motions of 1 or 2 SMBHs in a binary

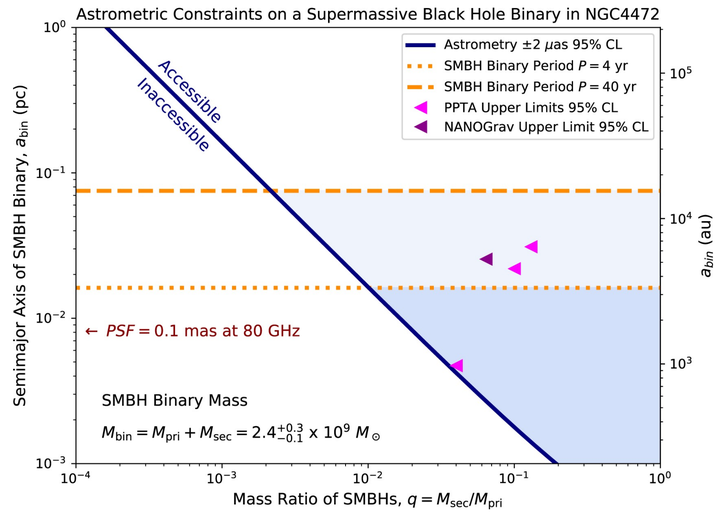
IMPLICATIONS -- Astrometric Monitoring



Binary Parameters

Primary SMBH mass M_{pri} Radio Emitter
Secondary SMBH mass M_{sec}
Mass $M_{bin} = M_{pri} + M_{sec}$ Rusli+2013
Orbital period P
Semimajor axis a_{bin} (M_{bin}, P) Kepler's 3rd
Mass ratio $q = M_{sec} / M_{pri} \leq 1$
Center of mass +

Follow Safarzadeh+2019. As the primary SMBH orbits about the center of mass, it exhibits a reflex motion with a semimajor axis $a_{pri} = a_{bin} \times q/(1+q)$. Recast as a_{bin} (M_{bin}, P) = $a_{pri} \times (1+q)/q$. The maximal excursion executed by the primary SMBH is independent of the viewing angle. Monitoring over ¼ P suffices to characterize the orbit of the primary SMBH.



Parameter space for a_{bin} and q for a putative SMBH binary in the early-type galaxy NGC4472. M_{bin} is from Rusli+2013. Region to the right of the diagonal line is accessible with ngVLA astrometric monitoring at 80 GHz with the labeled accuracy. Associated PSF of the ngVLA Long Array is marked for reference. GW constraints from Schutz+2016 are for PPTA, while that for NANOGrav is derived from Arzoumanian+2021. All quantities invoke the Blakeslee+2019 distance of 16.7 Mpc.

Orbits with fiducial periods of P = 4 yr and 40 yr could be spatially resolved and monitored. If, instead, the secondary SMBH is assumed to be the radio emitter, then the reflex motion will be larger. By assuming that the primary SMBH is the radio emitter, the predictions for the reflex motion could thus be considered conservative.

IMPLICATIONS -- Ties to Galaxy Evolution

For a 95% accuracy of 2 μas per monitoring epoch, subparsec values of a_{bin} could be accessed over a range of mass ratios notionally encompassing major ($q > 1/4$) and minor ($q < 1/4$) galaxy mergers. If no reflex motion is detected for M_{pri} after 1 (10) yr of monitoring, an SMBH binary with period P = 4 (40) yr and mass ratio q > 0.01 (0.003) could be excluded. This would suggest no present-day evidence for a past major merger like that recently simulated (Rantala+2019) where scouring by a q ~ 1 SMBH binary formed a stellar core with kinematic traits like those of NGC4472 (Thomas+2014).

IMPLICATIONS -- Ties to Gravitational Waves

Astrometric monitoring could independently check the upper limits on q from searches for continuous gravitational waves from NGC4472 (Schutz & Ma 2016, Aggarwal+2019, Arzoumanian+2021).

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