Multiple supermassive black hole systems: SKA’s future leading role

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two primary messages:

1. multiple SMBH science will become mainstream with next-generation facilities

2. SKA will lead through broad range of techniques and perspectives
from the **galaxy evolution** viewpoint

**micro/millil-pc** | **kpc**
galaxy mergers/interactions are a major observational focus
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dual/binary AGN are not (yet)
candidate dual/binary AGN in 2014
(from direct imaging)

squares = X-ray       triangles = optical/NIR       stars = radio

- 0402+379
- J1502S
- 3C75
- NGC 326
- NGC 6240
- Mrk 739
- Mrk 463
- NGC 3393
- SDSS J1715+6008
- IRAS 05589+2828
- SDSS J0952+2552
- CID-42
- LBQS 0103-2753
- SDSS J1108+0659
- SDSS J1131-0204
- SDSS J1146+5110
- SDSS J1332+0606
- CXO J1426+35

redshift

projected separation / parsec

triangles = optical/NIR
candidate dual/binary AGN in 2004
(from direct imaging)

squares = X-ray    triangles = optical/NIR    stars = radio
candidate dual/binary AGN in 2014
(from direct imaging)

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candidate dual/binary AGN 2014
(+ non-imaging)

squares = X-ray  triangles = optical/NIR  stars = radio

0402+379  J1502S  3C75  NGC 326  NGC 6240  Mrk 739  Mrk 463  NGC 3393  SDSS J1715+6008  IRAS 05589+2828  SDSS J0952+2552  CID-42  LBQS 0103-2753  SDSS J1108+0659  SDSS J1131-0204  SDSS J1146+5110  SDSS J1332+0606  CXO J1426+35  SDSS 1536+0441  OJ287

double-peaked BLR  optical variability
candidate dual/binary AGN 2014
(+ non-imaging)

squares = X-ray
triangles = optical/NIR
stars = radio

Milky Way SMBH Schwartzchild radius

redshift vs. projected separation / parsec
dual/binary AGN orbital evolution

<1 pc    ~10 pc    ~kpc

separation
dual/binary AGN orbital evolution

<1 pc  ~10 pc  ~kpc

separation

dynamical friction

1000s of examples
(e.g. Koss+2011, Liu+2011)
dual/binary AGN orbital evolution

<1 pc  ~10 pc  ~kpc

`hardened' binary: in-spiral driven by stellar 3-body interactions

dynamical friction

NGC 3393  150 pc  Fabbiano+2011

0402+379  7 pc  Rodriguez+2006

J1502S  138 pc  Deane+2014

1000s of examples (e.g. Koss+2011, Liu+2011)
`hardened' binary:
in-spiral driven by stellar
3-body interactions

gravitational radiation

candidates from spectroscopic & periodic light curve signatures
(e.g. Valtonen+2008; Boroson & Lauer 2009)

<1 pc

~10 pc

~kpc

dual/binary AGN orbital evolution

separation

0402+379
7 pc
Rodriguez+2006

J1502S
138 pc
Deane+2014

NGC 3393
150 pc
Fabbiano+2011

1000s of examples
(e.g. Koss+2011, Liu+2011)
binary separation ‘coverage’ with SKA

<1 pc  ~10 pc  ~kpc

separation

gravitational radiation

`hardened' binary:
in-spiral driven by stellar 3-body interactions

dynamical friction

pulsar timing (+ variability)

radio-jet morphology

direct imaging of flat-spectrum sources
direct imaging

• flat-spectrum sources (with jets, multi-wavelength counterparts, etc.)

• image-splitting in lensing searches

• super-resolution with polarization

• SKA/radio will lead due to:
  • insensitivity to dust/gas attenuation
  • raw sensitivity
  • angular resolution
max GW frequency of SMBH binaries

assumes:
- binary SMBHs have angular separation $= 2$ PSFs
- circular orbits
- equal mass $10^8 \, M_\odot$ SMBHs

pulsar timing array sensitivity

~ 1 day

~ 30 years
radio-jet morphology signatures
(aka “corkscrew relics”)

Rodriguez+2006
VLBA 8 GHz

0402+379
JVLA 1.4 GHz

Deane+2014
Massive black hole binaries in active galactic nuclei

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Most theoretical discussions of active galactic nuclei (including quasars) attribute their energy production either to an accreting black hole or to a precursor stage—for instance a dense star cluster or a supermassive star—whose inevitable end point is a massive black hole. We explore here the possibility that some active nuclei may contain two massive black holes in orbit about each other. This hypothesis suggests a new interpretation for the observed bending and apparent precession of radio jets emerging from these objects and may indeed be verified through detection of the direct consequences of orbital motion.
a simple precessing jet model (ala SS433)

SS 433
credit: Blundell & Bowler, NRAO/AUI/NSF
a simple precessing jet model (ala SS433)

SS 433
credit: Blundell & Bowler, NRAO/AUI/NSF

~0.1 pc
A simple processing jet model (ala SS433)

SS 433
credit: Blundell & Bowler, NRAO/AUI/NSF

~0.1 pc

SMBH binaries scaled up by 5-8 dex?
predicted binary SMBH in-spiral rates

binary separation evolves from 1 kpc to <1pc in ~few 10s of Myr
predicted binary SMBH in-spiral rates

binary separation evolves from 1 kpc to <1pc in \( \text{few } 10\text{s of Myr} \)

comparable to radio jet lifetimes of \( \text{~10 Myr} \)
radio-jet morphology signatures
(aka “corkscrew relics”)
radio-jet morphology signatures
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radio-jet morphology signatures
(aka “corkscrew relics”)

7 pc
7 kpc

<100 micro-arcsecond resolution

pulsar timing array

Deane+2014
Rodriguez+2006
stochastic GW background spectrum

- standard spectrum $\alpha = -2/3$ (assumes circular orbits)
- should change at $\sim 10$ nanoHz (when stellar scattering and gas dynamics dampen signal)
- binary eccentricity important in the nanoHz regime
- triple systems also lead to high eccentricities (via Kozai-Lidov mechanism) and recoiling/ejected SMBHs (Hoffman & Loeb 2007; Blecha+2011)
- therefore, very important to measure GW spectrum, not just single detection, from a galaxy evolution perspective to understand binary SMBH environment coupling

see Janssen talk
environment coupling
(with SKA and other facilities)

stellar `scouring'

- mass deficits 1-10 times mass of SMBH binary
- flattens inner density profile of galactic halo

molecular gas dynamics
- NGC 1433 CO (3-2)
- ALMA 24 pc spatial res.
- Coombes+2013

HI emission and absorption
- HI abs. in binary SMBH 0402+379
- Rodriguez+2009, Morganti+2009

variability/transients
- quasi-periodic accretion, light curves

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Nuclear Structure of Bright Galaxies

- $M_{\text{gal}} \lesssim 10^{10} M_{\odot}$
- $M_{\text{gal}} \gtrsim 10^{10} M_{\odot}$

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AASKA14

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summary plot

inspiral/mergers

direct imaging

radio-jet

morphology

pulsar timing

arrays

Milky Way SMBH Schwartzchild radius

inspiral/mergers via transients?
1. multiple SMBH science will become mainstream with next-generation facilities

2. the SKA is likely to lead through broad range of techniques and perspectives
summary

- most modes of the SKA will probe cosmic SMBH evolution history
- will do so over > 6 dex of orbital separation dynamic range
- high complimentarily between imaging & non-imaging methods which must form a consistent, cohesive picture
- SKA could lead the way ahead of other large multi-wavelength facilities
- gravitational wave astronomy will provide deep insights on galaxy evolution